Towards Climate-resilient River Systems in Chennai

Assessing Risks at the Sub-basin Level and Advancing a Circular Economy Approach

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Technical Partner

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Perspectives

"We are dedicated to enhancing climate resilience by securing Tamil Nadu's water future, in alignment with our Water Vision@2047."

Thiru M.K. Stalin
Honourable Chief Minister of Tamil Nadu

"For Tamil Nadu, the economic and industrial powerhouse of India, climate resilience is fundamental to long-term economic growth. The TNGCC and CEEW climate risk and water balance study for the Chennai river basin provides a strong, data-driven basis to prioritise investments in water security, efficiency, and reuse. It will help direct public and private capital towards adaptation strategies that reduce risk, safeguard water resources, and deliver lasting value for people and the economy."

Thiru Thangam Thennarsu
Honourable Minister for Finance, Environment and Climate Change, Tamil Nadu

"The climate risk and water balance study for the Chennai river basin strengthens Tamil Nadu's commitment to integrating climate resilience into water governance and planning. By integrating science-based climate risk assessment with policy scenarios such as the reuse of treated used water, the study demonstrates how data, innovation, and institutional collaboration can translate into resilient and equitable water management outcomes."

Smt. Supriya Sahu, I.A.S.
Additional Chief Secretary to the Government, Environment, Climate Change and Forests Department, Tamil Nadu

“This study on climate-induced water risk and water balance for the Chennai river basin reflects Tamil Nadu’s coordinated and evidence-based approach to climate-informed water planning. It brings together data, institutional expertise, and cross-sector collaboration to support clear sub-basin–level prioritisation and action. Through this effort, the Tamil Nadu Green Climate Company is working to strengthen water security and ensure that local interventions contribute meaningfully to the state’s long-term climate goals.”

Thiru A.R. Rahul Nadh, I.A.S.
Director, Tamil Nadu Green Climate Company, Environment, Climate Change and Forests Department

“This study adds a unique dimension by analysing climate risks to water systems and water balance at a localised hydrological scale. Led by TNGCC and CEEW, the analysis for the Chennai river basin establishes a clear baseline of current and future pressures on water resources and provides adaptable, data-backed guidance for thirteen state institutions to strengthen climate resilience.”

Thiru Bakan Jagdish Sudhakar, I.F.S.
Chief Executive Officer, Tamil Nadu Green Climate Company, Environment, Climate Change and Forests Department

Contents

Most river basins in India exhibit low resilience to climate extremes.

Image: iStock

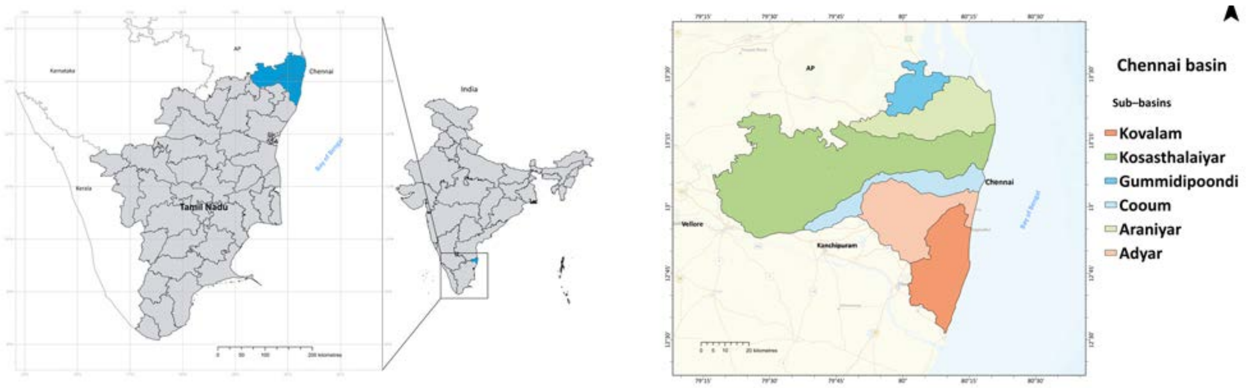
Executive summary

Eleven of India's 15 major river basins in India are at least water-stressed (Bassi et al. 2023), and a quarter of groundwater aquifers are being used beyond safe extraction limits (CGWB 2024). Further, most river basins in India are highly vulnerable to climate extremes; as a result, 600 million people in the country face extreme water scarcity (NITI Aayog 2018).

This study focuses on the Chennai basin, the majority of which (about 78 per cent) lies in the state of Tamil Nadu (CCCDM 2022), spanning five districts – Chennai, Chengalpattu, Kanchipuram, Ranipet, and Thiruvallur – which together contribute about 33 per cent to the state economy (DES 2024a). Within Tamil Nadu, the Chennai basin comprises six sub-basins – Adyar, Araniyar, Cooum, Gummidipoondi, Kovalam, and Kosasthalaiyar (Figure ES1).

> Short-duration, high-intensity rainfall events increased across the Chennai basin districts from 2011 to 2022, compared with 1981–2011.

Figure ES1. Tamil Nadu part of the Chennai basin and its sub-basins

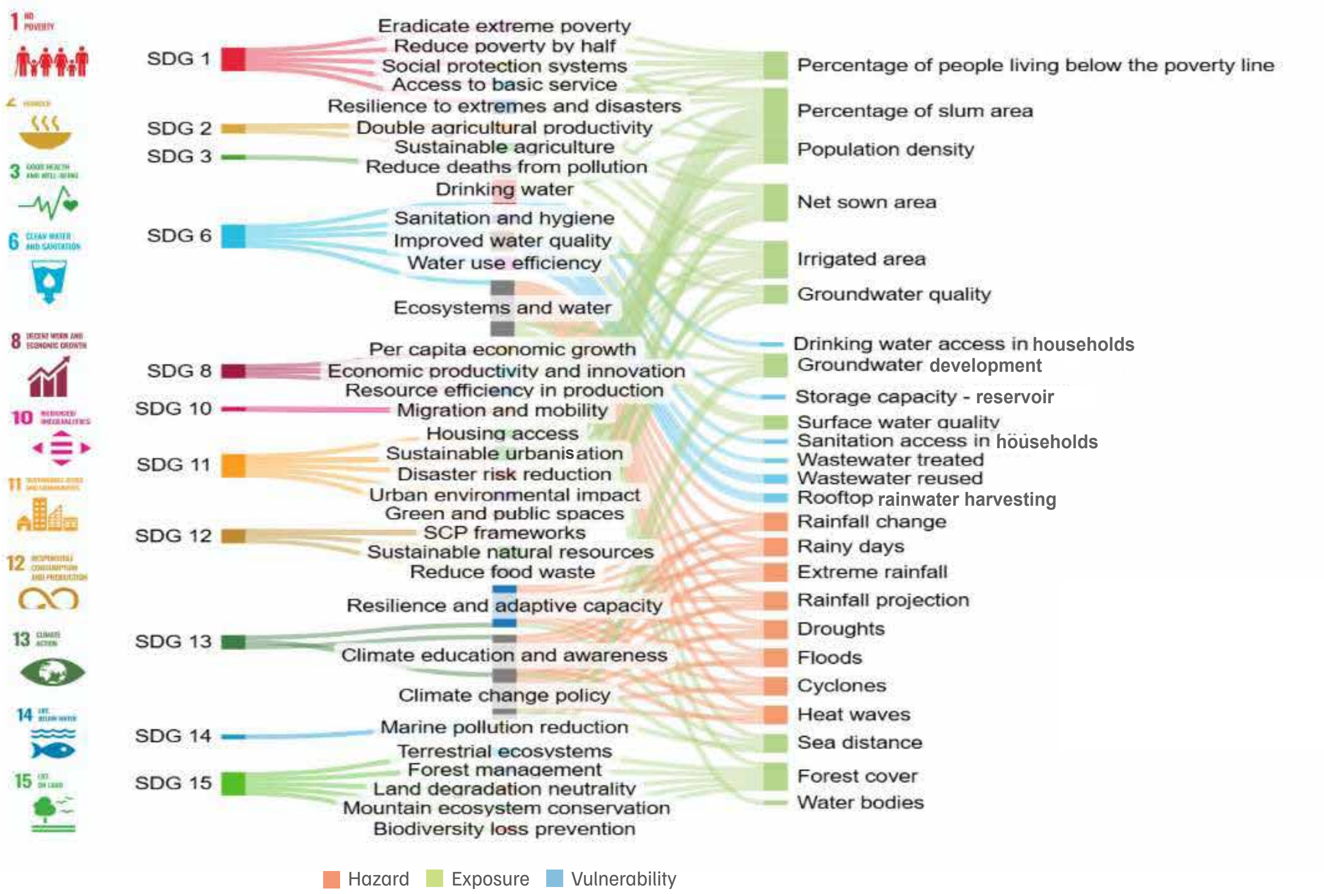


Source: Authors' analysis

The districts within the Chennai basin recorded a rise in short-duration, high-intensity rainfall events during both the south-west monsoon (SWM) (June–September) and the north-east monsoon (NEM) (October–December) in 2011–22 compared to 1981–2011 (Prabhu and Chitale 2024). Climate change has also increased the intensity and duration of cyclones in the Bay of Bengal over recent decades (Selva et al. 2025). Additionally, the basin is experiencing a surge in droughts and floods and faces a rising risk of future droughts (Anandharuban and Elango 2021; CCCDM 2022; Joseph 2022; Kaaviya and Devadas 2021).

Rapid urban expansion has further intensified water stress in the basin, predominantly through the loss of water bodies, including traditional tank systems that historically sustained irrigation and domestic water demand (Rajagopalan et al. 2024). Urbanisation has led to the loss of 13.6 million cubic metres (MCM) of tank storage within Chennai city, while an additional 175 MCM of tank storage outside the city is now at risk (Devi et al. 2025). At the same time, sewage treatment capacity in the region has become overwhelmed, leading to the discharge of untreated used water into rivers and the subsequent deterioration of both surface water and groundwater quality (Ramachandran et al. 2021; Rosado et al. 2024). The increasing frequency and severity of climate extremes, along with challenges to water quantity and quality, call for urgent action to build climate resilience in the Chennai basin. Assessing climate risk, including physical, social, economic, institutional, and policy factors, is the first step. Further, assessing the current and projected water balance in the basin, i.e., the difference between the water supply requirement and the water actually supplied, is crucial for enhancing water security and hence reducing the risks posed by climate-induced extremes. Such assessments can inform adaptation measures such as adopting a circular economy approach to water management and improving water use efficiency. **Further, interventions informed by water risk assessments in the Chennai basin can support 36 targets under 11 Sustainable Development Goals (SDGs)** (Figure ES2).

Figure ES2. Potential SDG targets that the state can attain from interdisciplinary climate-induced water risk assessments



Source: Authors' analysis based on Guppy, Lisa, Paula Uyttendaele, Karen G. Villholth, and Vladimir Smakhtin. 2018. "Groundwater and Sustainable Development Goals: Analysis of Interlinkages." Hamilton, Canada: United Nations University Institute for Water, Environment and Health and UN-Water. 2016. "Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development." Nairobi, Kenya: United Nations Environment Programme.

Note: SCP - Sustainable Consumption and Production

Objectives of the study

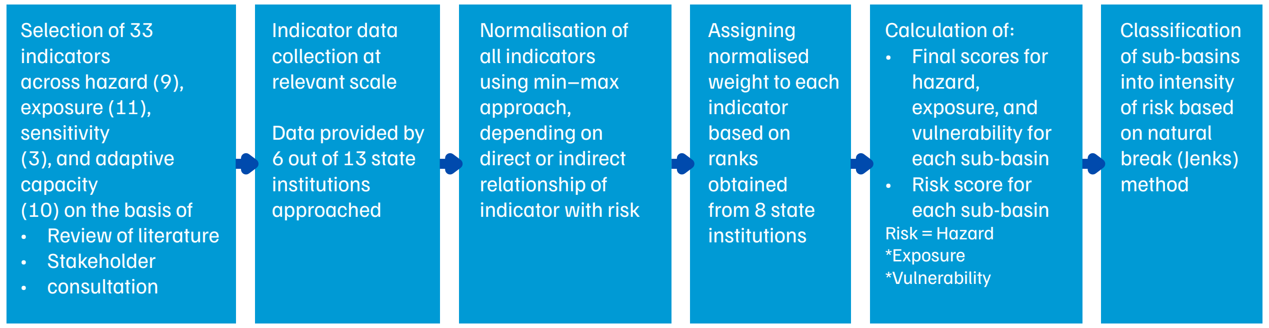
We conduct the analysis at the sub-basin level. The study has the following three objectives:

- Develop and compute an index to assess climate-induced risk to water systems in the Tamil Nadu portion of the Chennai basin.
- Update the existing water balance of the Chennai basin using the latest data and incorporate scenarios to model the water deficit.
- Develop a targeted water balance scenario to assess the potential of treated used water (TUW) reuse to reduce pressure on freshwater resources.

Methodology for risk assessment and establishing water balance

The methodology for Objective I is entailed in Figure ES3.

Figure ES3. Methodology for risk assessment



Selection of 33 indicators across hazard (9), exposure (11), sensitivity (3), and adaptive capacity (10) on the basis of
- Review of literature
- Stakeholder consultation

Indicator data collection at relevant scale

Data provided by 6 out of 13 state institutions approached

Normalisation of all indicators using min–max approach, depending on direct or indirect relationship of indicator with risk

Assigning normalised weight to each indicator based on ranks obtained from 8 state institutions

Calculation of:
- Final scores for hazard, exposure, and vulnerability for each sub-basin
- Risk score for each sub-basin

Risk = Hazard
*Exposure
*Vulnerability

Classification of sub-basins into intensity of risk based on natural break (Jenks) method

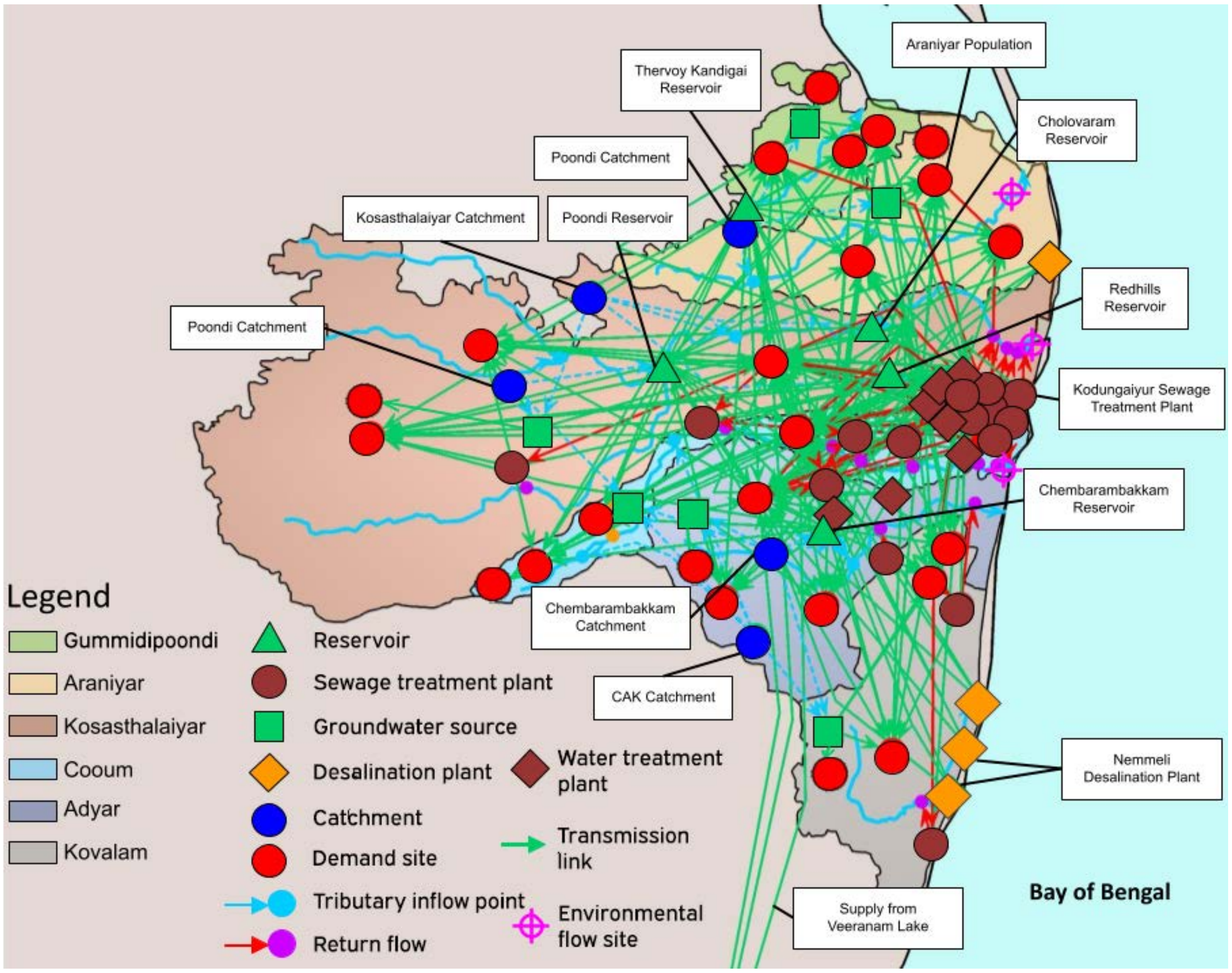
Source: Authors' analysis

To address Objectives II and III, we used the Water Evaluation and Adaptation Planning (WEAP) model to assess the water balance of the Chennai basin (1994–2050) under various climate, population, and TUW reuse scenarios. The model was configured for the six sub-basins of the Chennai basin and integrated data on rainfall, evapotranspiration, groundwater, reservoirs, and demand from domestic, agricultural, livestock, and industrial sectors (Figure ES4). Inputs were sourced from national and state agencies, and climate projections were based on the Representative Concentration Pathways (RCP) 4.5 scenario. The outputs were statistically bias corrected and downscaled to a spatial resolution of 25 kilometres (km). Following are the **six scenarios** developed to evaluate future water demand and availability:

- The **business-as-usual (BAU) scenario** assumes that current growth trends and water-use patterns will continue, without climate change impacts.
- The **high population growth scenario** assumes population growth rates that are 25 per cent higher than BAU rates from 2011 onwards.

- **Four intervention scenarios** were modelled in addition to the BAU case.
    - Two scenarios without climate change projections assess the combined impacts of micro-irrigation and treated used water (TUW) reuse, assuming that 13 per cent of the cropped area (excluding rice) adopts micro-irrigation, while TUW reuse increases to 25 per cent and 40 per cent by 2030, respectively.
    - Two corresponding climate change scenarios applied the same micro-irrigation and TUW assumptions, with added climate change projections.

Figure ES4. Water Evaluation and Adaptation Planning (WEAP) model configuration for the Chennai basin



Source: Authors' analysis

Key findings

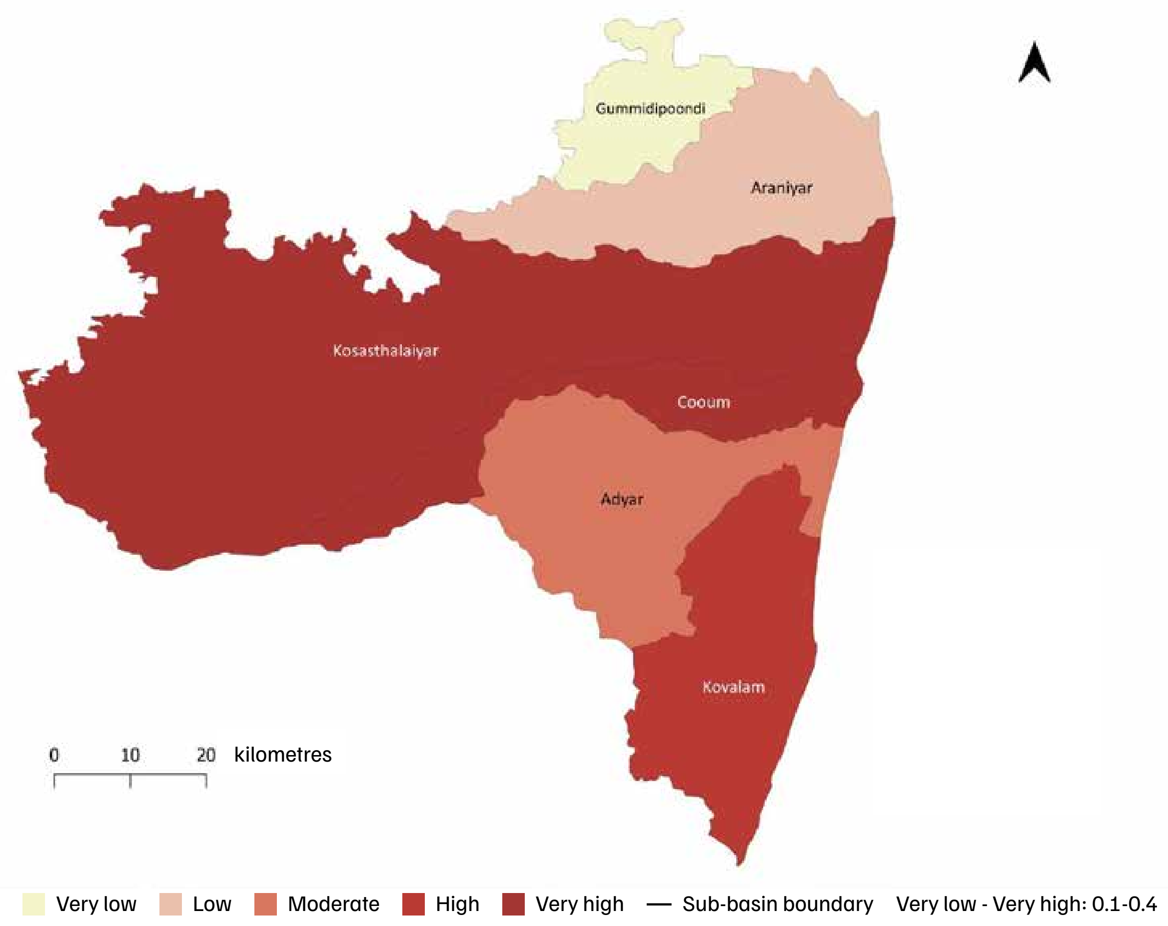
Sections below present the key findings from the risk assessment and WEAP modelling exercise.

Risk assessment

The risk to water resources in each sub-basin from the changing climate, calculated as a product of that sub-basin's hazard, exposure, and vulnerability, is presented in Figure ES5. **Among the sub-basins in the region, Cooum and Kosasthalaiyar exhibit the highest risk levels, followed by Kovalam, Adyar, Araniyar, and Gummidipoondi.** These ranks are comparative; a lower rank should not be interpreted as a dissolution of the need for climate action.

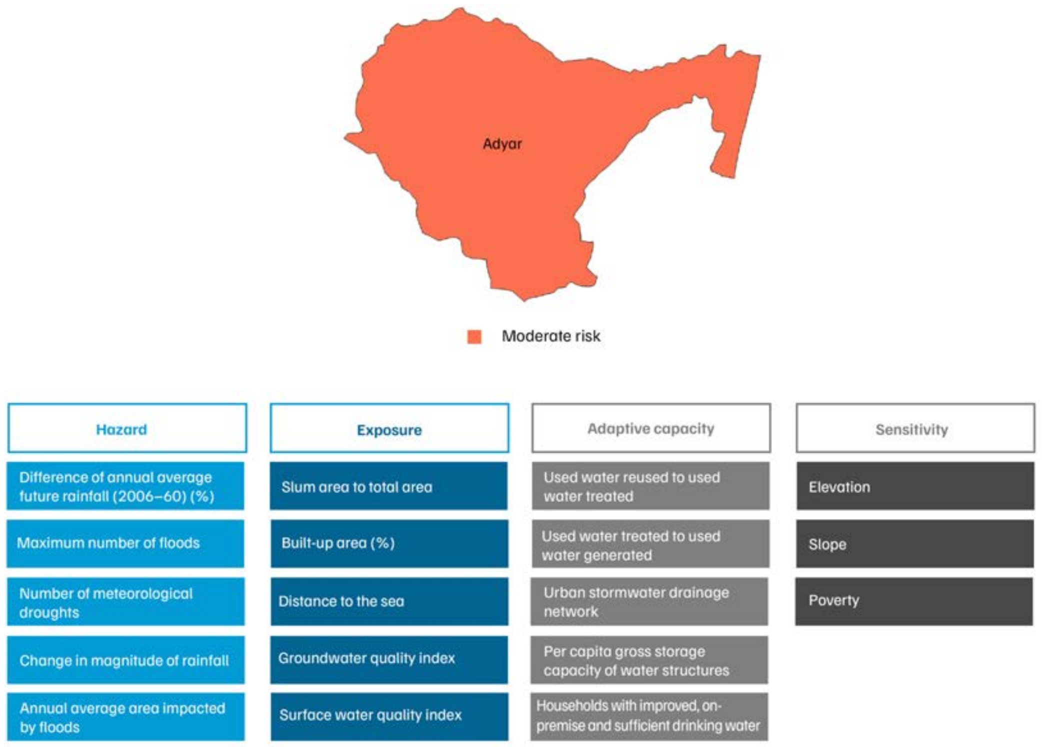
Figures ES6–ES11 present the top five contributing indicators for each risk sub-component. Since sensitivity had only three indicators, all three were deemed important. Overall, the indicators have been presented in descending order of their contribution to hazard, exposure, sensitivity, and adaptive capacity.

Figure ES5. Climate risk is highest in the Cooum and Kosasthalaiyar sub-basins of the Chennai basin



Source: Authors' analysis

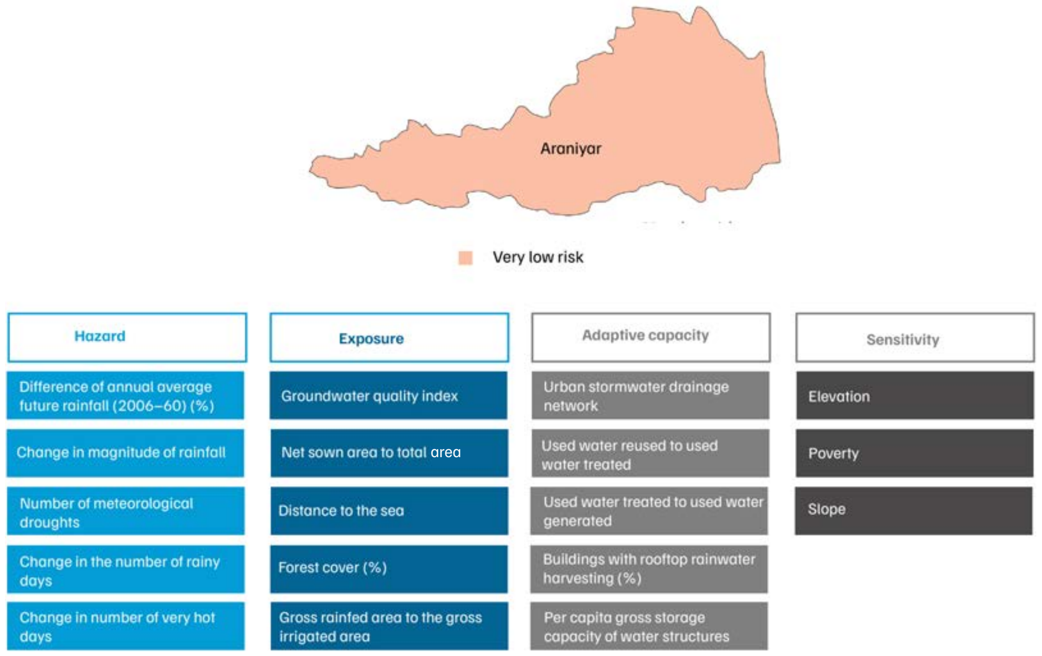
Figure ES6. Indicators contributing to risk, in decreasing order of contribution, in the Adyar sub-basin



Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Slum area to total area	Used water reused to used water treated	Elevation
Maximum number of floods	Built-up area (%)	Used water treated to used water generated	Slope
Number of meteorological droughts	Distance to the sea	Urban stormwater drainage network	Poverty
Change in magnitude of rainfall	Groundwater quality index	Per capita gross storage capacity of water structures	
Annual average area impacted by floods	Surface water quality index	Households with improved, on-premise and sufficient drinking water	

Source: Authors' analysis

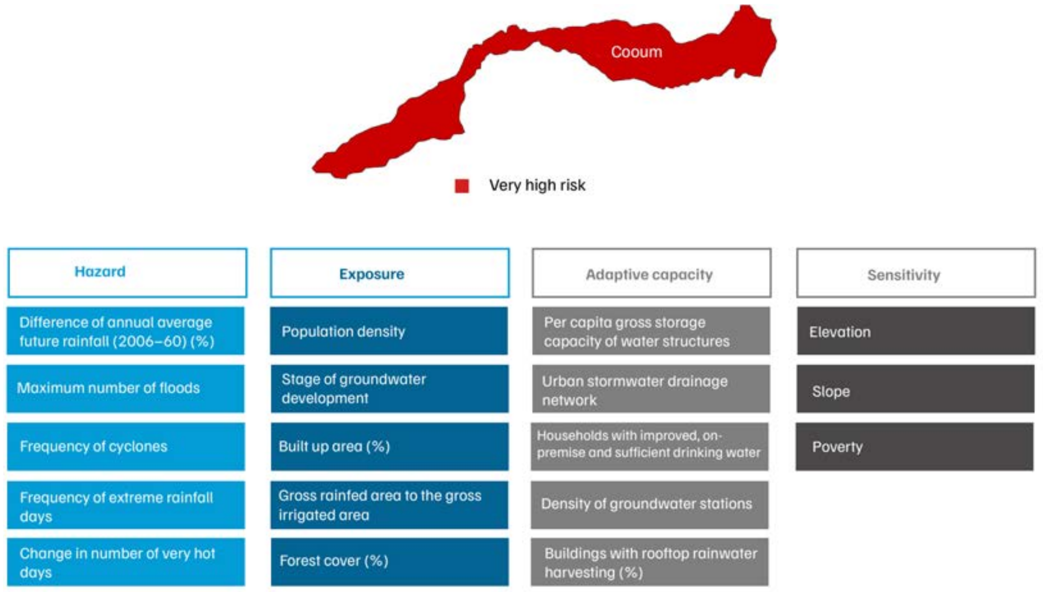
Figure ES7. Indicators contributing to risk, in decreasing order of contribution, in the Araniyar sub-basin



Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Groundwater quality index	Urban stormwater drainage network	Elevation
Change in magnitude of rainfall	Net sown area to total area	Used water reused to used water treated	Poverty
Number of meteorological droughts	Distance to the sea	Used water treated to used water generated	Slope
Change in the number of rainy days	Forest cover (%)	Buildings with rooftop rainwater harvesting (%)	
Change in number of very hot days	Gross rainfed area to the gross irrigated area	Per capita gross storage capacity of water structures	

Source: Authors' analysis

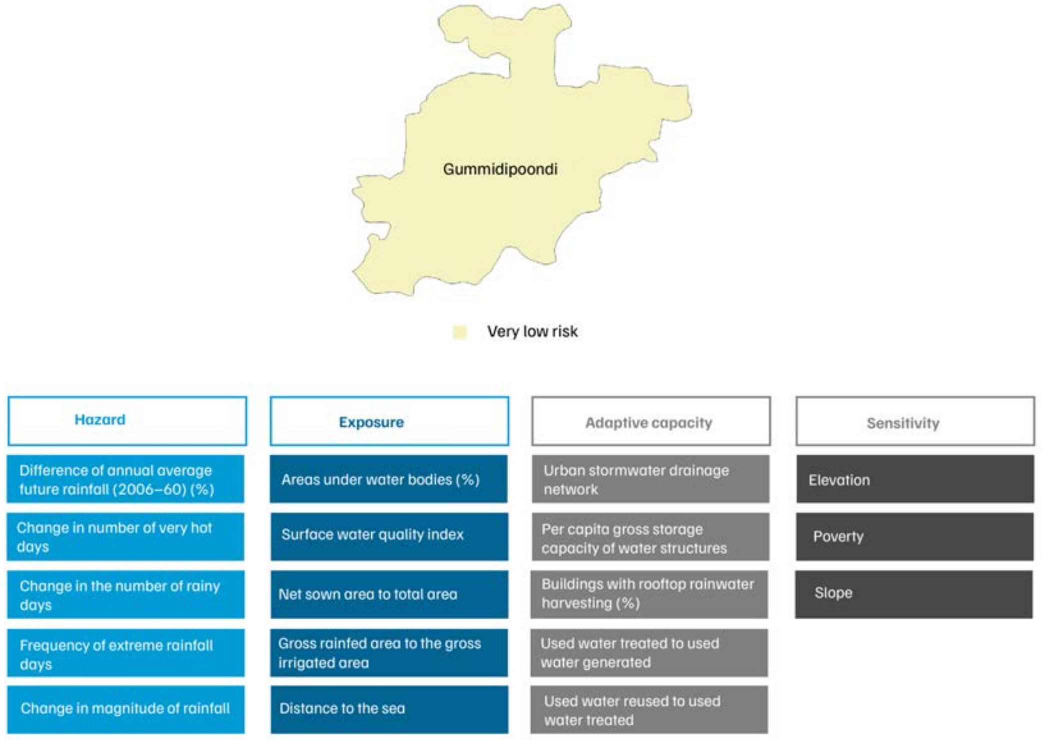
Figure ES8. Indicators contributing to risk, in decreasing order of contribution, in the Cooum sub-basin



Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Population density	Per capita gross storage capacity of water structures	Elevation
Maximum number of floods	Stage of groundwater development	Urban stormwater drainage network	Slope
Frequency of cyclones	Built up area (%)	Households with improved, on-premise and sufficient drinking water	Poverty
Frequency of extreme rainfall days	Gross rainfed area to the gross irrigated area	Density of groundwater stations	
Change in number of very hot days	Forest cover (%)	Buildings with rooftop rainwater harvesting (%)	

Source: Authors' analysis

Figure ES9. Indicators contributing to risk, in decreasing order of contribution, in the Gummidipoondi sub-basin



Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Areas under water bodies (%)	Urban stormwater drainage network	Elevation
Change in number of very hot days	Surface water quality index	Per capita gross storage capacity of water structures	Poverty
Change in the number of rainy days	Net sown area to total area	Buildings with rooftop rainwater harvesting (%)	Slope
Frequency of extreme rainfall days	Gross rainfed area to the gross irrigated area	Used water treated to used water generated	
Change in magnitude of rainfall	Distance to the sea	Used water reused to used water treated	

Source: Authors' analysis

Figure ES10. Indicators contributing to risk, in decreasing order of contribution, in the Kosasthalaiyar sub-basin

Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Gross rainfed area to the gross irrigated area	Buildings with rooftop rainwater harvesting (%)	Slope
Maximum number of floods	Groundwater quality index	Density of groundwater stations	Elevation
Annual average area impacted by floods	Net sown area to total area	Density of surface water stations	Poverty
Change in number of very hot days	Stage of groundwater development	Per capita gross storage capacity of water structures	
Change in magnitude of rainfall	Areas under water bodies (%)	Used water treated to used water generated	

Source: Authors' analysis

Figure ES11. Indicators contributing to risk, in decreasing order of contribution, in the Kovalam sub-basin

Hazard	Exposure	Adaptive capacity	Sensitivity
Difference of annual average future rainfall (2006–60) (%)	Distance to the sea	Urban stormwater drainage network	Elevation
Maximum number of floods	Surface water quality index	Used water reused to used water treated	Poverty
Frequency of cyclones	Stage of groundwater development	Households with basic sanitation	Slope
Number of meteorological droughts	Built-up area (%)	Used water treated to used water generated	
Annual average area impacted by floods	Groundwater quality index	Density of surface water stations	

Source: Authors' analysis

Water balance

- **Under a business-as-usual (BAU) scenario**
    - **The total water demand in the Chennai basin will rise from about 2,479 MCM in 2025 to 2,728 MCM by 2050, driven by a 34 per cent increase in population over the same period.**
    - Agriculture will continue to account for the largest share of water demand, accounting for around 60 per cent of total demand by 2050. **Unmet water demand will increase from 546 MCM in 2025 to 654 MCM by 2050, representing a 20 per cent increase.**
- **Under a high population growth scenario**
    - **The total water demand will reach 2,939 MCM in 2050, representing a 12 per cent increase from the 2025 level of 2,633 MCM.**
    - Unmet water demand will rise to 754 MCM by 2050, further stressing water resources and jeopardising access for domestic and agricultural users.
- **Scenarios under which unmet water demand reduces**
    - **The combined implementation of two primary strategies – the adoption of micro-irrigation and TUW reuse – can reduce unmet water demand in the Chennai basin.**
    - Scaling up **micro-irrigation to 13 per cent of the cropped area** and **achieving 25 per cent TUW reuse** will r**educe unmet water demand by about 52 per cent by 2050. Increasing TUW reuse to 40 per cent** will further reduce unmet demand, **reducing unmet water demand by about 63 per cent by 2050.**
    - Under the same intervention scenarios, incorporating climate change effects, unmet water demand will reduce by 90 per cent and 93 per cent by 2050, respectively.

By 2050, scaling up micro-irrigation to 13% and TUW reuse to 25% will reduce unmet water demand by 52%. Increasing reuse to 40% will further reduce it to 63%

Recommendations

The following recommendations aim to reduce water risk and deficits in the Chennai basin and are considered feasible for implementation over the next five years:

- **Mandate interdisciplinary water risk assessments and water balance preparations at the hyperlocal level**: This study demonstrates that it is possible to undertake such assessments at hyperlocal levels, such as sub-basins.To enable this, we apportioned data monitored by state institutions and departments at the administrative level to the sub-basin level. For future assessments, mandating data monitoring at the sub-basin level will help strengthen the system-level responses to climate-induced water risk and will help align assessments with natural hydrological boundaries rather than administrative ones. Such assessments should be jointly undertaken and periodically updated by the Municipal Administration and Water Supply Department and the Environment, Forest and Climate Change Department, with the former taking the lead role.

- **Assess and build capacity of state institutions to enable sustained water risk and balance assessments**: Although such assessments can be jointly undertaken and updated by the mentioned departments, the process requires coordination and support from other departments and institutions. It is therefore essential to conduct a training needs assessment across relevant departments and institutions followed by the design and delivery of tailor-made training programmes to strengthen institutional capacity for conducting such assessments. The Anna Institute of Management, whose mandate includes capacity building for prospective and practising administrators, can play a key role in conducting such training needs assessments and delivering targeted training programmes.

- **Strengthen existing datasets that enable water risk and balance assessments**: Water management complexity arises from wide hydrological span and competing sectoral demands. Strengthening existing datasets at the sub-basin level through initiatives, such as the Tamil Nadu Satellite-Based Water Bodies Information Monitoring and Safety System (TN-SWIP), as envisioned in the *State Draft Water Policy 2024*, can enable real-time monitoring of water bodies. Further, making such datasets publicly available through a dynamic dashboard, such as the Tamil Nadu Water Resource Information Management System (TN-WRIMS), can support more informed assessments.

- **Prioritise budgetary allocations and interventions for high-risk sub-basins**: Funding should prioritise sub-basins identified as high risk and design interventions to address the key indicators driving risk, particularly those common across multiple sub-basins. This should be guided by the results of the WEAP scenario analysis. For instance, the Kosasthalaiyar sub-basin faces the highest water risk but also shows strong potential to mitigate it. The results indicate that unmet water demand could be reduced by nearly 65 per cent by 2050 by scaling up TUW reuse to 40 per cent and micro-irrigation to 13 per cent. Similarly, investments and interventions in the Adyar sub-basin should prioritise decentralised, modular used water treatment plants near major demand centres to enable local reuse for non-potable domestic and industrial purposes. These efforts should be complemented by measures to promote and subsidise micro-irrigation coverage in water-intensive farms, alongside TUW reuse for groundwater recharge.

Together, these recommendations provide a clear direction for action in the near and medium term, supporting more resilient water systems under a changing climate in the Chennai basin.


Image: iStock

1. Introduction

Freshwater ecosystems provide a wide range of essential services, including water supply for drinking, irrigation, power generation, and industrial operations. They also deliver non-extractive benefits, such as flood control, transportation, recreational activities, and soil fertilisation, and serve as habitats for a wide variety of flora and fauna (Postel et al. 1997; Chung et al. 2021).

India has a vast network of freshwater resources, comprising wetlands, rivers, and aquifers, making it the ninth most diverse country in the world in terms of freshwater fauna (Mittermeier 1997; Arora et al. 2024). The country has 690 billion cubic metres (BCM) of utilisable surface water and 433 BCM of utilisable groundwater (CWC n.d.). Of total water withdrawals, irrigated agriculture accounts for 78 per cent of water consumption, the domestic sector for 9–10 per cent, and the industrial sector for the remaining 10–12 per cent (Singhal 2023). More than 60 per cent of agricultural and about 85 per cent of drinking water supply needs are met by groundwater (Ahmad 2025). In contrast, the industrial sector relies primarily on surface water (41 per cent), followed by groundwater (35 per cent), and municipal water (24 per cent) (FICCI 2011). The average annual per capita water availability is estimated to be 1,486 cubic meters in 2021 and is projected to decline to 1,367 cubic meters by 2031 (PIB 2022). As of 2023, agriculture and industry contributed 16 per cent and 25 per cent, respectively, to India's gross domestic product (GDP) and employed more than 43 per cent and 25 per cent of the workforce (Neill 2025a, 2025b). Ensuring water security is therefore critical to sustaining food and livelihood security as well.

Global freshwater systems are increasingly vulnerable to climate change due to their sensitivity to temperature shifts, precipitation variability, and the intensification of extreme weather events (IPCC 2008). Over recent decades, climate change has consistently altered multiple hydrological components, including precipitation patterns, cryosphere dynamics, atmospheric moisture content, evaporation rates, and soil moisture–runoff relationships. These changes are creating compounding stressors on these ecosystems.

In India, most of the major river basins are water stressed (11 out of 15) (Bassi et al. 2023), **and about 25 per cent of groundwater aquifers are extracted beyond safe limits** (CGWB 2024). These basins, home to 8.7 per cent of the country's population, face increasing stress from rapid urbanisation and resource overuse (NITI Aayog 2018). These pressures are further exacerbated by the impacts of climate change, making the basins more vulnerable. According to the Intergovernmental Panel on Climate Change (IPCC), rising temperatures and erratic rainfall are increasing the frequency of extreme floods and droughts in India (IPCC 2022). Over the past four decades, almost 30 per cent of Indian districts experienced a high number of deficient rainfall years, while 38 per cent experienced a high number of excessive rainfall years (Prabhu and Chitale 2024). In these districts, rainfall was either deficient or excessive for more than 10 out of 40 years, indicating the erratic rainfall patterns (Prabhu and Chitale 2024).

India's rainfall is also highly seasonal, with around half of its annual precipitation occurring within just 15 days. As a result, more than 90 per cent of the country's river flows are concentrated within four months (Sharma and Sharma 2008). Most river basins in India therefore exhibit low resilience to climate extremes (Jha et al. 2019).

The Chennai basin experiences the same situation with respect to the occurrence of climate extremes. About 78 per cent of the basin lies within the state of Tamil Nadu (CCCDM 2022), covering five districts that together contribute 36 per cent to the state economy. Given the basin's importance in meeting domestic, agricultural, industrial, and environmental water demands, a detailed assessment of climate-induced risks to its water resources is essential.

Image: iStock

2. The Chennai basin

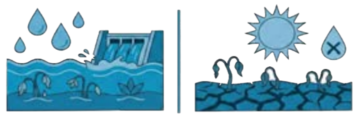
The Chennai basin is shared between the states of Andhra Pradesh and Tamil Nadu, with about 78 per cent of the basin area – covering 6,123 square kilometres (sq km) – located in the northern part of Tamil Nadu (CCCDM 2022). The basin is bounded by the Palar river basin to the south and west and by the Bay of Bengal to the east. The Tamil Nadu portion of the basin spans five districts – Chennai, Chengalpattu, Kanchipuram, Ranipet, and Thiruvallur – and comprises six sub-basins – Adyar, Araniyar, Cooum, Gummidipoondi, Kovalam, and Kosasthalaiyar (also known as Korattalaiyar). Together, these districts contribute to 32.8 per cent of the state's GDP (DES 2024a). In addition, over 92,000 small-scale industries and 652 medium- and large-scale industries operate within the basin (Anushiya and Ramachandran 2015).

The basin contains several key freshwater reservoirs, including Poondi, Cholavaram, Red Hills, and Chembarambakkam, as well as brackish water bodies, such as Pulicat Lake and the Ennore, Cooum, Adyar, and Covelong estuaries. Situated in a tropical monsoon zone, the region receives nearly 50 per cent of its annual rainfall during the northeast monsoon. The annual normal rainfall in Tamil Nadu is 965.6 mm (DES 2024b). Major land uses include built-up areas (53 per cent of the basin area), cultivation (21 per cent), vegetation (19 per cent), and water bodies (6 per cent) (CEEW analysis based on Waterman 2025).

Each sub-basin makes a significant contribution to supporting the water demands and ecological balance of Chennai and its surrounding areas. Additional details on individual sub-basins are provided in Annexure 1.

2.1 Impact of climate change on the Chennai basin

Climate change has intensified extreme weather events across Tamil Nadu, a state characterised by a large geographical area and diverse topographical features. State-wide temperature anomalies between 2014 and 2023 indicate an average rise of about 1°C, while projections suggest that temperatures could further increase by 1.7–3.5°C by the end of the century (CCCDM 2024). Districts within the Chennai basin, namely, Chennai, Chengalpattu, Kancheepuram, and Thiruvallur, are experiencing more severe increases in land temperatures than other districts in the state, reflecting higher mean land temperatures compared to those in other parts of Tamil Nadu (CCCDM 2024).



Chennai is prone to both floods and droughts.

Chennai's rainfall regime is monsoon-driven, with nearly 90 per cent of annual precipitation occurring between June and December, influenced by both the south-west monsoon (SWM) and north-east monsoon (NEM). A tehsil-level assessment reports increasing rainfall trends in parts of Chennai during the last decade (2012–22) compared to the period 1981–2011 (Prabhu and Chitale 2024). The same study also observes a rise in short-duration, high-intensity rainfall events during both the SWM and the NEM. The variability in Chennai's monsoon systems is shaped by broader climatic factors, including the El Niño phenomenon and anomalous sea surface warming in the Bay of Bengal, which are associated with above-normal rainfall during the October–December period (Dhana Lakshmi and Satyanarayana 2019). In addition, recent decades have witnessed an increase in cyclonic activity in the Bay of Bengal, contributing to more frequent coastal hazards (CCCDM 2024).

As a result of highly variable rainfall patterns and climatic conditions, Chennai is prone to both droughts and floods. Major flood events occurred in 2002, 2004, 2005, and 2015 (Neogi et al. 2021). The region has also experienced drought-related water crises due to monsoon failures, notably in 2000 and during successive years from 2016 to 2018 (Joseph 2022; Kaaviya and Devadas 2021). A spatio-temporal analysis of rainfall in the Adyar sub-basin attributes meteorological droughts in 1992, 1999, 2000, and 2002–03, as well as hydrological droughts during 2003–05, 2006–2007, 2009–10, and 2016–17, to interannual variability of the SWM and NEM (Anandharuban and Elango 2021). Climate risk projections further indicate that parts of the Cooum and Kosasthalaiyar sub-basins, along with most of the Gummidipoondi sub-basin, face high to very high drought risk in the period leading up to 2050 (CCCDM 2022).

Urban expansion within the basin has further intensified pressure on the water basin over time. For instance, historically, the Cooum sub-basin relied on a network of interconnected tanks and lakes with a combined storage capacity of 58 million cubic meters (MCM). Rapid urbanisation has since severely degraded many of these water bodies, with some tanks – including Mogappair, Kodungaiyur, and Valasaravakkam – losing up to 100 per cent of their water storage due to infrastructure development and encroachments (Rajagopalan et al. 2024). A similar pattern is evident in Chennai city, where urbanisation has led to the loss of 13.6 MCM of tank storage. The remaining tanks outside the city, with a storage capacity of 174.7 MCM of water, are now at risk (Devi et al. 2025).

During the 2015 floods in Chennai, the carrying capacity of the city's stormwater drainage system was overwhelmed in the highly urbanised sub-basins of Kosasthalaiyar and Cooum (Devi et al. 2019). Rapid urbanisation in the region has surpassed sewage treatment capacity, leading to the discharge of untreated used water into the Cooum and Adyar rivers. This has resulted in very high biochemical oxygen demand and faecal coliform contamination, particularly downstream of urban and industrial zones (Rosado et al. 2024). In addition to surface water degradation, the groundwater quality in the basin is also severely deteriorating. An assessment conducted in 2021 across potable zones found that only 10.7 per cent of post-monsoon samples and 17.9 per cent of pre-monsoon samples were rated as 'excellent' for drinking (Ramachandran et al. 2021). Most groundwater, particularly in the north, north-west, and west of the basin, was classified as very poor or unfit for consumption. The high levels of total dissolved solids (TDS), calcium (Ca), magnesium (Mg), sodium (Na), nitrate (NO_3), and sulphate (SO_4), with nitrate levels exceeding safe limits, indicate contamination from industrial discharge, agricultural runoff, and urban waste, which have altered groundwater chemistry (Ramachandran et al. 2021).

Overall, the Chennai basin is caught in a dual feedback loop. Climatic variability is intensifying hydrological stress, while rapid urban expansion is eroding the basin's natural resilience. The interplay of rising temperatures, increasingly erratic monsoon patterns, reduced soil water-holding capacity due to urbanisation, and water pollution has intensified the need for sustainable water management and climate resilience in the Chennai basin.

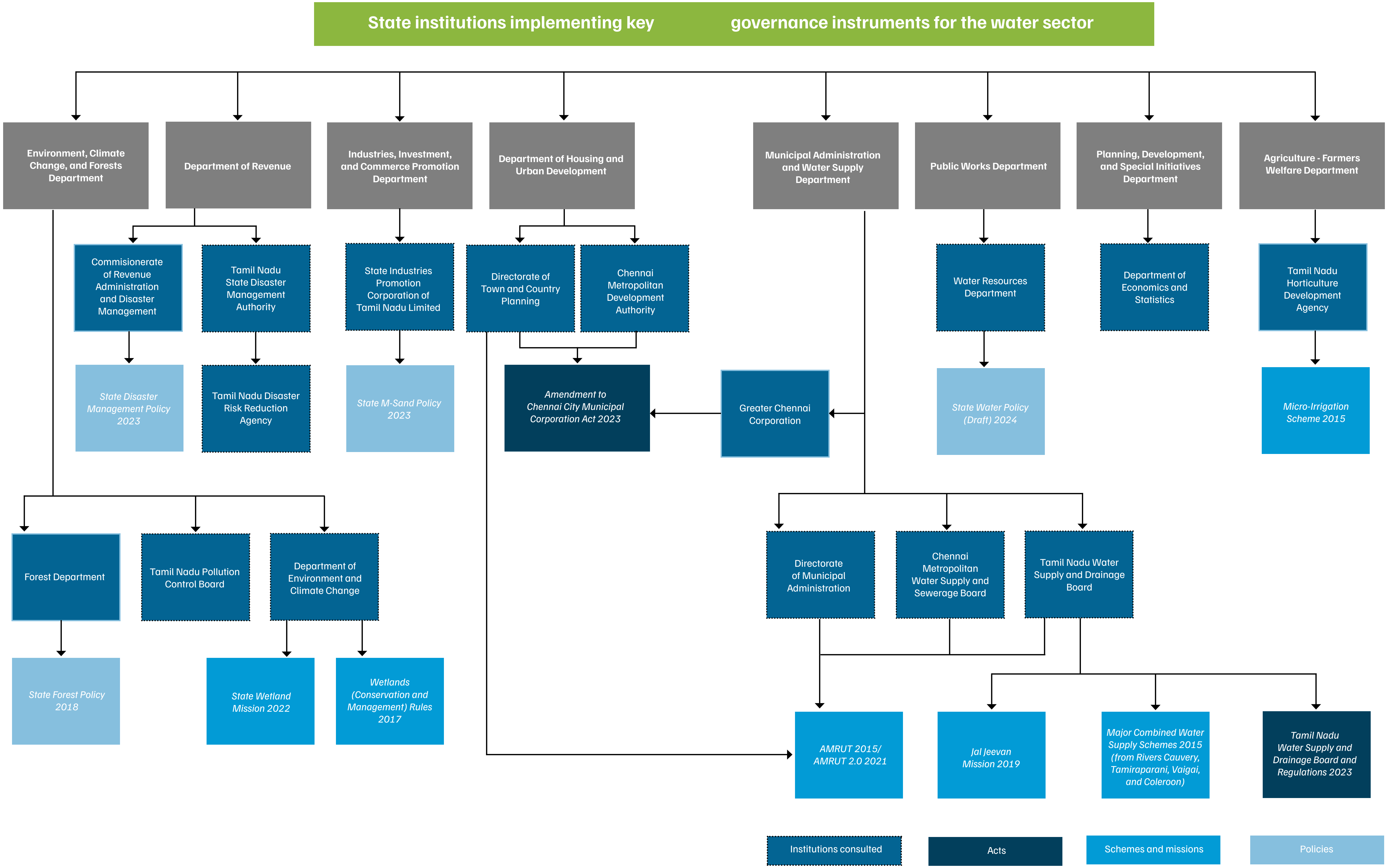
2.2 Governance of the water sector in the Chennai basin

The governance of various aspects of the water sector in the state, as relevant to this study, is overseen by eight departments (Figure 1). Through their respective sub-institutions, these departments are responsible for:

- preparedness for and response to disasters;
- provision of water supply services;
- protection, conservation, management, and rejuvenation of ecosystems such as forests and wetlands that sustain the hydrological cycle, including water quality management;
- development of plans for drinking water, sewerage, and rainwater harvesting systems in urban areas;
- ensuring access to water supply for all and effective sewerage management;
- formulation of policies related to the water sector;
- promotion of a circular economy for water resources in industries; and
- promotion of water conservation in irrigation practices.

Various initiatives distinguish water resource governance in the state. First, the ***Tamil Nadu State Water Policy (Draft), 2024*** aims to provide equitable access to clean water and envisions the establishment of the Tamil Nadu Satellite-Based Water Bodies Information Monitoring and Safety System (TN-SWIP) for real-time surveillance of water bodies and detection of encroachments (BL Chennai Bureau 2025). Second, the ***Tamil Nadu Disaster Management Policy, 2023***, seeks to embed disaster risk reduction within the state's broader sustainable development framework and advocates a holistic and integrated approach to disaster management, with an emphasis on risk reduction through multi-stakeholder collaboration and the adoption of appropriate technologies (SPC 2023b). Third, the ***Amendment to Chennai City Municipal Corporation Act and Other City Laws, 2003*** made Tamil Nadu the first state in India to mandate rainwater harvesting as a legal requirement and implement it as a state-wide programme (CSE n.d.). Fourth, the ***Chennai Metropolitan Area Groundwater (Regulation) Act, 1987*** made Chennai the first city in the country to introduce legislation specifically aimed at regulating groundwater extraction and transportation in an urban area (Sengupta 2019). Additional details are provided in Annexure 2.

Figure 1. State institutions implementing key governance instruments for the water sector



Source: Authors' analysis


Image: iStock

3. Purpose and scope of the study

This study aims to ensure the sustenance of **water security** in the Chennai basin under risks arising from a changing climate. To this end, it aims to provide a nuanced assessment of climate risk to the basin's water resources, update the existing water balance to better elucidate the impacts of current growth trajectories and climate change on different components of the hydrological cycle, and examine how increased uptake of treated used water (TUW) can enhance the region's climate resilience.

In accordance with the natural boundaries of water resources, the analysis has been conducted at the **hydrological scale** of sub-basins rather than administrative boundaries. To provide a granular understanding of how water resources in sub-basins are impacted by climate extremes, this study assesses and quantifies the impacts of acute climate events, chronic climate events, and projected future rainfall.

3.1 Objectives

- Develop and compute an **index to assess climate-induced risk to water systems** in the Tamil Nadu portion of the Chennai basin at the sub-basin level.
- Update the **existing water balance** of the Chennai basin with the latest data and incorporate scenarios to address water deficits at the sub-basin level.
- Develop a targeted water balance scenario to assess the **potential of TUW reuse** in reducing pressure on freshwater resources at the sub-basin level.

3.2 Research questions

- What are the key indicators of climate-induced risk to water systems in the Chennai basin?
- What level of climate risk does each sub-basin within the Chennai basin face, and which indicators exacerbate this risk?
- What are the unmet water demands or future water deficits?
- What is the potential of utilising TUW across sectors – irrigation, industries, and other non-potable purposes – to reduce freshwater withdrawals?


Image: iStock

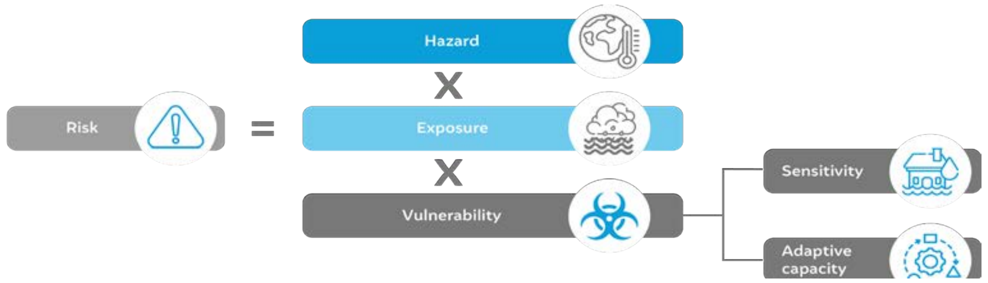
4. Methodology

The methodology is organised into two sections. Section 4.1 outlines the methodology used for risk assessment, while Section 4.2 presents the methodology used for WEAP modelling.

4.1 Methodology for risk assessment

This assessment follows the framework set out in IPCC's Fifth Assessment Report (AR5), which defines risk as the interaction between hazard, exposure, and vulnerability comprising sensitivity and adaptive capacity (Figure 2). AR5 further describes risk as the potential for adverse consequences for human and ecological systems, including impacts on lives, livelihoods, infrastructure, and ecosystems (Pachauri et al. 2014). We developed the risk index through a six-step process, as illustrated in Figure ES3. Additional details on this process are provided in Annexure 3.

Figure 2. Risk assessment equation



Source: Authors' representation based on Pachauri, Rajendra, Leo Meyer, Stephane Hallegatte, Gabriele Hegerl, Jean-Pascal Van Ypersele, Sander Brinkman, Noëmie Leprince-Ringuet, and Fijke Van Boxmeer. 2014. "Climate Change 2014 Synthesis Report." IPCC. Gian-Kasper Plattner.

For the purpose of computing the risk index, **we conducted consultations to collect data from 13 key state institutions** governing different aspects of the state's water sector, particularly in relation to climate-induced risk. These institutions include the Agriculture and Farmers Welfare Department (AFWD), Climate Studio (an exclusive state of art established at CCCDM, Anna University), Chennai Metropolitan Development Authority (CMDA), Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB), Department of Economics and Statistics (DES), Directorate of Municipal Administration (DMA), Directorate of Town Panchayats (DTP), Indian Institute of Technology (IIT)-Madras, State Industries Promotion Corporation of Tamil Nadu (SIPCOT), Tamil Nadu Disaster Risk Reduction Agency (TNDRRA), Tamil Nadu Pollution Control Board (TNPCB), Tamil Nadu Water Supply and Drainage (TWAD) Board , and Water Resources Department (WRD). The Tamil Nadu Green Climate Company (TNGCC) facilitated the stakeholder consultations and supported the flow of data and information.

Initially, we shortlisted a list of indicators for the risk assessment based on a review of the literature. The list of indicators was subsequently finalised through consultations with the 13 departments. They also supported us in the ranking of indicators according to their relevance to risk and provided data required for computing the indicators. Detailed information on the rationale for indicator selection, the data sources for indicators, the questionnaire for ranking indicators, the detailed steps for computing each indicator, and the absolute final indicator values for each sub-basin are provided in Annexures 4, 5, 6, 7, and 8, respectively. Interventions informed by the water risk assessment for the Chennai basin, based on the selected indicators, can support 36 targets across 11 Sustainable Development Goals (Figure ES2). Additional details are provided in Annexure 9.


Image: TWAD Board and CMWSSB

CEEW and TNGCC in consultation with TWAD Board (left side) and CMWSSB (right side) in December 2024

4.2 Water Evaluation and Adaptation Planning (WEAP) modelling

Hydrological modelling was undertaken for the Tamil Nadu portion of the Chennai basin using the WEAP tool to prepare the water balance for the basin for the period 1994–2050, using a monthly time step. Scenarios were developed to simulate the effects of business-as-usual (BAU) growth, high population growth, climate change, and interventions related to TUW reuse and the adoption of micro-irrigation systems. The WEAP tool is an integrated, scenario-based modelling platform designed to support water resources planning and management. Developed by the Stockholm Environment Institute, WEAP applies a mass-balance approach to simulate the allocation of water from various sources across competing demand sites (SEI 2001).

WEAP configuration

The WEAP tool was configured to model the water balance across the six sub-basins of the Chennai basin. The configuration consists of water demand sites, water supply nodes, and links representing the flow of water through the system (Bassi and Chaturvedi 2024). The data on climatic factors, such as rainfall, evapotranspiration, and humidity, were incorporated for each sub-basin to model reservoir inflows, groundwater recharge, and agricultural water demand. Water was supplied to demand sites in the basin – including population, agriculture, and livestock – from reservoirs, desalination plants, aquifers, and sewage treatment plants (STPs) (Table 1). Reservoirs primarily receive water from runoff, while groundwater is recharged through rainfall infiltration and percolation within catchments. Domestic and agricultural water demand sites were considered in the model. Network links between the supply and demand sites, as well as return flows, were established through transmission links, runoff pathways, and withdrawal points (Figure ES4).

Table 1. Category and number of nodes in the Water Evaluation and Adaptation Planning (WEAP) model

Category of node	Number of nodes
Demand sites and catchments	
Population	6
Agriculture	6
Catchments	5
Livestock	6
Industry	6
Supply and resources	
Rivers	7
Streams	1
Reservoirs	6
Aquifers	6
Desalination plant	4
Water treatment plant	6
Sewerage treatment plant	12
Common effluent treatment plant	3
Category of link	**Number of links**
Transmission	192
Return Flow	49
Runoff/Infiltration	21

Source: Authors' analysis

Data for WEAP

Data collection for the WEAP model was conducted in collaboration with the TNGCC to ensure a robust understanding of the historical and current characteristics of the Chennai basin water system and to inform projections through 2050. The CMWSSB provided key information on used water treatment plants, desalination facilities, and reservoir infrastructure. Demographic data on domestic and livestock populations were obtained from the Census of India and the Ministry of Statistics and Programme Implementation. Groundwater availability data were sourced from the Central Ground Water Board, while agricultural statistics were obtained from the Directorate of Economics and Statistics. Rainfall records were sourced from the Indian Meteorological Department. Climate change projections for rainfall and temperature were drawn from the Representative Concentration Pathways (RCP) 4.5 scenario, obtained from the Coordinated Regional Climate Downscaling Experiment – Coupled Model Intercomparison Project Phase 5 (CORDEX–CMIP5). These projections were generated using the Regional Climate Model Four (RegCM4) of the Indian Institute of Tropical Meteorology CORDEX programme and were driven by six CMIP5 global climate models. Data on micro-irrigation were sourced from the Press Information Bureau. Together, these datasets provide a comprehensive foundation for assessing current system conditions and modelling future scenarios in the Chennai basin. Additional details on the datasets used in the WEAP model are provided in Annexure 10.

Water demand

Domestic water demand was estimated using population projections for the five districts within the study area. These projections were generated through linear regression based on Census 2001 and 2011 population data, and the fitted regression model was used to extrapolate population values for the projection period. Population estimates for each modelled year were then reaggregated according to the overlapping area between each district and sub-basin within the study area. Following official norms, water demand was considered to be 150 litres per capita per day for urban areas and 50 litres per capita per day for rural areas (Bassi and Chaturvedi 2024).

Agricultural water demand was estimated by disaggregating cropped area data for each district by season – kharif (monsoon), rabi (winter), summer, and autumn – with missing data interpolated using linear regression. For each sub-basin and season, crops representing 95 per cent or more of the total cropped area were retained for analysis. Crop-wise water demand per unit area was estimated using the CROPWAT model developed by the Food and Agriculture Organization of the United Nations (FAO). CROPWAT is a tool used to estimate crop water requirements and develop irrigation schedules based on climate, crop, and soil data. Using the FAO Penman–Monteith method, CROPWAT calculates reference and crop evapotranspiration, enabling assessments of irrigation demand, water use efficiency, and the impacts of water stress on yields. CROPWAT was applied to estimate irrigation water requirements for each crop type under normal, wet, and dry conditions, using average monthly rainfall for each category. These crop-specific water demand estimates were applied to the cropped area in each year during 1994–2023 to calculate agricultural water demand. Livestock populations over the study period were estimated using linear regression, and their water demand was computed using the methodology presented in Bassi and Chaturvedi (2024).

To classify each year according to official standards, rainfall data for the period 1994–2023 were analysed using the long-period average (LPA) as the benchmark. Following India Meteorological Department (IMD) criteria, years are categorised based on their per cent deviation from the LPA. A year is classified as an excess rainfall year if the realised rainfall is 20–59 per cent of the LPA. Conversely, it is classified as a deficient year if the rainfall is between –20 per cent to –59 per cent of the LPA. Rainfall within the range of –19 per cent to +19 per cent of the LPA is categorised as normal (IMD n.d.).

Industrial water demand was estimated by assuming that it accounts for 10 per cent of the overall water demand from domestic and agricultural sectors. This assumption follows national-level estimates indicating that 80 per cent of total water demand is attributable to agriculture, 10 per cent to domestic use, and the remaining 10 per cent to industrial use (Ramprasad and Bhaduri 2025).

Catchments

Catchments contribute significantly to water availability by channelling rainwater to reservoirs, groundwater systems, and rivers. Drawing on prior analysis of the Chennai basin by RaziSadath et al. (2023), the Araniyar basin, the Kosasthalaiyar basin, and the Cooum–Adyar–Kovalam (CAK) basin, along with the Poondi and Chembarambakkam catchments, were incorporated into the model. Runoff from the Araniyar basin catchment flows into the Araniyar River. Runoff from the Kosasthalaiyar basin catchment encompassing the Nagariyar, Nandiyar, and Kosasthalaiyar rivers primarily recharges the Poondi Reservoir, from which water is subsequently diverted to the Cholavaram and Red Hills reservoirs through supply channels. Runoff from the CAK basin catchment flows into the Cooum and Adyar rivers, while the Chembarambakkam reservoir is primarily recharged by its own catchment (RaziSadath et al. 2023). The Poondi and Chembarambakkam catchments contribute inflows to the Poondi and Chembarambakkam reservoirs, respectively. Rainfall-runoff estimates for all catchments were prepared using the simplified coefficient method. Environmental flow (e-flow) requirements were incorporated for the Araniyar, Cooum, and Kosasthalaiyar rivers. In line with the National Green Tribunal's 2017 guidelines, rivers should maintain a minimum of 15–20 per cent of average lean-season flow (GoI 2018). For the Chennai basin, the lean season spans January–May. Accordingly, the e-flow requirements were set as 20 per cent of the monthly average lean-season flow for the period 1994–2023.

Water supply

Water supply sources represented in the model include reservoirs, aquifers, desalination plants, water treatment plants (WTPs), and used water treatment plants. Reservoirs were characterised using physical characteristics, such as volume–elevation curves, maximum storage capacity, and dead storage. Annual extractable groundwater was estimated by developing linear regression models to interpolate values for years with missing data. Water imports to the basin from Veeranam Lake were also incorporated into the model. Following the assumptions made by Bassi and Chaturvedi (2024), conveyance losses of 20 per cent were assumed for transmission links from surface water sources to demand sites, while conveyance losses of 5 per cent were assumed for transmission links from groundwater sources to demand sites (Table 3).

Table 2. Water supply percentage from each source

Year	Supply source percentage				
	Aquifers (in %)	Reservoirs (in %)	WTPs (in %)	Desalination plants (in %)	STPs (in %)
2020	40.25	43.81	5.09	1.62	9.23
2025	39.57	43.31	5.4	2.75	8.97
2030	39.4	43.32	5.42	3.02	8.84
2035	39.37	43.29	5.4	3.22	8.72
2040	39.35	43.22	5.39	3.44	8.6
2045	39.23	42.95	5.3	4.04	8.47
2050	39.13	42.66	5.23	4.62	8.36

Source: Authors' analysis

Scenarios

Overall, six scenarios were modelled. The first was the reference or business-as-usual (BAU) scenario, reflecting existing growth trends and water demand in the basin. The second was a high population growth scenario, under which urban and rural populations increased 25 per cent faster than historical rates after 2011, providing an upper bound for domestic water demand. The third scenario combined TUW reuse and micro-irrigation, assuming that 25 per cent of TUW is reused by 2030 and micro-irrigation is adopted in non-paddy areas. The fourth scenario considered reuse to be 40 per cent by 2030. Scenarios 5 and 6 incorporated the impacts of climate change on water availability in the basin and applied these to scenarios 3 and 4. For each reuse scenario, two sub-scenarios were evaluated: (1) treatment capacity in the basin increases according to historical growth rates, and (2) treatment capacity expands to enable 100 per cent of sewage to be treated by 2045 (Table 4).

Table 3. Water Evaluation and Adaptation Planning (WEAP) model scenarios

Scenarios	Description
Scenario 1 BAU – reference	Non–climate change environmental projections for precipitation and evapotranspiration considering the existing growth and water demand in the basin.
Scenario 2 High population growth (25%)	Same as BAU, but growth is assumed to increase 25% faster than BAU from 2011.
Scenario 3 Micro-irrigation + 25% reuse + BAU	13% of the cropped area in the basin, excluding rice, is considered to fall under micro-irrigation. We assume that reuse increases linearly from 0–25% over 2020–30 and consider non-climate change environmental projections.
Scenario 4 Micro-irrigation + 40% reuse + BAU	Same as scenario 3, but reaching 40% reuse by 2030.
Scenario 5 Micro-irrigation + 25% reuse + climate change	The same as scenarios 4 and 5, but incorporating climate change projections using CORDEX South Asia (CMIP5), which projects an increase in precipitation across South India.
Scenario 6 Micro-irrigation + 40% reuse + climate change	The same as scenarios 4 and 5, but incorporating climate change projections using CORDEX South Asia (CMIP5), which projects an increase in precipitation across South India.

Source: Authors' analysis

4.3 Limitations

Some limitations associated with both the risk assessment and WEAP modelling for the Tamil Nadu portion of the Chennai basin are presented in the following sections.

Risk assessment

Limitations in risk assessment arise on two fronts. First, there is scope to include mode indicators; second, inconsistencies and reliability issues in the input data used to calculate risk indicators. These limitations stem from the unavailability of data required for this study, gaps in the way data are collected by national and state governments, or the lack of data at the desired spatial or temporal resolution. The details are provided in Annexure 11.

WEAP modelling

The estimation of agricultural water demand is subject to several limitations arising from assumptions related to soil and crop parameter selection. To estimate agricultural water demand in the Chennai basin, the study defined soil and crop parameters using available datasets and literature sources, applying simplifying assumptions where detailed local data were unavailable. The analysis used the FAO Harmonised World Soil Database (HWSD) was used to identify the dominant soil type for each sub-basin, considering soil characteristics at depths of up to 100 centimetres (cm), which correspond to the upper bound of effective root zone depths for the crops analysed. Where multiple soil types occurred either vertically or spatially, the study selected the soil type with the lowest available water content. The analysis compiled effective root zone depths for each crop type from published sources. However, local variations in crop varieties, agronomic practices, and seasonal conditions may result in deviations from these generalised values. The study excluded perennial crops, such as coconut, pome fruits, and cashew. While these assumptions were necessary to generate basin-wide estimates, they introduce uncertainty into the results, particularly in regions with high soil variability or diverse cropping patterns, and should be considered when interpreting the findings.

The study further assumed the recharge of groundwater sources from catchment runoff to be 16 per cent of rainfall, based on existing literature (Pazhuparambil Jayarajan et al. 2022). In practice, however, groundwater recharge may be more variable.

Due to limited access to water quality data, the study did not consider the specific treatment levels required for different water reuse pathways; future research should address this gap.

Finally, the WEAP model develops predictions based on projected data that depend on socio-economic, hydrological, and other factors. Deviations from actual conditions in any domain may influence the results. Conclusions drawn from these results should be interpreted accordingly.

5. Findings and results

5.1 Outputs from the risk assessment

The results of the risk assessment for each sub-basin and each sub-component of risk are presented in the following sections.

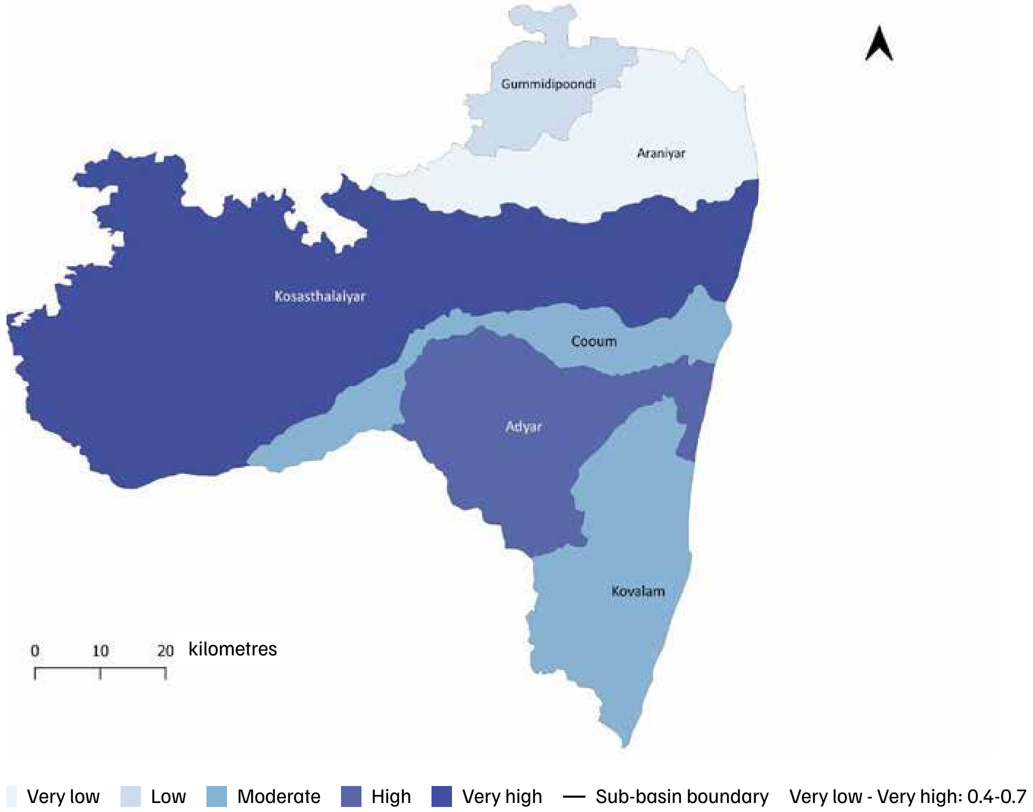
Hazard

The susceptibility of each sub-basin to climate-related hazards was assessed by considering changes in rainfall, past floods, droughts, cyclones, heat waves, and projected changes in future rainfall (Figure 3). **Kosasthalaiyar** records the highest hazard score, followed by **Adyar, Cooum, Kovalam, Gummidipoondi, and Araniyar.**

Further details on the top contributing indicators to the hazard score for each sub-basin are presented in Figures ES6–ES11. Across the six sub-basins, the most frequently occurring top contributors to the hazard sub-index are:

- the percentage **difference in annual average future rainfall** at the sub-basin level (2006–60) compared to the baseline (1951–2005) (top contributor for five sub-basins);
- **changes in rainfall magnitude** over the past 30 years (1994–2023) compared to the baseline period (1964–93) (top contributor for four sub-basins);
- the **maximum number of flood events** reported within a sub-basin over the past 50 years (1969–2019) (top contributor for four sub-basins);
- **changes in the number of very hot days** at the sub-basin level over the past 10 years (2014–23) compared to the baseline (1983–2013) (top contributor for four sub-basins).

Figure 3. Hazard level is the highest in the Kosasthaliyar sub-basin



Source: Authors' analysis

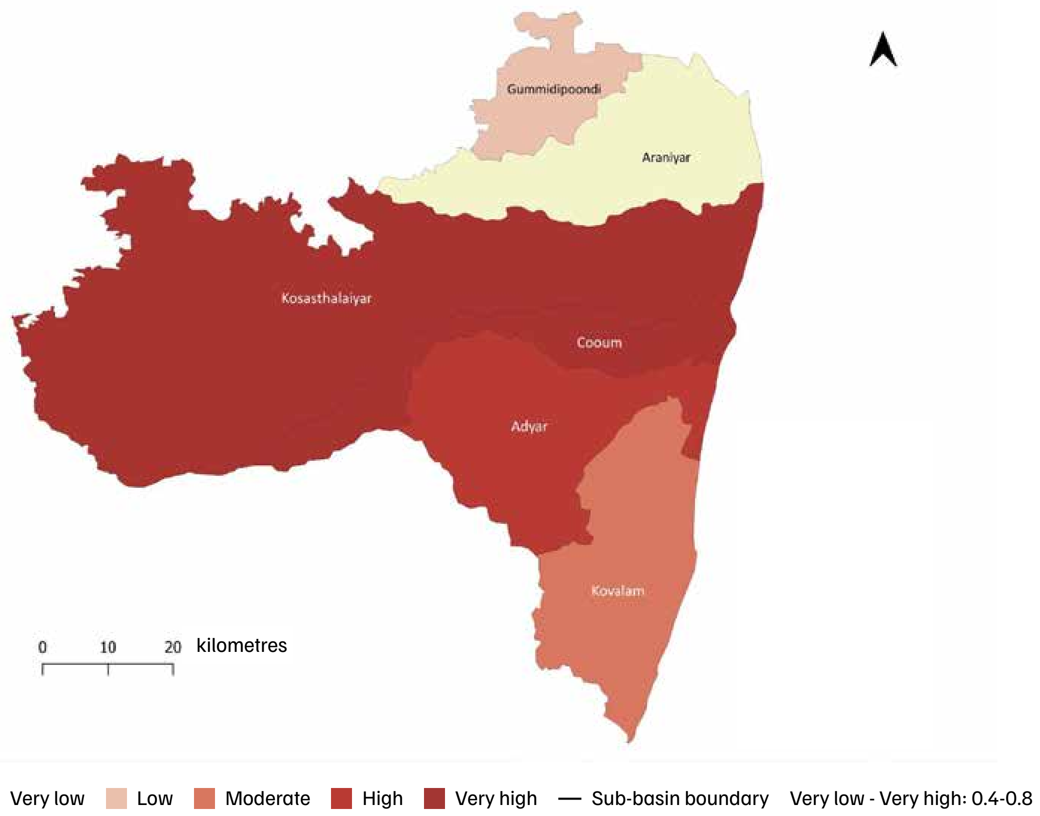
Exposure

The exposure of each sub-basin to a changing climate is presented in Figure 4. The exposure sub-index is highest for **Kosasthalaiyar** and **Cooum**, followed by **Adyar**, **Kovalam**, **Gummidipoondi, and Araniyar**.

Further details on the top contributing indicators to the exposure score for each sub-basin are presented in Figures ES6–ES11. Across the six sub-basins, the most frequently occurring top contributors to the exposure sub-index are:

- the **distance of the sea** from the centre of the sub-basin in 2023 (top contributor for four sub-basins);
- the **groundwater quality index** of the sub-basin for 2023 (top contributor for four sub-basins);
- the percentage of **gross rainfed area to gross irrigated area** within the sub-basin for 2023 (top contributor for four sub-basins).

Figure 4. Exposure level is the highest in the Cooum and Kosasthaliyar sub-basins



Source: Authors' analysis

Vulnerability

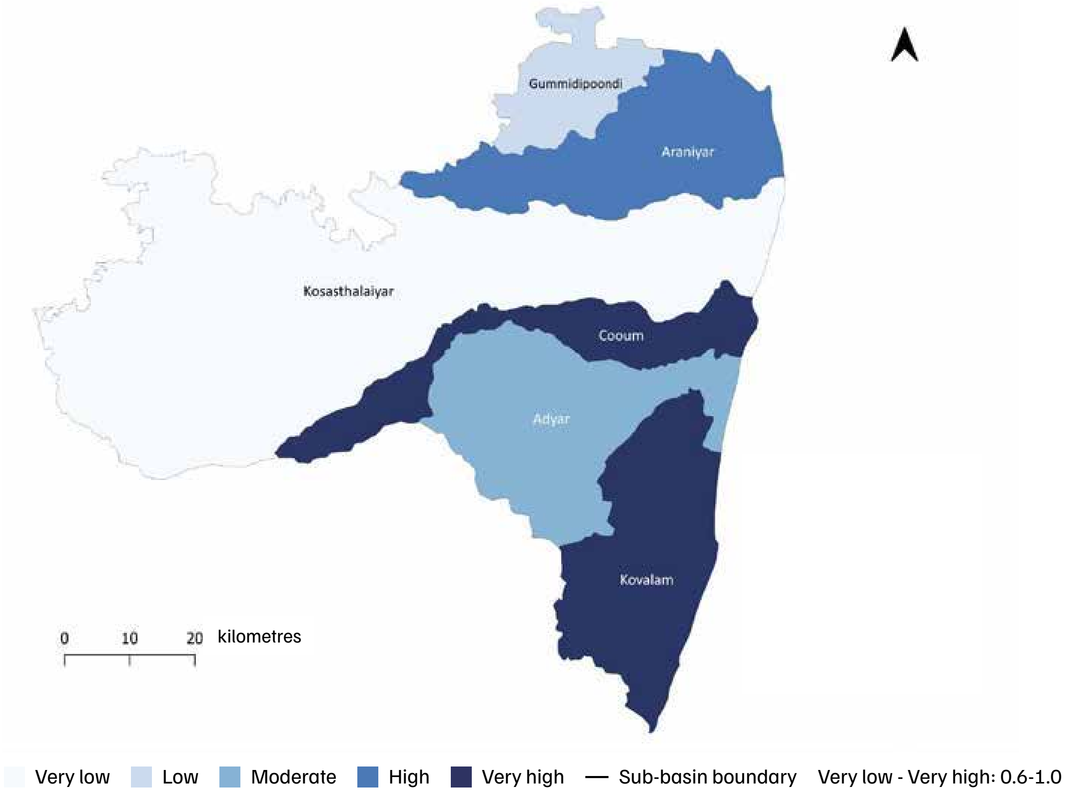
The vulnerability of each sub-basin to a changing climate stems from the interaction of its **sensitivity** and **adaptive capacity**. The vulnerability of each sub-basin to a changing climate is presented in Figure 5. The vulnerability sub-index is highest for **Cooum** and **Kovalam,** followed by **Araniyar, Adyar, Gummidipoondi, and Kosasthalaiyar**.

Further details on the top contributing indicators to both sub-components of vulnerability for each sub-basin are presented in Figures ES6–ES11. Across the six sub-basins, the most frequently occurring top contributors to adaptive capacity are:

- **coverage of the stormwater drainage network** in urban areas of the sub-basin in the latest year (top contributor for five sub-basins);
- **per capita gross storage capacity** of small tanks, large tanks, and reservoirs at the sub-basin level for 2023 (top contributor for five sub-basins);
- percentage of **used water treated to total used water generated** at the sub-basin level in 2023 (top contributor for five sub-basins);
- percentage of **used water reused to total used water treated** at the sub-basin level in 2023 (top contributor for four sub-basins);
- percentage of **buildings with rooftop rainwater harvesting systems** in the sub-basin in 2023 (top contributor for four sub-basins).

Since sensitivity was represented by only three indicators, all three were found to be significant.

Figure 5. Vulnerability level is the highest in the Cooum and Kovalam sub-basins

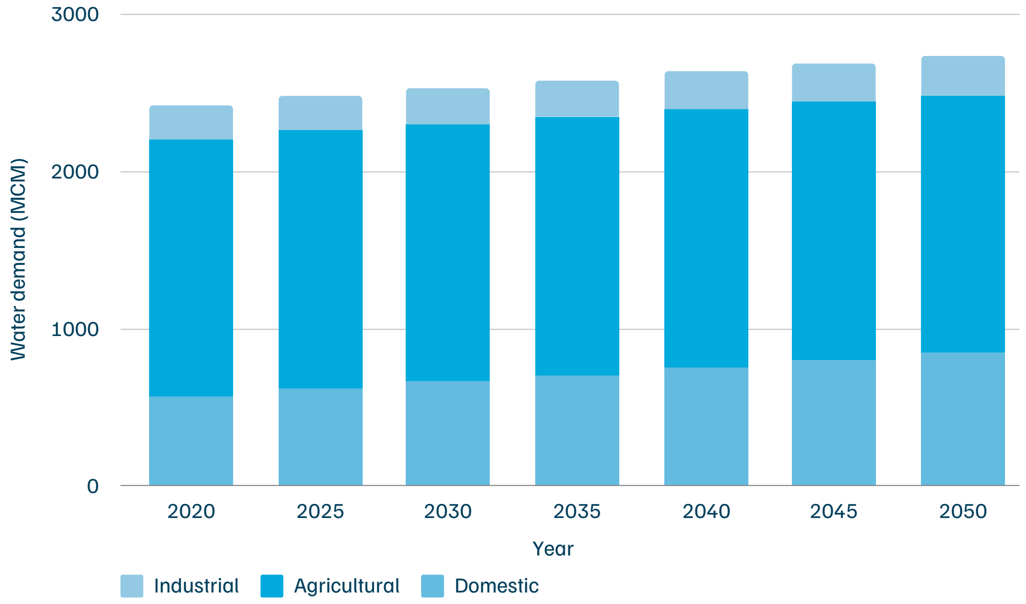


Source: Authors' analysis

5.2 Results from the Water Evaluation and Adaptation Planning (WEAP) model

As per the WEAP model results, **the total water demand in the Chennai basin under the BAU scenario is nearly 2,479 MCM in 2025**, mainly accounting for domestic and agricultural demand. **This demand is projected to rise to 2,529 MCM by 2030 and further to 2,728 MCM by 2050** (Figure 6). In 2050, agriculture alone is projected to account for 1,639 MCM of water demand in the basin and is predicted to remain the largest consumer, representing about 60 per cent of total water demand in the basin. Further, population growth in the region is expected to rise steadily, contributing to rising water demand. The basin's population is estimated to increase by approximately 34 per cent from 2025 levels.

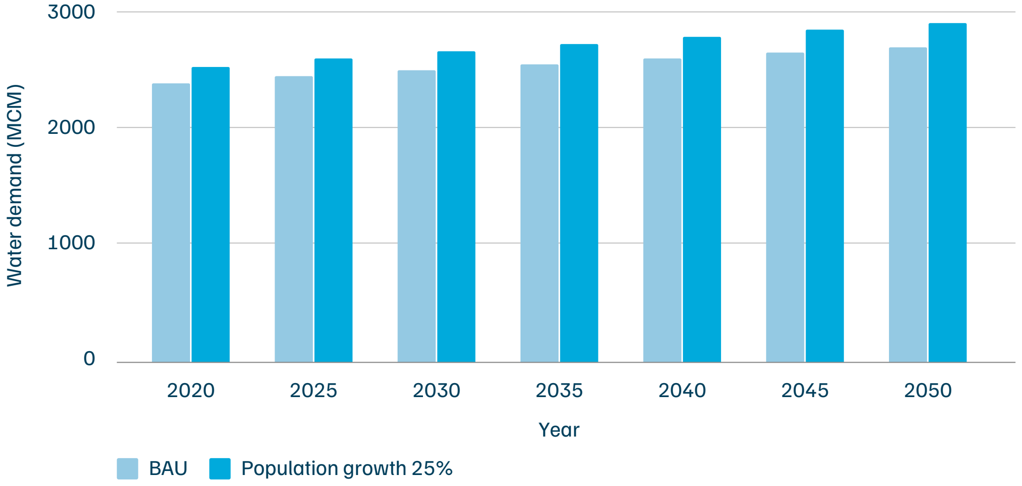
Figure 6. Under the BAU scenario, rising water demand will strain the Chennai basin, reaching 2,728 MCM by 2050



Source: Authors' analysis

Under the high population growth scenario, the population increase in the Chennai basin diverges from baseline estimates from 2012 onwards. In 2030, the high growth scenario represents a 165 MCM increase in demand above the baseline. Overall, it will be 2,694 MCM by 2030. And by 2050, **the high growth scenario water demand will rise to 2,939 MCM, which is 210 MCM greater than the BAU scenario** (Figure 7). If population growth exceeds the levels anticipated under the reference BAU) scenario, water resources in the basin will face greater stress, further jeopardising access to safe water for domestic and agricultural purposes.

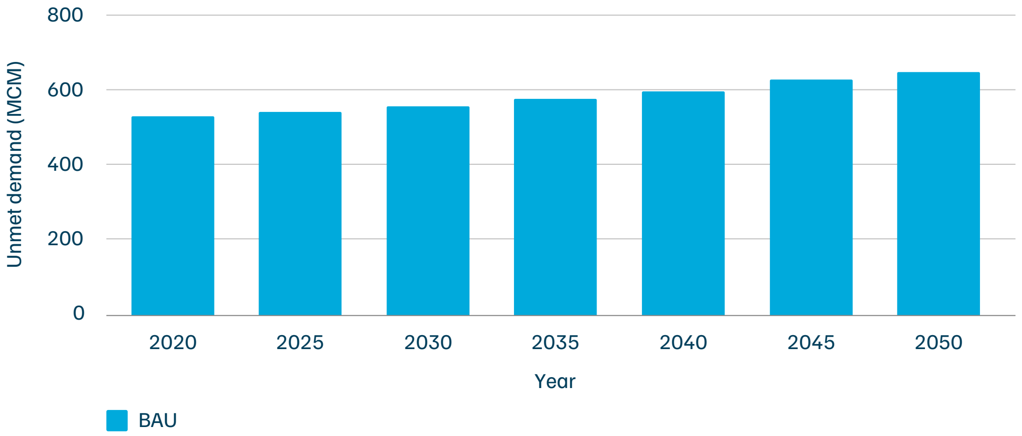
Figure 7. High population growth could push demand to 2,939 MCM by 2050



Source: Authors' analysis

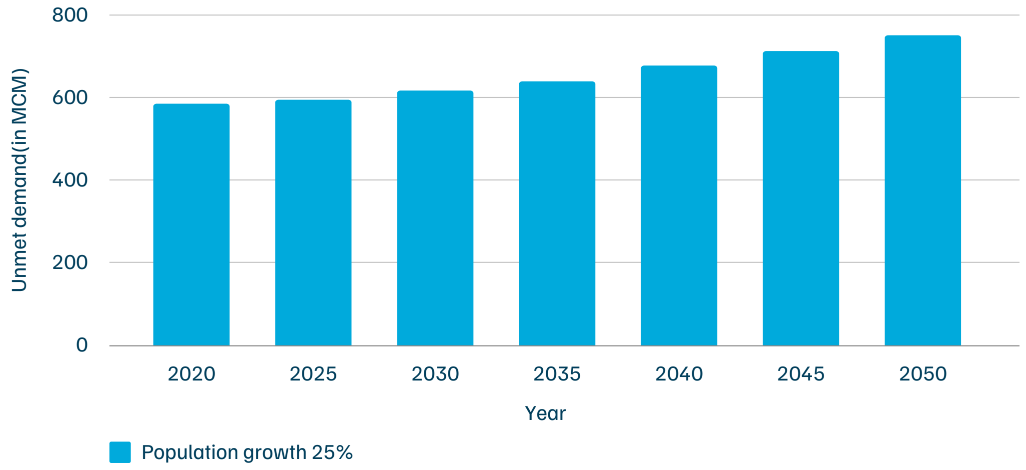
Under the BAU scenario, unmet water demand in the Chennai basin is estimated at around 546 MCM in 2025 and is projected to increase gradually to 563 MCM by 2030. By 2050, unmet water demand is projected to reach about 654 MCM (Figure 8), representing an increase of about 20 per cent between 2025 and 2050. This trend indicates that water supply is expected to continue lagging behind growing water requirements across the basin. Under the high population growth scenario, unmet water demand is projected to increase from 598 MCM in 2025 to 754 MCM by 2050, representing an increase of approximately 26 per cent over the period (Figure 9).

Figure 8. Without intervention, unmet water demand in the BAU scenario may surge to 654 MCM by 2050



Source: Authors' analysis

Figure 9. High population growth could push unmet demand to 754 MCM by 2050



Source: Authors' analysis

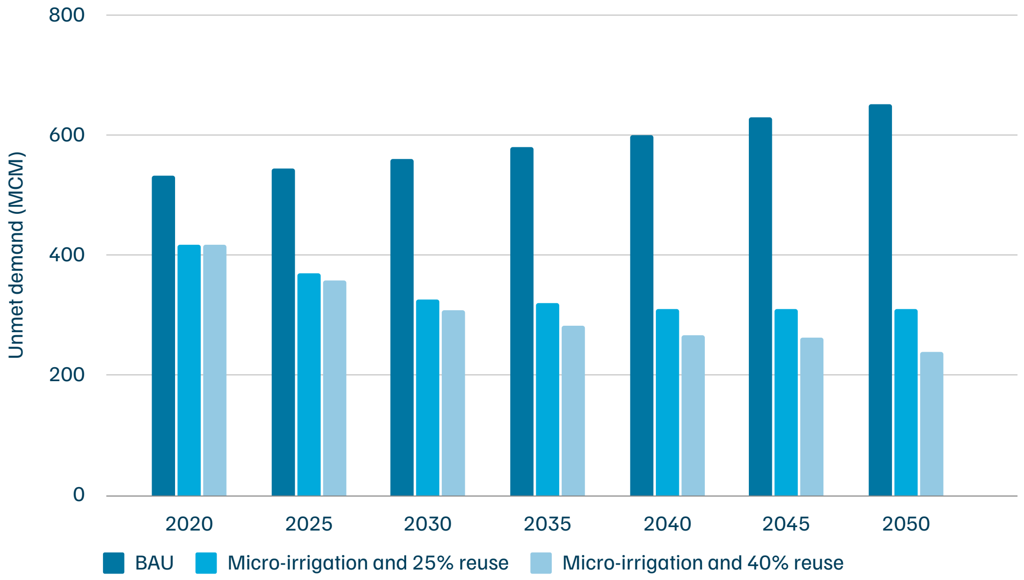
Rapid increases in water demand in the absence of effective mitigation strategies may intensify water scarcity in the Chennai basin, emphasising the urgent need to either enhance the availability of water or manage its demand more effectively. For instance,100 MCM of water is sufficient to meet the annual water needs of approximately 1.8 million urban residents in the basin. While some households can support themselves through the use of private water tankers during periods of water stress, low-income households that rely on government-operated tankers have reportedly faced waiting of up to a month (Yeung et al. 2019). Unmet water demand will also adversely impact the agricultural economy of the basin, where the water-intensive cultivation of rice, a staple crop in the state, represents approximately 80 per cent of all crops in the region.

Prioritising increased maintenance of existing used water treatment infrastructure, expanding new treatment capacity and mainstreaming the reuse of TUW across domestic, agricultural, and industrial sectors can provide a substantial opportunity to meet rising water demand. The adoption of drip irrigation systems in non-paddy areas also offers significant scope.

Water balance under micro-irrigation and reuse scenarios

It was assumed that 13 per cent of the non-paddy cropped area in the Chennai basin could be brought under micro-irrigation beginning in 2015, and that 100 per cent sewage treatment could be achieved by 2030, with reuse ranging from 25 to 40 per cent of TUW in both scenarios. Under this combined scenario, unmet water demand declines substantially compared to the BAU case. By 2050, the combined implementation of micro-irrigation and 25 per cent TUW reuse is projected to reduce the water deficit by about 52 per cent, while 40 per cent reuse results in an even greater reduction of around 63 per cent (Figure 10).

Figure 10. By 2050, Chennai can cut its unmet demand by up to 63% under the micro-irrigation and reuse scenario compared to BAU



Source: Authors' analysis

Table 4. Water balance under micro-irrigation and reuse scenarios

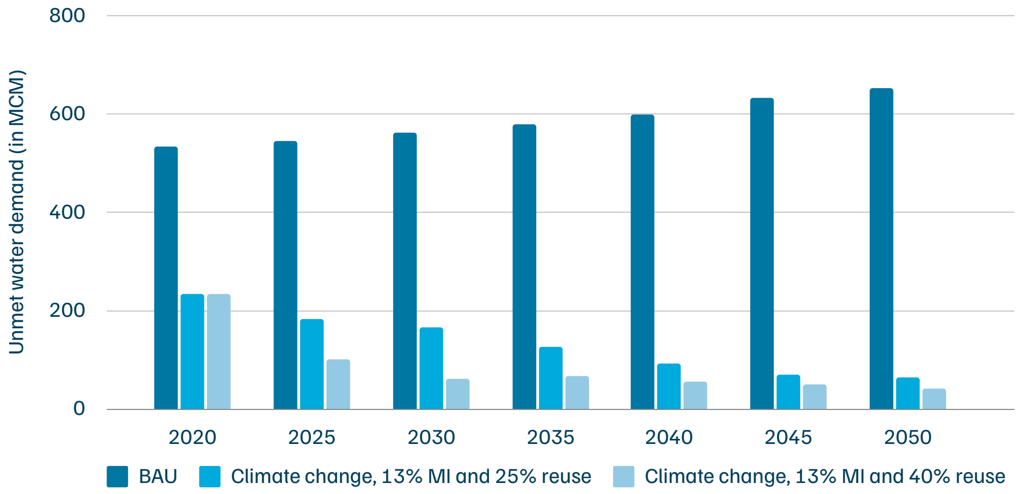
Sub-basin	**Scenario results for unmet demand**		
	BAU	**Micro-irrigation + 25% reuse**	**Micro-irrigation + 40% reuse**
Adyar	Unmet demand rises consistently from 17 MCM (2020) to 31 MCM (2050) with no interventions.	By 2050, there is a 77% reduction compared to BAU, owing to micro-irrigation and moderate reuse.	Compared to BAU, there is an 84% decrease, showing higher effectiveness of 40% reuse along with micro-irrigation by 2050.
Araniyar	Unmet demand increases from 141 MCM (2020) to 169 MCM (2050).	A notable 30% decrease by 2050 relative to BAU.	There is a 35% reduction compared to BAU, with gains visible after 2035 as higher reuse becomes impactful.
Kosasthalaiyar	Unmet demand increases from 377 MCM (2020) to 439 MCM (2050).	Micro-irrigation and reuse efficiency reduce unmet demand by almost 60%.	By 2050, with an increase in reuse, there is a 65% reduction compared to BAU.

Source: Authors' analysis

Micro-irrigation, reuse, and climate change scenarios

It was considered that 13 per cent of the non-paddy cropped area in the Chennai basin would be brought under micro-irrigation beginning in 2015, that 100 per cent sewage treatment would be achieved by 2030, and that reuse would fall in the range of 25–40 per cent of TUW. In addition, there would be an increase in water availability due to climate change. Under this combined scenario, unmet water demand declines substantially compared to the BAU scenario. **By 2050, the water deficit will be reduced by 90 per cent for 25 per cent reuse and almost 95 per cent for 40 per cent reuse.**

Figure 11. Under the climate change scenario, reuse and micro-irrigation could reduce Chennai's unmet water demand by 90–93%



Source: Authors' analysis

Table 5. Water balance under micro-irrigation and reuse scenarios with climate change projections

	Scenario results for unmet demand		
Sub-basin	**BAU**	**Micro-irrigation + 25% reuse + climate change**	**Micro-irrigation + 40% reuse + climate change**
Adyar	Unmet demand rises from 17 MCM (2020) to 31 MCM (2050).	Considering climate change, by 2050, there is a decrease of almost 90% relative to BAU.	Compared to BAU, there is a 97% decrease by 2050, including the climate change projections.
Araniyar	Unmet demand increases from 141 MCM (2020) to 169 MCM (2050).	By 2050, there is a 66% reduction compared to BAU.	By 2050, there is almost a 74% reduction compared to BAU.
Kosasthalaiyar	Unmet demand rises from 377 MCM (2020) to 439 MCM (2050).	Unmet demand drops to 0 MCM by 2040–50, achieving a 100% reduction by 2050 compared to BAU.	Similar to the 25% reuse case, unmet demand reduces to 0 MCM by 2035 onward, achieving a 100% reduction compared to BAU by 2050, accelerated due to 40% higher reuse.

Source: Authors' analysis

Environmental flow (e-flow) requirements

E-flow requirements were estimated for 1994–2050 for the Araniyar, Cooum, and Kosasthalaiyar rivers. The minimum monthly average e-flow requirement was estimated at 7.5 MCM for the Araniyar river, 8.3 MCM for the Cooum river, and 18.8 MCM the Kosasthalaiyar river. **Across the length of each river, nearly 100 per cent of e-flow requirements were met under all scenarios, with minimal deficits observed during lean seasons**. In the Araniyar and Kosasthalaiyar river sub-basins, e-flow deficits of less than 0.1 per cent occurred during February – May across all scenarios. The average e-flow deficit during the lean season was about 0.19 MCM for the Araniyar river and 0.22 MCM for the Kosasthalaiyar river. In the Cooum river sub-basin, e-flow deficits of less than 0.1 per cent were observed during April and May across all scenarios, and the average e-flow deficit during March and April across scenarios was about 0.18 MCM. Overall, the scenarios considered using the WEAP model represent environmentally feasible conditions with regard to e-flow requirements.


Image: iStock

6. Recommendations and way forward

The state government of Tamil Nadu has been proactively taking steps to address the challenges that a changing climate and rising climate extremes pose to the state's water resources and water security. This study, undertaken with the support and guidance of TNGCC, is also a step in the same direction. The state's commitment to climate resilience in the water sector is also reflected in the objectives and recommendations of India's first All India Secretaries' Conference on Water Vision @ 2047, which Tamil Nadu hosted (PIB 2024). Based on the climate risk assessment and water balance modelling undertaken under multiple scenarios for the Chennai basin at the sub-basin level, the recommendations outlined here can support the state's vision of ensuring climate resilience in water security.

6.1 Recommendations for the Chennai basin

The following recommendations aim to reduce water risk and deficits in the Chennai basin and are considered feasible for implementation over the next five years.

- **Mandate interdisciplinary climate-induced water risk assessment and water balance preparations at the hyperlocal level**: This study demonstrates that it is possible to undertake water risk and water balance assessments at the hyperlocal level, such as sub-basins, with the risk assessment using an interdisciplinary lens that integrates hydrological, climatological, social, terrain, land-use, and infrastructural dimensions. To enable this, data monitored by state institutions at administrative levels were apportioned to the sub-basin level. For future assessments, mandating data monitoring at the sub-basin level will help strengthen the system's lens of approaching climate-induced water risk and align better with natural hydrological boundaries rather than administrative ones. Maharashtra's approach to preparing river basin-wise water plans can be a good example to replicate. Such assessments should be jointly undertaken and periodically updated by the Municipal Administration and Water Supply Department and the Environment, Forest and Climate Change Department, with the former taking the lead role.

Training needs assessment should guide capacity building across relevant institutions to perform water risk and balance assessments.

- **Assess and build state institutional capacity to enable sustained water risk and water balance assessments**: Although such assessments can be jointly undertaken and updated by the Municipal Administration and Water Supply Department and the Environment, Forest and Climate Change Department, the process requires coordination and data support from multiple other departments and institutions. It is therefore essential to conduct a training needs assessment for all relevant departments and institutions and design tailor-made capacity-building programmes to systematically enhance their ability to effectively carry out such assessments. These capacities span multiple domains, including alignment with government visions and mandates; perception, knowledge, and analytical skills; innovative and participatory planning and implementation; monitoring and evaluation; interdepartmental collaboration and coordination; financing; information sharing; and both technical and non-technical human resource capabilities (Abraham et al. 2024). Such training programmes could be delivered by existing state-run training institutions, such as the Anna Institute of Management, whose primary objective is to impart knowledge and skills to prospective and practising administrators.

- **Strengthen existing datasets that enable such assessments**: Water management is inherently complex due to its wide hydrological span and competing sectoral demands. Strengthening existing datasets at the sub-basin level through initiatives, such as the Tamil Nadu Satellite-Based Water Bodies Information Monitoring and Safety System (TN-SWIP), as envisioned in the State Draft Water Policy 2024, can support more informed assessments. TN-SWIP enables real-time monitoring of water levels and quality and facilitates the detection of encroachments. The system is currently being implemented in pilot mode in four districts of Tamil Nadu (The New Indian Express 2025). Such initiatives shall be expanded to cover the whole state. Further, such datasets should be made publicly available through a dynamic dashboard, such as the Tamil Nadu Water Resource Information Management System (TN-WRIMS). Launched in October 2022, TN-WRIMS integrates all water-related data, including surface water flow, groundwater levels, and sectoral water demands, on a unified platform. Regular maintenance of such dashboards will be critical to enable future assessments. As highlighted in the limitations section (Annexure 11), existing datasets need to be strengthened and made available in the public domain to better capture both risk and risk resilience in a more informed manner.

- **Prioritise budgetary allocation and interventions for high-risk sub-basins**: Funding should prioritise high-risk sub-basins and design interventions to address the top indicators driving risk, particularly those common across multiple sub-basins, and guided by results from the WEAP scenario analysis. For instance, the Kosasthalaiyar sub-basin faces the highest water risk, but also has strong potential to mitigate it through reducing unmet water demand by nearly 65 per cent by 2050, through scaling up TUW reuse by 40 per cent and micro-irrigation by 13 per cent. Similarly, investments and interventions in the Adyar and Araniyar sub-basins should prioritise decentralised and modular used water treatment near large demand centres to enable local reuse for non-potable domestic and industrial purposes. These measures should be complemented by efforts to promote and subsidise micro-irrigation coverage in water-intensive farms, alongside the reuse of TUW for groundwater recharge. Existing institutional mechanisms, such as the Tamil Nadu Urban Development Fund, which aims to finance the implementation of urban infrastructure projects (TNUIFSL n.d.a.), and the Water and Sanitation Pooled Fund, which aims to mobilise resources from the capital market on pooled finance framework and finance urban infrastructure projects implemented by the urban local bodies (TNUIFSL n.d.b.), set the precedence for the state's spirit of innovation on the financing front.

Acronyms

AFWD	Agriculture and Farmers Welfare Department
AMRUT	*Atal Mission for Rejuvenation and Urban Transformation*
AR5	Fifth Assessment Report
BAU	business as usual
BCM	billion cubic metres
CAK	Cooum–Adyar–Kovalam
CCCDM	Centre for Climate Change and Disaster Management
CGWB	Central Ground Water Board
cm	centimetre(s)
CMA	Commissionerate of Municipal Administration
CMDA	Chennai Metropolitan Development Authority
CMIP5	Coupled Model Intercomparison Project Phase 5
CMWSSB	Chennai Metropolitan Water Supply and Sewerage Board
CORDEX	Coordinated Regional Climate Downscaling Experiment
CROPWAT	Crop Water and Irrigation Requirements Program
CSE	Centre for Science and Environment
CWC	Central Water Commission
DES	Department of Economics and Statistics
DMA	Directorate of Municipal Administration
DTP	Directorate of Town Panchayats
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization
FICCI	Federation of Indian Chambers of Commerce and Industry
GDP	gross domestic product

GoI	Government of India
HWSD	Harmonised World Soil Database
IAMWARM	Irrigated Agriculture Modernisation and Water-Bodies Restoration and Management
IBTrACS	International Best Track Archive for Climate Stewardship
IIT	Indian Institute of Technology
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
km	kilometre(s)
LPA	long period average
MCM	million cubic metres
MoA&FW	Ministry of Agriculture and Farmers Welfare
MoHUA	Ministry of Housing and Urban Affairs
MoJS	Ministry of Jal Shakti
NCEI	National Center for Environmental Information
NEM	north-east monsoon
NITI Aayog	National Institution for Transforming India Aayog
NOAA	National Oceanic and Atmospheric Administration
NRSC	National Remote Sensing Centre
RCP	Representative Concentration Pathway
RegCM4	regional climate model 4
RSMC	Regional Specialized Meteorological Centre
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SIPCOT	State Industries Promotion Corporation of Tamil Nadu

SPC	State Planning Commission
sq km	square kilometre(s)
STPs	sewage treatment plants
SWM	south-west monsoon
TDS	total dissolved solids
TNGCC	The Tamil Nadu Green Climate Company
TNDRRA	Tamil Nadu Disaster Risk Reduction Agency
TNPCB	Tamil Nadu Pollution Control Board
TN-SWIP	Tamil Nadu Satellite Based Water Bodies Information Monitoring and Safety System
TNUIFSL	Tamil Nadu Urban Infrastructure Financial Services Limited
TN-WRIMS	Tamil Nadu Water Resource Information Management System
TUW	treated used water
TWAD	Tamil Nadu Water Supply and Drainage
WEAP	Water Evaluation and Adaptation Planning
WQI	water quality index
WRD	Water Resources Department
WRIS	Water Resources Information System

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