The Energy and Resources Institute
Creating Innovative Solutions for a Sustainable Future

Mahindra LIFESPACES

Water Sustainability Assessment of Chennai Metropolitan Area

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Centre of Excellence for Sustainable Habitats

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Message

The Mahindra-TERI Centre of Excellence (MTCoE) is a joint research initiative of Mahindra Lifespace Developers Limited (MLDL) and The Energy and Resources Institute (TERI). MTCoE has been established to develop science-based solutions for India's future built environment with emphasis on enhanced occupant comfort, resource efficiency and sustainable construction. The CoE aims to create a repository of innovative materials and technologies and provide an array of strategies for achieving sustainable habitats.

Overutilization of water resources and contamination of river systems along with lack of water treatment facilities has aggravated the already existing water crisis in India. Climate change impact has led to alteration in rainfall patterns across the country, thus creating an imbalance between water demand and supply. The future of India consists of rapid urbanization and an increasing population which will excessively multiply the water demand across sectors energy, industry, domestic, irrigation etc. Hence, it is crucial to spread awareness and adopt sustainable practices to replenish and conserve water.

The Mahindra-TERI CoE is pleased to present a report on "Water Sustainability Assessment of Chennai Metropolitan Area' as a part of our 3-report series for the cities of Chennai, Gurugram and Pune. This report has been prepared to help building professionals, researchers, real estate developers, policy makers, administrative agencies and end users to generate awareness on the aspects of water sustainability and provide potential solutions to overcome the challenges.

I gratefully acknowledge the support of all those associated with the development of this report and look forward to their continued guidance for its enhancement.

Sanjay Seth
Senior Director- Sustainable Habitat Programme
TERI

Preface

Literature describes urban areas as open systems with porous boundaries and highlights the importance of the system's perspective for understanding ecological sustainability of human settlements. Similarly, a socio-ecological framework helps in understanding the nexus between social equity, environmental sustainability, and economic efficiency. India is urbanizing rapidly with characteristic inequality and conflicts across the social, economic, and locational axes. Following the global pattern, Indian cities use social and natural resources of the rural hinterland and their own resources for survival and growth and, in the process, generate large amounts of waste. Water is the most important 'resource flow' in an urban area, driven by a complex set of intersecting socio-economic, political, infrastructural, hydrological, and other factors. These drivers vary a great deal within a city and have a significant impact on the water flow management in a city, and require both micro- and macro-level study to address the challenges associated with it.

To enhance the water flow management in cities, a water sustainability assessment of Pune, Chennai, and Gurugram was conducted. The aim of the study was to assess the potential risks associated with water sources and the demand and supply of water at the city level and, subsequently, provide recommendations to combat those risks. This report presents the analysis of Chennai Metropolitan Area.

Approach

A number of studies have been conducted w.r.t. urban water management across the country. Most of these studies focus on certain aspects of water such as storm water management, wastewater treatment systems, water supply systems, etc. But in these studies planning for water is oversimplified by governments as the assessments were conducted in isolated entities. Therefore, drifting from the age-old approach, this study takes up 'One Water' approach, which basically defies the segregation of water in various categories such as storm water, wastewater, etc. Secondly, it follows a metabolism approach. It is an emerging field and, since 2013, there have been a number of international studies on this. For the first time, the metabolism approach was adopted for this kind of study. Also, the past and existing data on water management were studied, based on which potential risks were computed for 2025. This was followed by recommendations for combating these risks.

Outcome

The metabolism approach provides disaggregated understanding about the areas where water could be secured without creating negative hydrological footprint to the surrounding regions. Thus, it was envisaged that the output of this approach would inform about (a) the new sources of water, (b) amount of water that is wasted, which could help in addressing the issue of inefficiency in per capita water storage and availability, (c) seasonal problems such as flooding and inefficient storm water management and required balance for an equitable water distribution over time, (d) water-related infrastructure, and (e) water recycling potential.

Audience

As the world faces the challenges of water scarcity, there is a growing realization that citizens have to contribute in the efforts towards achieving water sustainability. With this background, it is expected that this report would not only help urban planners, policymakers, and administrative agencies but also every stakeholder in the water sector including citizens to understand the present and the future challenges and the means by which these challenges could be addressed.

Challenges

It has to be mentioned here that data gathering for this report was a challenging exercise. The data elements were fed into the study model to calculate the output metrics/indicators by extrapolations from the available historical data. In this context, the researchers succeeded in tiding over the obstacles to access data.

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Abbreviations

AMC	Annual Maintenance Contract
CETP	Common Effluent Treatment Plant
CGWB	Central Ground Water Board
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
CMWSSB	Chennai Metropolitan Water Supply and Sewerage Board
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CWC	Central Water Commission
GDDP	Gross District Domestic Product
GHG	Greenhouse Gas
ICT	Information and Communication Technology
IT	Information Technology
ITES	Information Technology Enabled Services
IUWM	Integrated Urban Water Management
KPI	Key Performance Indicator
lpcd	Litres per Capita per Day
MCM	Million Cubic Meters
MLD	Million Litres per Day
MoEFCC	Ministry of Environment, Forest and Climate Change
MoWR	Ministry of Water Resources
MWC	Mahindra World City
NA	Not Applicable
RWA	Resident Welfare Association
RWH	Rainwater Harvesting
SPCB	State Pollution Control Board
STP	Sewage Treatment Plant
ULB	Urban Local Body
WTP	Water Treatment Plant

Executive Summary

The urban population in India was estimated to be 34.5% in 2019, as per the World Bank.[1] There has been an increase in urbanization by almost 4% in the last decade due to more number of people migrating from rural areas to cities in search of better job opportunities. It is estimated that at this rate by 2030 and further in 2050, population in Indian cities will go beyond 40% and 50%, respectively.[2]

With the growing population, expanding economies, urbanization, and changing lifestyles there has been a significant impact on our economic, social, and environmental well-being due to increasing pressure on already strained water resources. The rapid population growth along with rising consumption levels and pollution contributes in spiralling water insecurities in urban India. The depleting water resources together with rising water demand limits the possibilities to augment water supply in future. Rising effects of climate change may further aggravate the situation by generating higher magnitude and frequency of extreme weather events and by altering precipitation volume and pattern. This shall have adverse effects on the available sources of freshwater supply.

Water stress has specifically magnified for metropolitan cities including Bengaluru, Chennai, Delhi, Kolkata, Pune, etc., with depleting groundwater levels, widening of water demand and supply gap, and rising pollution in waterbodies, to name a few. Thus, to combat these issues, there is a need to enhance the sustainable water flow management in cities. In this context, Mahindra-TERI Centre of Excellence (MTCoE) carried out a study to assess water sustainability in Chennai, Gurugram, and Pune. This report presents the water sustainability assessment of Chennai Metropolitan Area (CMA).

To achieve the aforementioned objective, a desk-based research was carried out by exploring different types of literature. A number of official reports and documents, Acts, etc., by the state government (Tamil Nadu), urban local bodies, municipalities, and other concerned institutions including research by private organizations were studied.

Various parameters were analysed including city growth, land use, demographics, social and economic character, water policies and institutional set-up at central, state, and city levels, and water sources and the related infrastructure. The parameters were essential to find avenues for water sustainability, quantify anthropogenic and natural flows into and out of a town, and develop a metaphorical framework of water metabolism of an area to analyse water flows within it and to select dominant indicators that impact urban hydrology.

The study of these parameters led to the identification of potential risks associated with urban hydrology and water management in CMA. To overcome these threats, a list of recommendations was prepared. The study also goes a step further to identify the reasons for weak implementation of the proposed recommendations and suggests measures to strengthen them.

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[1] Details available at https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?end=2019&locations=IN&start=1960, last accessed on September 13, 2021

[2] Details available at https://www.thestatesman.com/business/urban-population-india-may-go-beyond-50-2050-mohua-secretary-1502757868.html, last accessed on September 13, 2021

1. Introduction

This report presents a study of metabolic flow of water within the urban system of Chennai Metropolitan Area (CMA) for water planning and illustrates the nexus between various urban goals. The central objectives of the study are (a) to account for inflows and outflows of water (including wastewater) and to construct a well-defined water mass balance, (b) to illustrate how the metabolic flow of water is shaped by economic, policy, social, and other variables and how it alters the background water hydrology of the city, and (c) to demonstrate the spatial diversity and variation among the drivers of water flow in the city.

Chapter II: City Growth and Environment discusses about geographical features, city growth and land use, demographics, and social and economic character of the city. These are important drivers for urbanization and were used to analyse the urbanization rate and its impact on the water systems in CMA.

Chapter III: Water Governance and Administration includes water policies and institutional set-up at central, state, and city levels. Water use and its management is influenced by governance over water, that is, who gets what, when, and how and who has the right to water and related services, and their benefits. Water governance determines the equity and efficiency in water resources, services allocation and distribution, and balances water use between socio-economic activities and ecosystems. This chapter also presents the identified gaps pertaining to water governance in the city.

Chapter IV: Water Source Management and Infrastructure expounds various water sources available for the city and their related infrastructure including water treatment plants, sewage treatment plants, water meters, etc., and also discusses water quality of waterways carrying wastewater. The study helps in the analysis of existing water sources in CMA and deficiencies in the existing water-related infrastructure.

Note: Water quality analysis of rivers was not conducted in detail as it is out of scope of this study and would require a separate assessment. Moreover, the study focuses on the quantity aspect with a brief touch upon quality issues.

Chapter V: Potential Risks in Water Management highlights the possible threats to the urban water cycle and water demand and supply of the city. This chapter is significant as it identifies the issues interconnected with each other on the projections for 2025, starting from water availability, its allocation, to capacities of water and sewage treatment plants.

Chapter VI: Recommendations on Sustainable Water Management lays down a list of suggestions to combat the identified risks and improve the existing water management system. The chapter lists the recommendations through an upgraded urban water cycle for the city and covers all the topics/drivers discussed in the previous chapters that impact urban water management systems including the stakeholder engagement. The chapter also discusses about micro-level assessment on water efficiency of audited residential townships in the city. This has helped in analysing the impact of micro-level systems on macro-level systems.

System definitions

The system boundary is defined as the CMA under the jurisdiction of Chennai Metropolitan Development Authority, which includes both urban and rural parts of the city. To analyse water hydrology, water mass balance, and water demand of the city, the study is confined to urban areas due to inaccessibility of data of rural areas.

2. City Growth and Environment

2.1 Geographical Characteristics

The geographical characteristics considered in this study included location, physiography and landforms, climate, forest, and biodiversity.

2.1.1 Location

Chennai is the capital city of the Indian state of Tamil Nadu. It is one of the metropolises in the country and serves as the cultural gateway to South India. The latitude and longitude coordinates of the city are 13.0827° N and 80.2707° E, respectively. It is located on the south-eastern coast of India and is bounded on the east by the Bay of Bengal and on the remaining three sides by Kanchipuram and Thiruvallur districts. It stretches nearly 25.6 km along the Bay of Bengal coast.

Chennai urban agglomeration is classified into two broad categories: Chennai district and the CMA.

Chennai district: It consists of the original historic centre and is the Central Business District (CBD) of the CMA. Most of the settlements in early days sprawled from here, which have now gone beyond the district borders. According to Census 2011, Chennai district covered an area of 178 km^2. In 2018, the city limits were expanded and reached a new area of 426 km^2, which is governed by Chennai Municipal Corporation.

Chennai Metropolitan Area: CMA is under the administration of Chennai Metropolitan Development Authority which covers an area of 1189 km^2. CMA includes the Chennai district and parts of Kanchipuram and Tiruvallur districts as shown in Figure 1. The Thiruvallur district covers an area of 3427 km^2, out of which approximately 637 km^2 includes Ambattur, Madhavaram, Maduravoyal, Thiruvottriyur, Thiruvallur, Ponneri, and Poonamallee taluks that fall under the jurisdiction of CMA. Similarly, Kanchipuram district covers an area of 4433 km^2 and out of which approximately 376 km^2 of area includes Alandur, Tambaram, Sholinganallur, Sriperumbudur, and Chengalpattu talukas that come under CMA.

For the purpose of the study, the researchers considered the entire CMA.

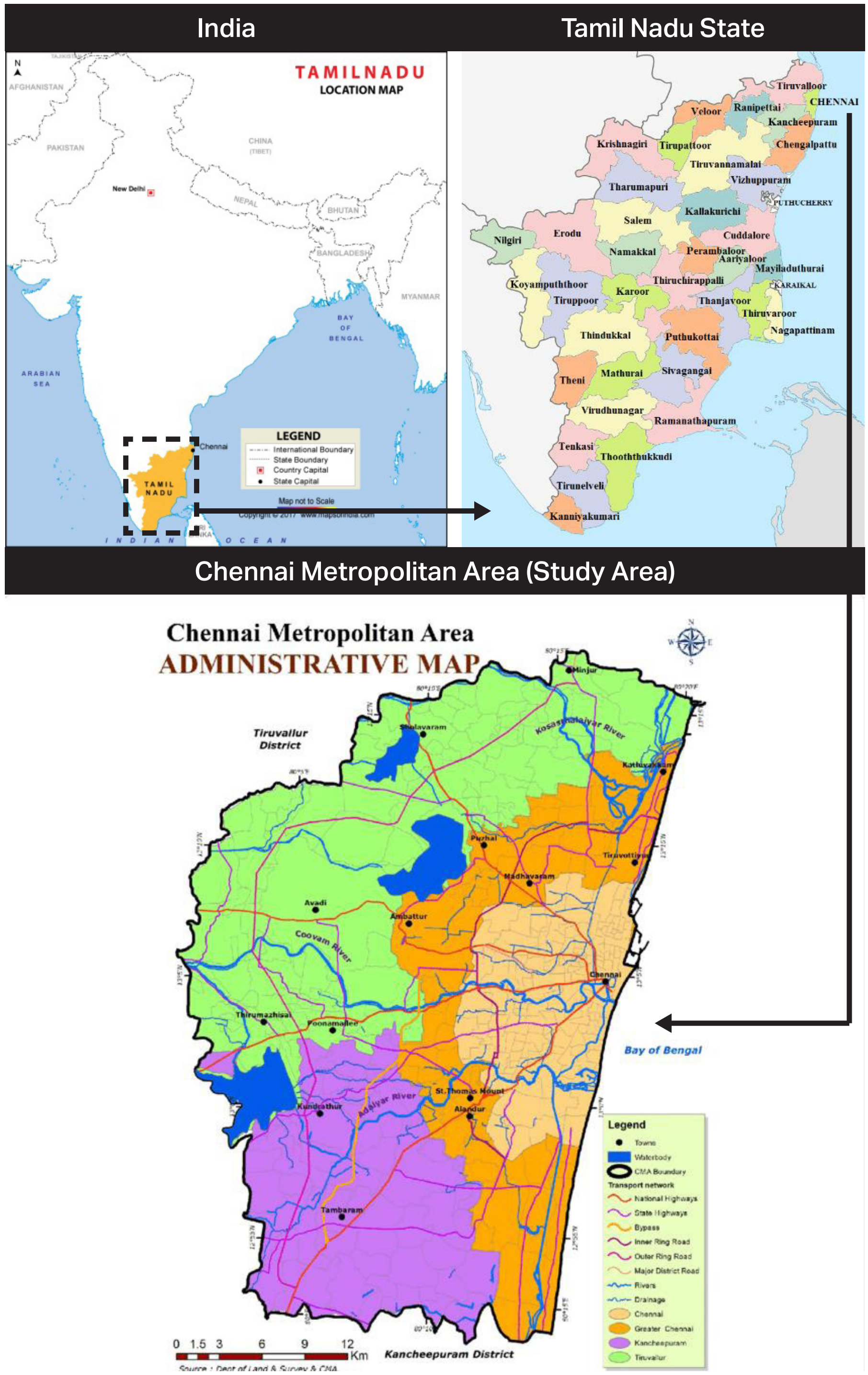


FIGURE 1: Geographical location of Chennai Metropolitan Area[3]

3 Narmada K and B Govindarajan. 2017. Multi-temporal analysis and quantification of the carbon stocks in the urban forests of Chennai Metropolitan Area using geoinformatics techniques to identify their role in climate change mitigation. Geoinformatics & Geostatistics: An Overview. doi: 05.10.4172/2327-4581.1000172

2.1.2 Physiography and Landform

The region is a flat coastal plain and has a low-lying topography with an average elevation of 6.7 m.[4] It slightly elevates as the distance from the seacoast increases but the average elevation of CMA is not higher than the mean sea level. Most of the localities are situated at the sea level, therefore, drainage in such areas remains a serious problem. The coastal area at the eastern part of CMA represents a unique mangrove ecosystem and the dense forest at the western part represents a rare composition of tropical flora and fauna.

Clay, shale, and sandstone are the three major types of soil found in the region. There are also portions of sandy soil found along the coastline and the river banks. The region is broadly classified into three sub-regions based on geology, which are sandy areas, clayey areas, and hard rock areas. Sandy areas are found along the river banks and the coasts. Clayey regions are located in most of the inland parts of the CMA. Hard rock areas are generally found in Guindy, Velachery, Adambakkam, and Saidapet. In the clayey and hard rock areas, rainwater percolates slowly and is held by soil for a longer time.

There are three main rivers – Cooum River, Adyar River, and Kosasthalaiyar River – that flow in the CMA as shown in Figure 2. The Cooum river runs through the centre of the CMA and the Adyar river flows in the southern part of the CMA region. Kosasthalaiyar river is the most important of the three in terms of both its domestic and non-domestic use, which flows in the northern part of the region. An 8-km long stretch of Buckingham Canal, which runs parallel to the coastline, links the rivers Cooum and Adyar and is the main channel carrying wastewater of the city. Both the rivers, which are found in the city, are heavily polluted due to discharge of untreated waste and effluents from domestic, commercial, and industrial areas. There are a number of lakes as well, which are located in the western part of the CMA. The lakes are the major source of water supply to the area along with groundwater.

4 Geographical and physical features. Chennai District. Archived from the original on 30 July 2013. Retrieved 28 December 2012

FIGURE 2: Water bodies serving Chennai Metropolitan Area[5]

[5] Details available at https://maps-chennai.com/chennai-water-map

2.1.3 Climate

Chennai has a tropical wet and dry climate. The coastal city lies on the equatorial region and benefits from extreme variations in the temperature throughout the year. The hottest time of the year in Chennai starts from late May to early June, with maximum temperatures ranging from 35°C to 40°C. Whereas, the coolest part of the year is January for the city, with minimum temperatures ranging from 19°C to 25°C. The highest recorded temperature in the region was 45°C on May 31, 2003, while the lowest recorded temperature was 13.9°C on December 11, 1895 and January 29, 1905. Chennai receives its majority of rainfall twice a year; first from south-west monsoon winds between June and September and second from north-east monsoon winds between October and December.[6] The average annual rainfall of the city is 1400 mm.[7] The highest annual rainfall recorded here is 2570 mm in 2005. Sometimes, cyclones in the Bay of Bengal hit the region. Chennai is dependent on the yearly monsoon rains for its water reservoirs to be recharged, as there is no major river flowing through the city.

2.1.4 Forest and Biodiversity

The total forest area in CMA is 943 hectares. Out of the total forest area, 320 hectares lies in Chennai district and 623 hectares in the metropolitan area under Thiruvallur district. There is no forest area in Kancheepuram district under the jurisdiction of CMA.

According to the State of Environment Report of CMA, there are five major ecosystems in Chennai Metropolitan Region as shown in Table 1.

TABLE 1: Ecosystems in Chennai Metropolitan Area 8

S. No.	Name of the Ecosystem	Total Area (in hectares)	Type of Flora	Type of Fauna
1	Guindy National Park	270	Dry evergreen scrub and thorn forest , grasslands, and waterbodies. 350 species of plants including shrubs, climbers, herbs, and grasses. 24 varieties of trees, including sugar apple, wood apple, and neem	130 species of birds, 14 species of mammals, over 60 species of butterflies and spiders

6 Department of Economics and Statistics, Government of Tamil Nadu. District Statistical Handbook Chennai District 2016-17

7 Details available at https://web.archive.org/web/20121121080418/http://www.imdchennai.gov.in/rdwr.htm, last accessed on September 14, 2021

8 ENVIS Centre, Department of Environment, Government of Tamil Nadu. State of Environment Report of Chennai Metropolitan Area, 2013.

TABLE 1: Ecosystems in Chennai Metropolitan Area 8

S. No.	Name of the Ecosystem	Total Area (in hectares)	Type of Flora	Type of Fauna
2	Pallikaranai Marsh Land	8000	114 species of plants, 29 species of grass	10 species of mammals, 112 species of birds, 21 species of reptiles, 9 species of amphibians, 46 species of fish, 7 species of butterflies, 5 species of Crustaceans and 9 species of Mollusk
3	Nanmangalam Reserve Forest	320	Scrubland with some rare territorial orchids	85 species of birds like Red-wattled Lapwing, Crested Honey Buzzard, Grey Partridge, Coucal, Indian Eagle-owl, White-breasted Kingfisher, Pied Kingfisher, Southern Bush Lark, and Red-whiskered Bulbul
4	Adyar Estuary (Protected Wildlife Reserve)	120	Islands and mangrove including river, marsh, woods, backwaters, islets, sea, and open ground	150 species of birds and small wildlife including jackals, foxes, wild cats, snakes, and other reptiles
5	Chennai coast between Neelankarai and Napier Bridge stretch	-	-	Olive ridley turtles

2.2 Urban Growth and Land Use

This section discusses about spatial growth pattern, land utilization, and land cover of the Chennai district.

2.2.1 Spatial Growth Pattern

A grid pattern of urban growth in the core of the Chennai district runs in north–south and east–west directions.[9] Post 20th century, roads and localities in the city have gone under significant changes. Localities have been developed with wide roads and Cartesian grid layouts. Road and rail network originating from the core of the city shows the urban growth in a radial pattern in the metropolitan area.[10]

9 Details available at https://en.wikipedia.org/wiki/Architecture_of_Chennai, last accessed on October 11, 2021

10 Prof. Dr. S.P. Sekar and S. Kanchanamala. 2011. An analysis of growth dynamics in Chennai Metropolitan Area. Institute of Town Planners, India Journal 8–4, October–December, 31–57

The urban form of CMA is distinct from other Indian cities of similar size. Unlike other cities, it has a very dense CBD that continues to add population. Meanwhile, changes in land use indicate that the region is simultaneously growing in a sprawling pattern. The population growth at the periphery of the district and in the CMA is evident along the transit corridors to the north, south, and west.11

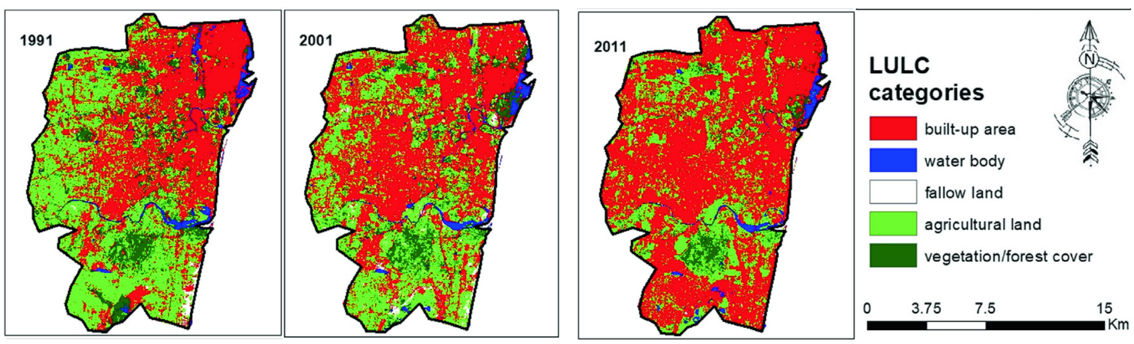


FIGURE 3: Urban sprawl pattern in Chennai district (with 178 km2 area) from 1991 to 2011[12]

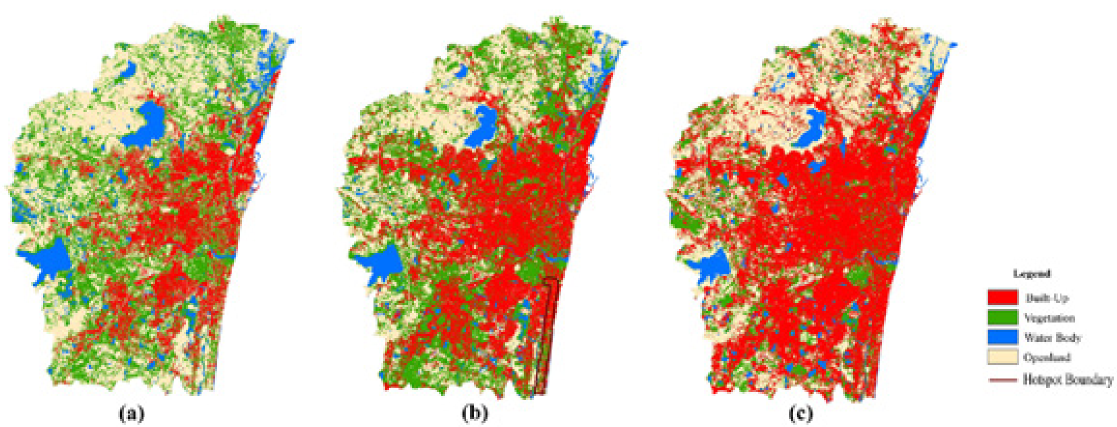


FIGURE 4: Urban sprawl pattern in Chennai Metropolitan Area from 2010 to 2017[13]

11 Details available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.521.9460&rep=rep1&type=pdf, last accessed on September 14, 2021

12 Sikarwar, A and A Chattopadhyay. 2016. Change in land use-land cover and population dynamics: A town-level Study of Ahmedabad city sub-District of Gujarat. International Journal of Geomatics and Geosciences. 7

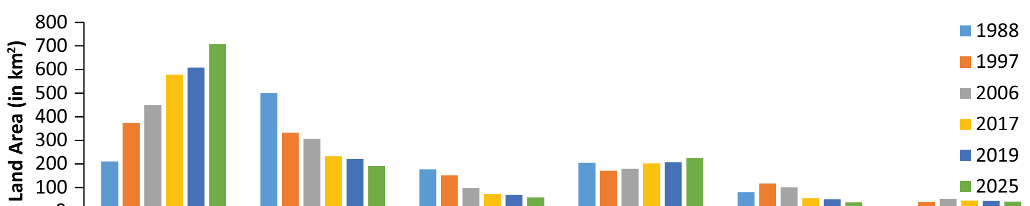
13 Devendran, A A and G Lakshmanan. 2019. Comparison of urban growth modeling using deep belief and neural network based cellular automata model—a case study of Chennai Metropolitan Area, Tamil Nadu, India. Journal of Geographic Information System. 11: 1–16

As can be seen in Figure 3, the built-up area in the Chennai district had been expanding in a sprawling pattern from 1991 to 2011. The built-up land, which was concentrated at the north-eastern corner of the city, started extending towards the southern and western parts of the city and further spilling out in CMA region. This happened due to increase in the built-up land, fulfilling the demand of infrastructural facilities for the increasing population and providing space to the industries, mainly IT industries.

From 2010 to 2017, the sprawling pattern continued, as can be seen in Figure 4, along the transit corridors in a radial pattern spreading all across the CMA. Since Chennai is located on the south-east coast of India, the city grows radially towards the west direction. Also, being a capital city, people tend to shift to Chennai for better education and job opportunities. CMA is seen to be growing rapidly in terms of spatial extent by engulfing new surrounding villages, evolving demography, and rapidly changing economic activities. There have been discussions on expanding the CMA area seven-folds from existing 1189 m^2 to 8878 m^2. But due to opposition from the farmers in giving up their agricultural lands, the decision is on hold.

2.2.2 Land Utilization and Land Cover

The classification of land use for CMA is shown in Figure 5. Significant changes were observed in land use pattern in the period 1988–2017.



	Built Up Land	Agriculture/Fallow Land	Vegetation	Barren/Semi Barren Land	Water Bodies/Wetlands	Others
1988	211.2	501.3	177.7	205.6	80.2	11.6
1997	374.3	333.2	151.7	172	117	39.3
2006	450.9	306.9	97.7	179.4	101.3	51.3
2017	578.3	232.5	72.8	202.6	55.6	45
2019	608.3	221.3	69.1	207.8	50.7	43.9
2025	708.3	191	59.2	224.5	38.4	40.7

Types of land use

FIGURE 5: Land use land cover change in Chennai Metropolitan Area (1988–2017)[14] and estimated change in 2019 and 2025

[14] Mathan, M and M Krishnaveni. 2019. Monitoring spatio-temporal dynamics of urban and peri-urban land transitions using ensemble of remote sensing spectral indices: A case study of Chennai Metropolitan Area, India. Environmental Monitoring and Assessment doi: 192. 10.1007/s10661-019-7986-y

The description of the types of land use land cover is as follows:

- » Built up land: Residential, commercial, industrial, transportation, communication, utilities, and mixed areas
- » Agriculture/fallow land: Crop land, pastures, groves, and fallow land
- » Vegetation: Dense forest, open forest, parks, plantation, orchard, urban vegetation, and mangroves
- » Barren/semi-barren land: Sandy areas, beaches, dry salt areas, open areas, mixed barren lands, transitional areas, and empty riverbeds
- » Water bodies/wetlands: Lakes, pond, rivers/streams, wetlands, estuaries, and waterlog areas
- » Others: Waste land, dump yard, quarry pits, and dirt roads

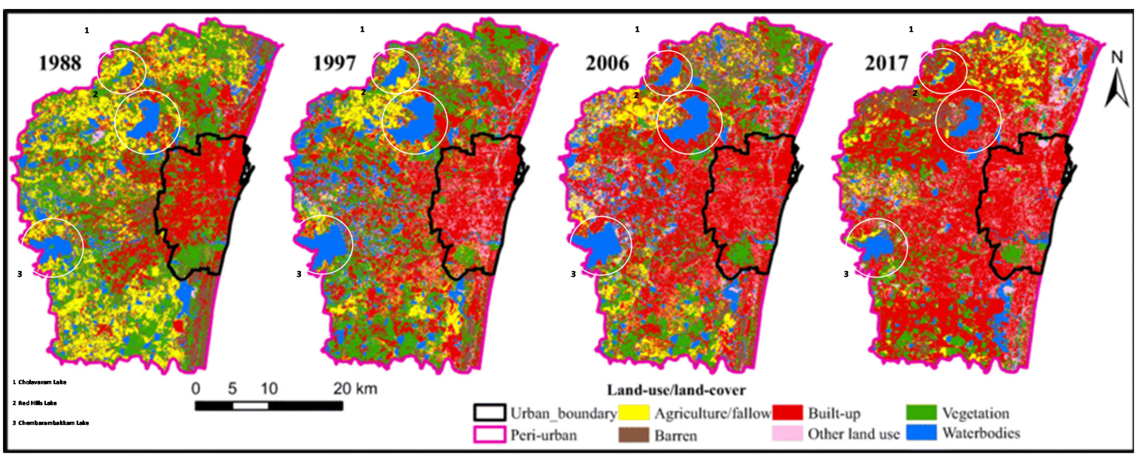


FIGURE 6: Graphical representation of land use land cover change in Chennai Metropolitan Area with highlighted change in waterbodies (1988–2017)[15]

CMA has witnessed significant changes in land use pattern in the period 1988–2017 due to rapid urban sprawl and population influx. As seen in Figures 5 and 6, the following land use land cover changes have been experienced in CMA:

1. The built-up area in CMA has grown almost three times from 211.2 m^2 in 1988 to 578.3 m^2 in 2017. The built-up area has spread out in the west direction radially with Chennai district being the nucleus. Between 1988 and 1997, the region saw a high rate of urban sprawl due to unprecedented increase of domestic and foreign investments in the automobile, electronics, and other financial and industrial sectors. From 1997 to 2006, the built-up area continued to expand with scattered settlements being converted into dense settlements and development of many educational institutions and industries. Post 2006 and till 2017,

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[15] Mathan, M and M Krishnaveni. 2019. Monitoring spatio-temporal dynamics of urban and peri-urban land transitions using ensemble of remote sensing spectral indices—a case study of Chennai Metropolitan Area, India. Environmental Monitoring and Assessment doi: 192. 10.1007/s10661-019-7986-y

the unprecedented rise in the built-up area can be attributed to the development of software companies, highly enabled services, medical tourism, etc., which attracted people to settle down in CMA. It is estimated that if this urban growth trend continues, the built-up area would increase to 708.3 km^2 by 2025.

2. The agriculture land and vegetation have experienced a steady decline in this area. Both the typologies have reduced to half of the areas in 2017 as compared to 1988. This has been due to the conversion of peri-urban areas with fallow/agriculture land and vegetation into built-up land. It is estimated that this trend would continue till 2025, considering the existing declining rate.

3. A significant point to be noted is that barren land areas increased from 1997 to 2017 in this region, though at a slow pace. This reflects the increasing use of pesticides, fertilizers, herbicides, and insecticides, which pollute soil and make it unproductive.

4. In 1997, waterbodies/wetland area in the region was quite high (117 km^2) as compared to 2017, when they shrunk to 55 km^2. As can be seen in Figure 6, due to rapid increase in built-up land, waterbodies decreased in the region. Lakes including Cholavaram, Red Hills, and Chembarambakkam and other small ponds shrunk due to encroachment by buildings and industries. River Adyar also seems to have reduced in its area due to rising encroachments and dumping of municipal and industrial waste in it, thus changing the course of waterbody. Necessary interventions are required from the authorities to conserve the waterbodies that are estimated to continuously shrink in future. This is because these waterbodies are important sources of water supply in the region. And, in recent years, CMA has witnessed recurrent droughts, thus, if the waterbodies are not protected then there could be a serious water scarcity threat in near future for the region.

5. The remaining land types including wasteland and dump yards increased from 1988 to 2006. This can be attributed to the effects of rapid expansion of built-up areas. More built-up land results in deforestation and establishment of more dump yards, thus increasing wastelands. Post 2006, there is a downward trend in wasteland and dump yards creation, which could be due to interventions such as plantation drives from the concerned authorities – but they exist at a low rate.

6. The shrinking lakes, rivers, wetlands, and vegetation cover, as already discussed, are attributed to the drastically increasing urban sprawl due to the reasons explained in point 1. This expansion of built-up areas has in turn increased the risk of climate change. This is because it accelerates deforestation and replaces land that could have been used for agriculture or other purposes. Consequently, it limits the ability of the natural landscape to capture carbon dioxide. Urban sprawl also requires more transportation, resulting in increased emissions. These factors contribute in altering the regional climate, which results in increasing risk of climate-induced natural disasters including floods, droughts, and cyclones. One of the major reasons of increase in monsoon floods in CMA and cyclones in the adjacent Bay of Bengal is climate change, which is caused by urban sprawling that damages natural habitats and environmentally sensitive areas.

2.3 Demographic Description

This section discusses about the population growth trend in context of the study area.

2.3.1 Population Growth Trend

Chennai is one of the largest cities in south India. According to 2011 Census, Chennai ranked sixth on the scale of most populated cities and fourth among the most populated urban agglomerations in India.

The recorded population of Chennai Metropolitan region in 1971 was 35,05,502 lakh which increased to 86,53,521 lakh in 2011.[16] CMA has witnessed a rapid increase in population since its formation in 1974 due to sporadic growth of the hardware manufacturing, automobile, healthcare, and IT sectors on the outskirts of the Chennai district, which has, in turn, resulted in population influx in CMA. The population growth of CMA region is shown in Figure 7. The population is estimated to increase in future and reach 1,18,82,610 in 2025, considering the existing rate of decadal change in population (from 2001 to 2011).

According to District Census Handbook 2011 of Chennai, CMA has a combination of urban and rural areas. Out of the total CMA, Chennai district is completely urban. Rural population in CMA is found to be in parts of Kanchipuram and Thiruvallur districts only.[17]

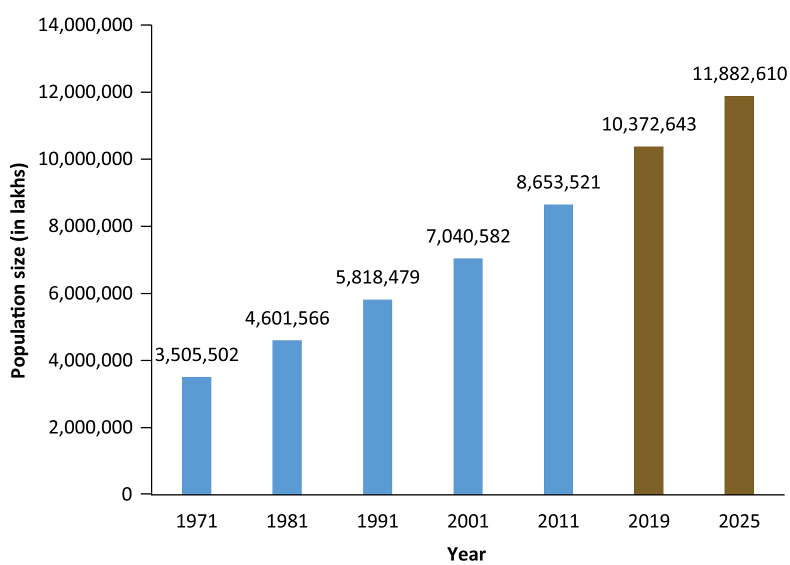

FIGURE 7: Population increase in Chennai Metropolitan Area from 1971 to 2011 and estimated population change in 2019 and 2025

16 District Statistical Handbook Chennai District 2016-17, Department of Economics and Statistics, Government of Tamil Nadu

17 District Census Handbook Chennai, Tamil Nadu, Census of India 2011

18 Census of India 2011. Details available at http://www.censusindia.gov.in/2011census/PCA/A-2_Data_Tables/33%20A-2%20Tamil%20Nadu.pdf, District Census Handbook Chennai, last accessed on September 21, 2021 Details available at http://censusindia.gov.in/2011census/dchb/3302_PART_B_DCHB_CHENNAI.pdf, last accessed on September 21, 2021 An analysis of growth dynamics in Chennai Metropolitan Area, Institute of Town Planners, India Journal 8-4. Details available at http://www.itpi.org.in/files/oct3_11.pdf, last accessed on September 21, 2021

As far as the decadal variation in population of CMA is concerned, though the population continued to increase, the rate of decadal growth decreased post 1981. CMA was found to have a decadal growth rate of 31.27% in 1981 which dipped to 21% in 2001, although, there was a slight increase of 22.9% in the decadal variation from 2001 to 2011.

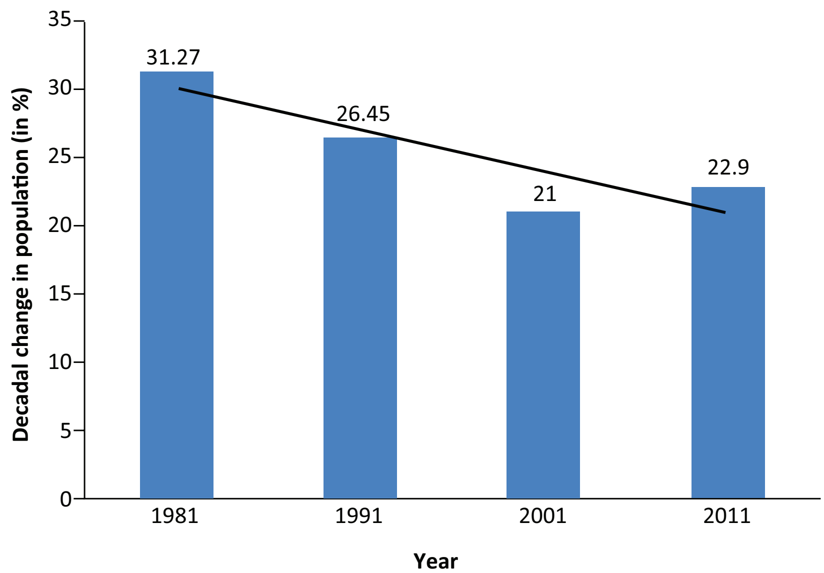

FIGURE 8: Percentage decadal variation in population of Chennai Metropolitan Area (1981–2011)[19, 20, 21]

The population density of CMA continued to increase from 2948 persons/km^2 in 1991 to 5921 persons/km^2 in 2011 due to industrial and economic development which generated more employment opportunities resulting in influx of migrant population. The population density of CMA is presented in Figure 9. Considering the rate of change from 2001 to 2011, the population density is expected to further increase to 7918 persons/km^2 by 2025.

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19 Details available at http://www.censusindia.gov.in/2011census/PCA/A-2_Data_Tables/33%20A-2%20Tamil%20Nadu.pdf, last accessed on September 9, 2020

20 Details available at http://censusindia.gov.in/2011census/dchb/3302_PART_B_DCHB_CHENNAI.pdf, last accessed on September 9, 2020

21 An analysis of growth dynamics in Chennai Metropolitan Area, Institute of Town Planners. India Journal 8-4. Details available at http://www.itpi.org.in/files/oct3_11.pdf, last accessed on September 9, 2020

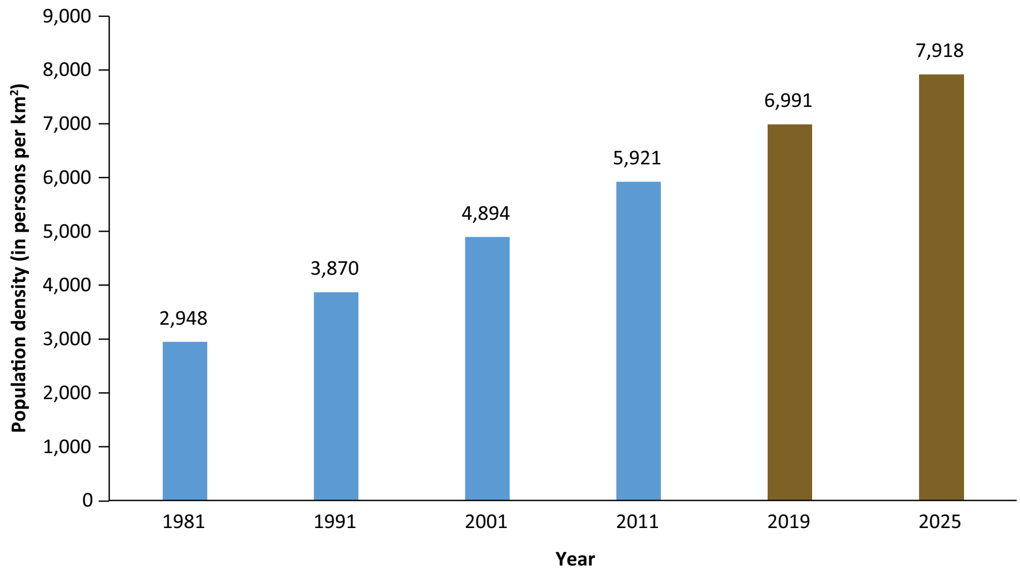

FIGURE 9: Population density change in Chennai Metropolitan Area (1981–2011) [22, 23, 24] and estimated change in 2019 and 2015

2.4 Socio-economic Description

The socio-economic description section covers economy, agriculture, industry, and housing segments.

2.4.1 Economy

Since India's independence, Chennai has been a manufacturing-driven economy. This trend has slowly transformed with the growth of the tertiary sector, which includes IT industry, in the region. The tertiary sector in CMA including transport, railways, communication, real estate, banking, and finance services contributed significantly to the gross district domestic product (GDDP) in the last two decades.

The GDDP of CMA is not available as it is a combination of a number of districts.

As far as the employment in CMA is concerned, the workers in primary activity constituted 6.52% in 1991 which dipped to 2.91% in 2001 and further to 1.3% in 2011.[25] This indicates that the primary activities in the region are on a decline in the peripheral areas due to the emergence of manufacturing and new industries. The number of workers in primary activities, such as livestock

[22] Details available at http://www.censusindia.gov.in/2011census/PCA/A-2_Data_Tables/33%20A-2%20Tamil%20Nadu.pdf, last accessed on September 9, 2020

[23] Details available at http://censusindia.gov.in/2011census/dchb/3302_PART_B_DCHB_CHENNAI.pdf, last accessed on September 9, 2021

[24] An analysis of growth dynamics in Chennai Metropolitan Area, Institute of Town Planners, India Journal 8-4. Details available at http://www.itpi.org.in/files/oct3_11.pdf, last accessed on September 9, 2021

[25] Details available at http://www.spc.tn.gov.in/DHDR/Chennai.pdf, last accessed on September 9, 2021

and poultry, is dwindling, and even negligible when compared to the total employment in CMA with more than 90% of the people are now engaged in the tertiary sector.[26, 27]

Table 2 reveals that a shift in the economic structure of the CMA took place from agriculture (primary) to manufacturing (secondary) to IT and other services (tertiary); the transformation to the tertiary sector is on fast track.

TABLE 2: Employment structure in Chennai Metropolitan Area[28]

S. No.	Occupational Structure	1971 (in %)	1981 (in %)	1991 (in %)	2001 (in %)
1	Primary	4.01	3	6.5	2.9
2	Secondary	34.21	32	26.7	97.1
3	Tertiary	61.78	65	66.8	

2.4.2 Agriculture

The total geographical area of CMA is 1189 km^2, which covers Chennai district and parts of Kanchipuram and Tiruvallur districts. As of 2013, the total net sown area in the region was 233.16 km^2, which forms 26% of the geographical area.[29] The Chennai district and part of Kanchipuram region under CMA does not have any cultivable crop area, whereas, there is only cultivable area in the Tiruvallur district, which comes under CMA. Major crops that are grown in CMA are pulses, paddy, and oilseeds.

Groundwater has remained the dominant source for irrigation in CMA. However, the agriculture activity in the region has been facing constraints due to decreasing water levels and siltation of irrigation tanks.

The other source of water for irrigation in CMA is the Kosthalaiyar River which starts from Andhra Pradesh and flows across Chennai. For this purpose, an anicut in Vallur across Kosthalaiyar River was constructed from where water is supplied for irrigation. A number of lakes in CMA are also used for irrigation purposes.

As no recent data on agriculture output and its water consumption are available for CMA, agricultural water demand was not considered in the final calculations for CMA's water demand and supply.

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26 Details available at http://dcmsme.gov.in/dips/IPS%20Chennai_Revised.pdf

27 Details available at http://www.cmdachennai.gov.in/Volume1_English_PDF/Vol1_Chapter03_Economy.pdf, last accessed on September 9, 2021

28 Details available at http://www.cmdachennai.gov.in/Volume1_English_PDF/Vol1_Chapter03_Economy.pdf, last accessed on September 9, 2021

29 State of Environment Report of Chennai Metropolitan Area, 2013, Envis Centre, Department of Environment, Government of Tamil Nadu

2.4.3 Industry

Tamil Nadu is one of the most industrialized states in India. Its capital city Chennai has been among the fastest growing industrial regions in the country. The manufacturing sector has been the front runner in CMA's industrial growth, contributing largely to employment and GDDP enhancement. In recent past, Chennai has witnessed massive infrastructure development, resulting in boom in the industrial sector especially medium and large-scale industries in the peripheral areas and extended Chennai Metropolitan region.

Major industries in CMA are automobile and transport equipment manufacturers and their ancillary industries, railway coach building, petro chemicals and fertilizers, automotive tyres, bicycles, electrical and other machinery, and leather products. Tamil Nadu accounts for 70% of leather tanning companies in India and 38% of leather footwear and components companies; most of the footwear industries are located within CMA.

In the small-scale industrial sector, there were 56,913 units in Chennai District and 37,531 in Kancheepuram and 17,843 in Thiruvallur District as on March 2007, which accounts for about 21.16% of the units in the state (530,552 units).[30] The small-scale industrial sector in Chennai, Kancheepuram, and Thiruvallur districts is dominated by metals, rubber and plastic products, electrical machinery, transport equipment, leather and fur products, and non-metallic mineral products.[31]

Chennai is perhaps the only city in India to have all the top 10 IT Indian multinational companies, and in fact, three IT majors have acquired lands in and around Chennai to meet their expansion plans.[32]

Currently, industries in CMA receive water from both surface and groundwater sources. To reduce the industries' dependence on municipal freshwater supply, sewage treatment plants have been planned in CMA, which shall work on reverse osmosis treatment method. By this method, sewage that is usually let into the city's river after secondary treatment will be diverted to these new plants for a third level of treatment, making water fit enough for industrial use. Around 40 million litres per day (MLD) of freshwater is being supplied to water-intensive industries in Manali, Minjur, and Ennore in North Chennai and Oragadam and Sriperumbudur in the city's suburbs from Chembarambakkam reservoir (lake) and Minjur desalination plant. Once the plants are commissioned, the freshwater that is now given to these industries will be diverted to residential areas.[33]

As the CMA is a combination of a number of districts, aggregated data on water distribution to industries is not available. Therefore, industrial water demand was not considered in the final calculations of CMA's water demand and supply.

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30 Details available at http://www.cmdachennai.gov.in/Volume3_English_PDF/Vol3_Chapter04_Economy.pdf, last accessed on October 11, 2021

31 Details available at http://www.cmdachennai.gov.in/Volume3_English_PDF/Vol3_Chapter04_Economy.pdf, last accessed on October 11, 2021

32 Details available at http://www.cmdachennai.gov.in/Volume3_English_PDF/Vol3_Chapter04_Economy.pdf, last accessed on October 11, 2021

33 Details available at http://www.newindianexpress.com/states/tamil-nadu/2019/jul/30/chennai-set-to-become-first-indian-city-to-supply-recycled-sewage-to-industries-2011647.html, last accessed on October 11, 2021

2.4.4 Housing

Chennai Metropolitan Development Authority is the agency responsible for land development and defining and implementing urban policies and promoting housing in CMA. As CMA is an agglomeration of a number of districts, aggregated data on housing is not available. Therefore, only Chennai district's data were considered and analysed in this study. As per 2011 Census, there were 11,54,982 households in the Chennai district as compared to 798,279 households in 1991. There was an increase of 44.7% from 1991 to 2011 in the number of households, also shown in Table 3.

TABLE 3: Number of households in Chennai district (1991–2011)[34]

Year	Total No. of Households	Percentage Change (%)
1991	798,279	NA
2001	962,213	20.5
2011	1,154,982	20.03

As of March 2018, the area covered with piped supply was 99% in Chennai.[35] This clearly reflects that the expansion of piped water supply has been in sync with the increasing population in the region.

As far as slums statistics are concerned, Chennai has witnessed drastic increase in the number of slums post 1956. In 2001, the slum population was found to be 819,872 which increased to 1,324,319 in 2011, also shown in Table 4. Slums in Chennai receive water mostly from tankers due to lack of piped water supply. Information on piped water coverage in slums post 2011 is not available.

TABLE 4: Slum statistics in Chennai district (1956–2011)[36]

Year	Slum Population (in lakhs)	Number of Slums
1956	2.87	306
1961	4.12	548
1971	7.37	1202
1986	6.5	996
2001	8.2	1431
2011	13.2	Not available

34 Sikarwar, A and A Chattopadhyay. 2016. Change in land use-land cover and population dynamics: A town-level Study of Ahmedabad city sub-District of Gujarat. International Journal of Geomatics and Geosciences. 7

35 Details available at https://chennaimetrowater.tn.gov.in/watersupplysystem.html, last accessed on September 17, 2021

36 Resettlement and rehabilitation of objectionable slums on waterways – Role of TNSCB report. Thiru T.K. Ramachandran, TNSCB

2.5 Inferences

» CMA is going to experience a continuous built-up expansion by engulfing new surrounding villages due to rapid economic development. This shall lead to an unprecedented growth of the area in terms of population, which in turn will increase the demand for housing and other civic amenities such as water supply. A major chunk of the migrated population shall be constituted of lower strata group, who would be forced to live in slums due to demand–supply gap of housing in the metropolitan region. Providing water connections to growing population in slums could pose a challenge for the authorities, as it furthers the burden on water resources that are already under pressure and an overall urban infrastructure.

» Rapid built-up expansion in coming years would put an enormous pressure on land and water resources, which might change the resource availability and ecology of the area. Waterbodies such as ponds, lakes, and rivers would continue to shrink due to encroachments, unauthorized constructions, and poor disposal of municipal and industrial waste into them. Flood intensity during monsoons is expected to increase in CMA due to reduction in catchment area with shrinking waterbodies and green cover and expansion in built-up land.

» Rapid industrialization and coming up of software companies in CMA, especially in the last decade, has resulted in massive urban sprawl with booming population in the region. With Chennai district realizing its utmost urbanization potential, CMA is going to experience rapid urban growth in coming years with increase in water demand for residential, commercial, and industrial projects.

» The sectors responsible for most of the water consumption in CMA would be residential housing, commercial, and industrial establishments. In this regard, agriculture is on a decline due to conversion of cultivable land into built-up area. As the region is a rapidly developing industrial centre, water demand here shall increase manifolds in recent future. Reclaimed water can be a strong alternative for meeting the rising industrial water demand.

3. Water Governance and Administration

3.1 Water Laws and Policy in India

In India, legal provisions related to water are available in the constitution, court decisions, central and state laws, and various irrigation acts. However, India does not have any exclusive or comprehensive water law. Water was included in the State List of the 7th Schedule of the Constitution of India. Hence, all activities related to planning, development, and management of water resources are undertaken by the respective states through their water resources or irrigation departments. In many cases, state governments have established autonomous bodies and corporations for the development and management of water resources.

India does not have any specific law that defines the ownership of and rights over water sources. The laws are derived from court rulings and customs. Several court judgments in post-independent India have affirmed that all natural resources – resources that are by nature meant for public use and enjoyment – are held by the state in public trust. For example, the legal position on whether groundwater is a resource meant for public use is fuzzy, and India has no law that explicitly defines groundwater ownership. It is customarily accepted across India that a well on a piece of land belongs to the owner of that land, and others have no right to extract water from the well or to restrict the landowner's right to use the water. This belief and practice is indirectly supported by various laws such as land acts and irrigation acts that list all the things to which the government has a right, but groundwater is not mentioned in any such list.

As yet, no law or policy has been formulated that asserts that water is a fundamental and inviolable right enjoyed by every citizen of the country. The 'right to water' can, therefore, be obtained in India on a case-by-case basis, by appealing to the court. At the same time, it has been implicitly accepted that the central and the state governments have a primary responsibility to provide drinking water and, subsequently, water for other purposes. Accordingly, a host of programmes and policies have been framed and implemented at the central and the state levels including the National Water Policy (National Water Policy 2002 and National Water Policy 2012).

3.1.1 Institutional Setup at Central Level

At the central level, the Ministry of Water Resources, set up in 1985, is the nodal ministry responsible for developing, conserving, and managing water as a national resource.

In May 2019, the Ministry of Water Resources, River Development and Ganga Rejuvenation and the Ministry of Drinking Water and Sanitation were merged to form the Ministry of Jal Shakti to streamline their functions, that is, to maintain the quality of drinking water and natural waterbodies, ensure efficient use of water resources to meet the growing demand, and sensitize citizens for water conservation, thus contributing towards the enhancement of sustainable development. The ministry's remit covers areas as diverse as irrigation, multipurpose groundwater exploitation, command area development, drainage, and flood control. It also tackles issues related to waterlogging, soil erosion, dam safety, and creation of structures for navigation and hydropower, and oversees the development and regulation of interstate rivers.

The following three principal technical organizations are part of the ministry: Central Water Commission is responsible for developing and quality measurement of surface water in the basins of major and medium-sized rivers; Central Ground Water Board (CGWB) monitors, develops, and regulates groundwater resources; and the National Water Development Agency was set up to assess the possibilities of inter-basin water transfers.

The Central Pollution Control Board, in collaboration with the State Pollution Control Boards in several states, has been separately monitoring aquatic resources at selected locations since 1977.

Water quality and environmental matters come largely under the Ministry of Environment, Forest and Climate Change (MoEFCC), which coordinates India's Environmental Action Plan. The Ministry of Housing and Urban Affairs coordinates projects in urban water supply and sanitation. The Rajiv Gandhi National Drinking Water Mission, which is part of the Ministry of Rural Areas and Employment, handles rural water supply and sanitation. The Ministry of Power and the Central Electricity Authority manage water for power generation. Water is also a subject of several other ministries and departments, such as the Ministry of Agriculture (irrigation), the Ministry of Health and Family Welfare, the Ministry of Surface Transport, the Inland Waterways Authority of India, and, for planning and financing, Niti Aayog, the Ministry of Finance, and the Finance Commission.

3.1.2 Institutional Set-up at State Level

Water Resources Organization of Tamil Nadu Public Works Department (TNPWD)[37] is a state government-owned authority responsible for executing and maintaining all the government buildings and all irrigation projects such as dams, canals, tanks, and multifarious works including construction of buildings, roads, bridges, culverts, water harvesting structures, implementation, and maintenance of water supply in rural areas.

Tamil Nadu Pollution Control Board (TNPCB) was constituted by the Tamil Nadu government in 1982. It enforces the provisions of the Water (Prevention and Control of Pollution) Act, 1974, the Air (Prevention and Control of Pollution) Act, 1981, the Environment (Protection) Act, 1986, and the rules made under these Acts in the state.[38]

Tamil Nadu Water Supply and Drainage Board, formed by the government of Tamil Nadu under the Ministry of Local Administration and Water Supply, is entrusted with the development of all water supply and sewerage schemes in Tamil Nadu excluding the Chennai Metropolitan Area (CMA).[39]

3.1.3 Administrative Set-up of CMA

The 74th Amendment to the Constitution mandates state governments to transfer the responsibility for water supply services to urban local bodies (ULBs). The local bodies in Chennai are governed by important pieces of legislation, namely The Madras Metropolitan Water Supply and Sewerage Act, 1978 and The Chennai Metropolitan Area Groundwater (Regulation) Act, 1987.

Chennai district is administered by the Greater Chennai Corporation, which is the second oldest municipal body in the world after the UK. The district is divided into 15 zones, which are further divided into 200 wards.[40]

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37 Details available at http://www.wrd.tn.gov.in/AboutUs.htm, last accessed on September 20, 2021

38 Details available at https://tnpcb.gov.in/about-us.php, last accessed on September 20, 2021

39 Details available at https://www.twadboard.tn.gov.in/about-us, last accessed on September 20, 2021

40 District Statistical Handbook Chennai District 2016-17, Department of Economics and Statistics, Government of Tamil Nadu

On the other hand, the CMA is under the administration of Chennai Metropolitan Development Authority (CMDA). This includes the Chennai district and parts of Kanchipuram and Tiruvallur districts. The Chennai Metropolitan Development Authority consists of Chennai district along with 8 municipalities, 11 town panchayats, and 179 village panchayats.[41]

Various agencies working in the water sector and their functions in Chennai Metropolitan region are as follows:

» Water supply and sewerage services in CMA are under Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB).[42] Internal water distribution is done by the respective ULBs.

» The construction, maintenance, and desilting of storm water drains is undertaken by Chennai Municipal Corporation for the Chennai district. The storm water drain management for the remaining parts of CMA is undertaken by respective municipalities of Kanchipuram and Tiruvallur districts.[43]

» Water Resources Organization of Tamil Nadu Public Works Department looks after the surface water management (such as dams, local ponds, lakes, etc.), irrigation, and flood control works in CMA.[44]

» The water quality monitoring of the abovementioned waterbodies is done by TNPCB.

» CMWSSB has made it mandatory for all new buildings, irrespective of their size, to have a proposal for construction of rainwater harvesting (RWH) structures for issue of new water and sewer connections. Furthermore, the planning permission for multi-storied buildings/ special buildings shall be accorded by CMDA only if RWH is proposed. In addition, the owner has to submit a declaration that the RWH structures would be properly maintained and should not be dispensed with in future.[45]

» Groundwater is an important source of water supply in CMA. The onus of groundwater control, regulation, abstractions, and transportation in CMA is on CMWSSB.

» The water supply to industries and the management of effluent water are also done by CMWSSB.

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41 Details available at http://www.cmdachennai.gov.in/, last accessed on September 20, 2021

42 Details available at https://chennaimetrowater.tn.gov.in/metrowateroperationalarea.html, last accessed on September 20, 2021

43 Details available at https://chennaicorporation.gov.in/departments/storm-water-drain/index.htm

44 Details available at http://www.wrd.tn.gov.in/AboutUs.htm, last accessed on September 20, 2021

45 Details available at https://chennaimetrowater.tn.gov.in/tipsandrules.html, last accessed on September 20, 2021

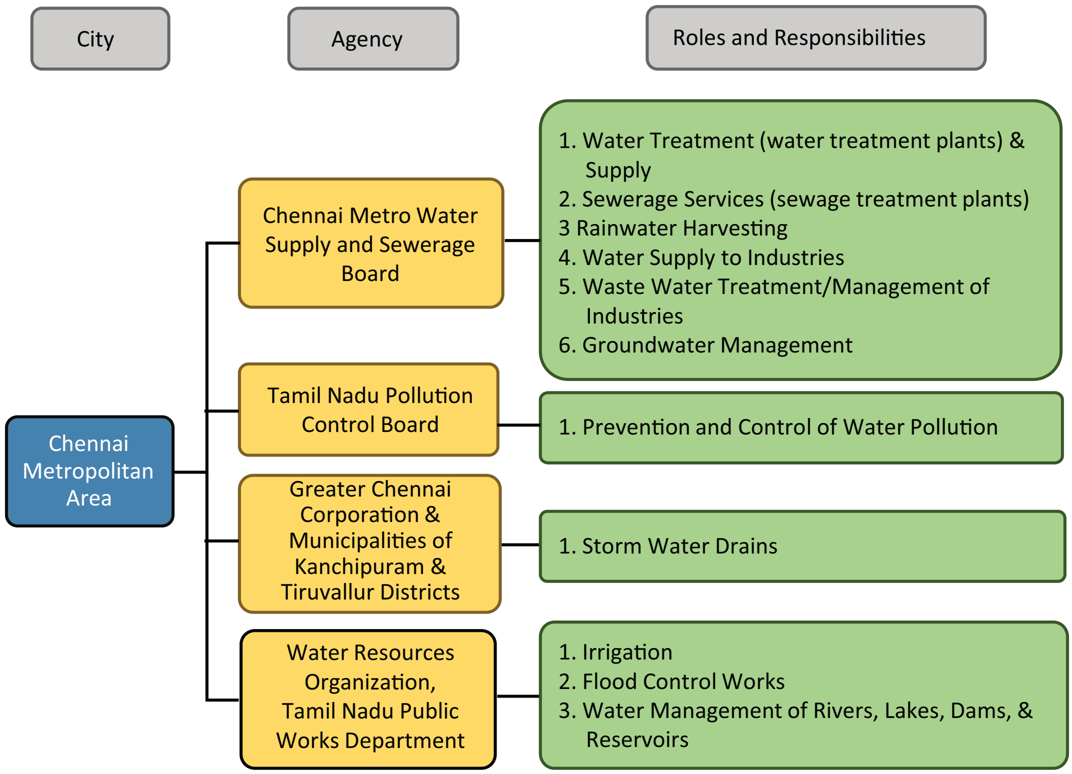

FIGURE 10: Institutional framework for the water sector in Chennai Metropolitan Area

3.2 Inferences

- As shown in Figure 10, surface water in CMA is managed by the Water Resources Organization, TNPWD, which looks after all the waterbodies in Tamil Nadu. Managing local ponds, rivers, and lakes requires the ULBs' attention as they are more aware of their local jurisdiction. Therefore, PWD should work closely with the CMWSSB to rejuvenate and manage these waterbodies in CMA and bring out the best results in enhancing water sustainability.
- The increasing water crisis in Chennai over the years brings about the need for an urban water planning and management boards in metropolitan cities across the country. The boards would perform all the key functions including sustainable surface and groundwater extraction, RWH, wastewater treatment, water distribution efficiency, storm water systems, water meters installation, water pricing, and aquifer conservation. This integrated water resources management approach could enhance the water governance framework and bring out better results improving water sustainability of the city (refer Chapter 6, section 6.4).
- Multiplicity in responsibility sharing is one reason for non-accountability in performance. Therefore, more robust coordination among the existing institutional mechanisms is required.

4. Water Source Management and Infrastructure

4.1 Water Sources

4.1.1 Historical Background

Till 1870, Chennai district received water from wells built in individual houses, public wells, and tanks. There was no protected water supply and these sources were not adequate. The development of the first organized water supply system in Chennai was commenced in 1872. In this regard, a masonry weir was constructed across the Kosasthalaiyar River in Tamaraipakkam, located at the north-western side of Chennai. The water from masonry weir was diverted to Cholavaram Lake followed by Redhills Lake, and finally brought to Kilpauk from where the unprotected water was distributed through cast iron pipes to the nearby areas.

In 1914, for the first time, protected water was supplied to Chennai. It was supplied from the first constructed water treatment plant (WTP) in the city, established at Kilpauk, which used filtration and pumping techniques and had a capacity of 80,000 m^3. The purification technology used in this plant till 2000 was using pebbles, fine sand, and bricks. This system was later replaced by chemicals and rapid sand filter technology. To meet the immediate needs, various works for conveyance, treatment, and distribution were carried out between 1946 and 1966.[46]

Over the time, several sources of water supply for the city were developed. In 1944, Poondi reservoir was constructed adjacent to Kosasthalaiyar River with a capacity of 72.81 MCM, which was later increased to 91.4 MCM. Groundwater aquifers were identified in Panjetty, Minjur, Tamaraipakkam, Poondi, floodplains, and Kannigaiper. The aquifers were developed for groundwater abstraction through borewells from these well fields.[47]

4.1.2 Current Scenario

To fulfil the increasing water demand in **CMA**, several sources are being tapped to procure and distribute water to the region. CMA receives its water from three main sources – surface water, rainwater, seawater, and groundwater. Out of these three sources, ground aquifers have been the most important source of water supply to Chennai. Although in today's time the surface water is the most used source in CMA, during water-deficit months groundwater continues to play an important role in meeting the water requirements of the region.

Rainwater

No separate rainfall data are available for CMA region. Thus, as it is an extended region of Chennai district, Chennai city was considered and taken as the representative for CMA region.

[46] Details available at https://chennaimetrowater.tn.gov.in/metrowateroperationalarea.html, last accessed on October 11, 2021

[47] Details available at https://chennaimetrowater.tn.gov.in/watersupplysystem.html, last accessed on October 11, 2021

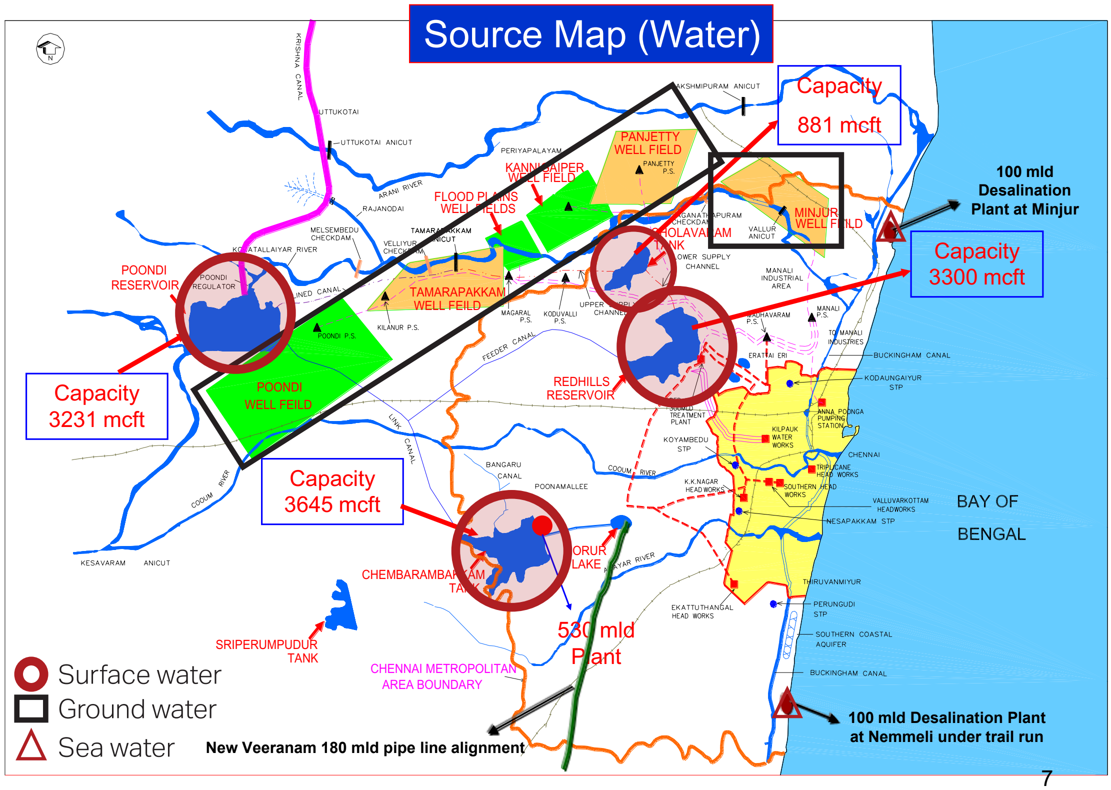

FIGURE 11: Surface, sea, and groundwater sources in Chennai Metropolitan Area (2013)[48]

Chennai receives heavy rainfall during the monsoon season with an average annual rainfall of 1400 mm.[49] As mentioned in Section 2.1.3, Chennai receives its majority of the rainfall twice a year; first from south-west monsoon winds between June and September and second from north-east monsoon winds between October and December (as highlighted in table 5). Water from monsoon rains fills the lakes, rivers, and replenishes the groundwater periodically. This water is then distributed to meet the requirements of the city. Nonetheless, inefficiency in rainwater management leads to severe water crisis in the region during summer months. The rainfall and evapotranspiration statistics of Chennai city is shown in Table 5.

Also shown in Table 5, Chennai city receives maximum rainfall from October to December. From 2001 to 2011, October was recorded as the wettest month, and November having the lowest evapotranspiration rate.[50,51]

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48 Details available at http://icrier.org/pdf/chennai_CMWSSB_Delhi_Feb2013.pdf, last accessed on September 20, 2021

49 Details available at https://web.archive.org/web/20121121080418/, last accessed on September 20, 2021

50 State of Environment Report of Chennai Metropolitan Area 2013, ENVIS Centre, Department of Environment, Government of Tamil Nadu

51 India Water Portal

TABLE 5: Average month-wise rainfall and evapotranspiration statistics of Chennai city

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average rainfall (mm)[52] (2001–2011)	17.4	2.8	15.6	20.3	51.5	57.3	119	117.1	141	384.8	365.9	168	**1460.7**
Rainy days[53] (1951–1980)	1	0.3	0.2	0.7	1.6	4.1	7.3	9.5	6.6	10.2	10.1	5.5	**57.1**
Evapotranspiration (mm/d)[54] (1960–2002)	5.35	6.19	6.87	6.95	7.28	6.73	6.28	6.23	6.17	5.45	4.86	4.8	**73.16**

52 State of Environment Report of Chennai Metropolitan Area 2013, ENVIS Centre, Department of Environment, Government of Tamil Nadu

53 Climatological Table of observations in India, IMD

54 India Water Portal

TABLE 6: Month-wise rainfall and rainy days statistics of Chennai city from 2010 to 2020[55]

Months		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	Rain (mm)	15.24	14.42	5.92	0.8	4.37	7.77	7.66	10.47	5.28	3.1	53.1
	Days	12	7	7	1	4	6	4	6	3	7	14
February	Rain (mm)	0	27.62	0.07	26.02	7.1	1.5	0.25	0.46	1.4	2.7	7.5
	Days	0	4	0	6	6	1	0	1	1	8	8
March	Rain (mm)	0.51	1.3	1.75	6.37	1.12	11.52	0.13	10.1	1.18	2.3	0.8
	Days	2	4	3	2	3	13	0	6	3	4	3
April	Rain (mm)	0.14	49.16	35.31	7.24	0.07	8.78	0.37	0.26	1.6	1	13.1
	Days	0	9	7	4	0	6	7	0	10	3	6
May	Rain (mm)	33.98	7.02	9.09	20.87	18.61	37.47	116.59	8.3	10.54	7.4	1.2
	Days	6	5	7	6	9	8	7	4	8	4	2
June	Rain (mm)	24.16	30.63	16.47	61.57	18.96	63.16	81.6	37.82	27.14	48.9	92.9
	Days	15	12	13	20	9	20	24	19	12	20	27
July	Rain (mm)	68.45	115.86	39.38	55.18	16.95	36.44	25.37	18.8	5.94	148.7	255.8
	Days	23	26	17	24	10	19	18	14	5	30	31
August	Rain (mm)	200.12	95.38	72.34	65.32	37.99	82.1	58.14	78.37	25.82	208	-
	Days	27	25	17	19	10	28	17	21	12	28	-
September	Rain (mm)	127.22	86.98	102.36	105.36	99.86	105.81	95.94	65.99	47.24	205.2	-
	Days	26	22	26	24	25	24	25	21	18	28	-
October	Rain (mm)	240.73	150.17	154.2	87.92	102.62	81.46	34.8	133.94	216.48	319.3	-
	Days	28	24	24	22	17	21	15	23	20	30	-
November	Rain (mm)	344.43	244.13	48.38	59.98	58.46	367.9	15.03	245.53	449.6	296.9	-
	Days	23	18	8	12	12	25	7	22	24	27	-
December	Rain (mm)	152.01	74.97	84.83	44.43	58.63	111.32	110.77	14.81	52	261.4	-
	Days	21	8	10	14	13	13	10	11	18	28	-
Total annual rainfall (mm)		**1206.9**	**897.64**	**570.1**	**540.93**	**424.74**	**915.23**	**546.65**	**624.85**	**844.22**	**1504.9**	**-**
Total number of rainy days in a year		**183**	**164**	**139**	**154**	**118**	**184**	**134**	**148**	**134**	**217**	**-**

55 Details available at https://www.worldweatheronline.com/chennai-weather-history/tamil-nadu/in.aspx, last accessed on September 20, 2021

According to Table 6, the analysis of the rainfall pattern in Chennai from 2010 to 2019 is as follows:

» It can be seen that in the non-monsoon months, that is, from January to May, there has been an extremely inconsistent rainfall pattern over the span of last 10 years.

» Secondly, in the last 10 years, November was the wettest month in Chennai as compared to 2001–2011 in which October was the wettest month, indicating the postponement of heavy spell of rain.

» The peak rainfall between 2010 and 2019 occurred in the monsoon months from September to November. However, an anomaly was observed in 2016 wherein the peak month rainfall took place in a non-monsoon period, that is, in May (116.59 mm).

» The total annual rainfall decreased three-times between 2010 (1206.9 mm) and 2014 (424.74 mm). However, in the subsequent year, that is, 2015, it shot up twice to 915.23 mm, leading to worst floods in the region, resulting in huge loss of lives and property. Post 2016, there has been a three-times increase in the total annual rainfall from 546.65 mm to 1504.9 mm in 2019.

Such an unpredicted rain spell can be majorly attributed to the changing climate across the world due to global warming, for which GHG emissions are the most prominent reason. In Chennai, extreme El Nino conditions and continuous warming of the Bay of Bengal off the Tamil Nadu coast led to the unprecedented heavy rainfall in 2015, which led to massive flooding.[56] Ostensibly, it becomes difficult to predict the rainfall intensity in forthcoming years. Thus, to estimate the water availability in the rivers and reservoirs has become a challenging task for the authorities and to prepare accordingly.

This increasing risk of flooding in the CMA can be further attributed to years of illegal development and inadequate levels of flood preparedness.

Surface Water

There are five main surface water sources in Chennai – Poondi, Cholavaram, Red Hills, Chembarambakkam, and Veeranam lakes (reservoirs), which get replenished by the annual rainfall. The combined capacity of all these lakes is 360.01 MCM, also shown in Table 7.

TABLE 7: Storage capacity at full reservoir level of surface water sources and capacity of desalination plants (seawater) supplying water to Chennai Metropolitan Area

Source of Water		Storage Capacity at Full Reservoir Level (MCM)[57]
Lakes (Surface water)	Poondi	91.43
	Cholavaram	30.59
	Redhills	93.39
	Chembarabakkam	103.15
	Veeranam	41.45
Total Combined Capacity		360.01
Desalination Plant (Seawater)	Minjur	0.1
	Nemmeli	0.1

56 Boyaj, A, K Ashok, S Ghosh, A Devanand, and G Dandu.2018. The Chennai extreme rainfall event in 2015: The Bay of Bengal connection. Clim Dyn 50: 2867–2879

57 Details available at https://chennaimetrowater.tn.gov.in/watersupplysystem.html, last accessed on September 9, 2021

The first reservoir, that is, Poondi reservoir was built in 1944 across the Kosathalaiyar River with a capacity of 72.8 MCM, which was later increased to 91.43 MCM. The reservoir's surplus water flows down the river which is again intercepted by Tamaraipakkam anicut and diverted to Cholavaram Lake and further to Red Hills Lake. A part of water supply for CMA is drawn from Chembarabakkam Lake, from where river Adyar also originates.

The Veeranam reservoir was developed as an additional source of water for the Chennai city. The project was commissioned in 2004 to supply 0.18 MCM of water per day to Chennai city by drawing water from Veeranam Lake. This lake receives water from the Cauvery River system through Kollidam, lower anicut, and Vadavar canal, besides rainwater from its own catchment area. The capacity of the lake is 41.4 MCM.

As the city's population escalated, it experienced acute water shortages and groundwater depletion. To meet the increasing water demand in Chennai, the existing water sources of the state were found to be insufficient. Therefore, an interstate agreement was signed in 1983, wherein Andhra Pradesh agreed to supply 424.5 MCM annually (339.6 MCM after losses and evaporation) of Krishna river water under the Telugu Ganga project. The water was received for the first time at Poondi reservoir in 1996 after the construction and completion of several canals.

Taking advantage of its geographical location along the sea, Chennai has established two desalination plants in Minjur and Nemmeli, each with 100 MLD capacity, to meet the water requirements of CMA.

Figure 12 shows the water flow system in CMA from surface and seawater sources.

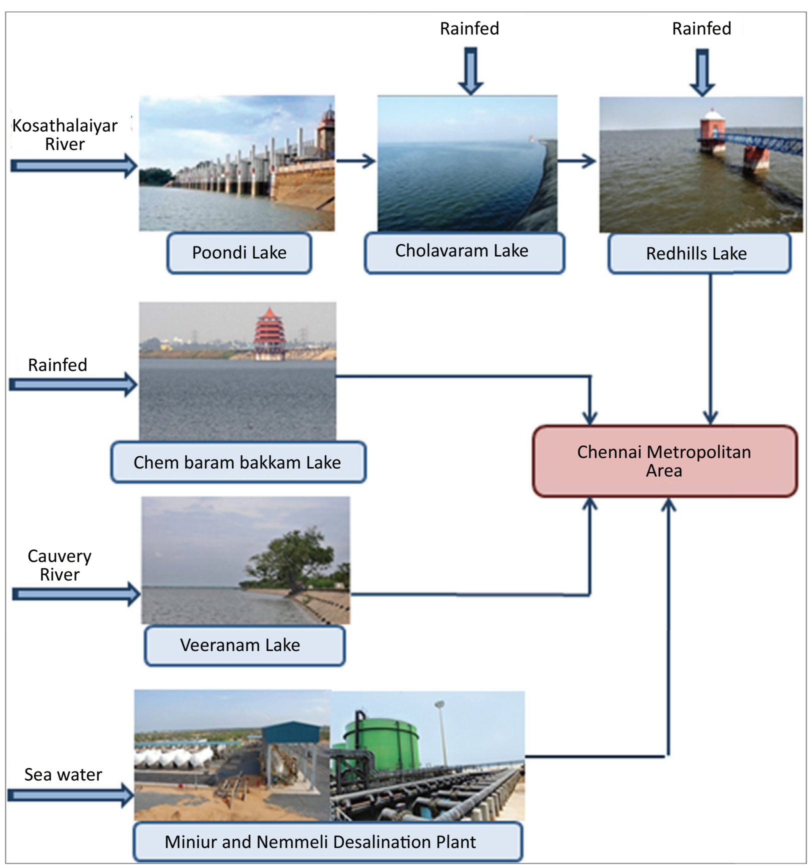

FIGURE 12: Water supply system in Chennai Metropolitan Area from surface and seawater sources

Tables 8–11 show month-wise live water storage of the four reservoirs located in CMA, that is, Poondi, Cholavaram, Red Hills, and Chembarabakkam from 2011 to 2019.

TABLE 8: Live storage of water in Poondi reservoir in Chennai Metropolitan Area from 2011 to 2020 (in MCM)[58]

Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	91.4	80.3	43.04	4.16	13.7	88.1	17.4	28.6	8.43	40.3
February	88	86.3	38.4	7.19	6.65	74.3	20.5	39.2	5.38	44.8
March	77.3	80.9	27.9	14.8	6.65	58	22.6	56.9	13.5	43.8
April	71.6	72.9	11.6	2.63	2.18	54.1	4.53	45.6	9.42	40.7
May	67.4	66.4	11.4	8.32	4.3	35	1.64	11.2	5.46	24
June	48.1	58.8	9.54	12.1	2.7	30.1	1.104	5.2	1.58	10.6
July	33.4	48.2	6.2	2.97	2.26	28.8	0.53	3.7	0.509	-
August	50.9	26.6	5.6	2.29	1.47	18.2	0.56	1.41	0.45	-
September	65.4	17.3	8.69	16.2	1.67	16.1	0.76	0.36	0.45	-
October	86.4	16.7	9.31	11.6	1.67	8	1.18	2.63	16.9	-
November	75.4	19.6	12.9	8.09	1.98	6.4	9.4	19.6	47.6	-
December	70.3	22.5	21.1	7.92	77.7	5.49	28.4	10.7	28	-
Average	68.8	49.7	17.14	7.8	10.24	35.21	9.05	18.75	11.47	-

The above-mentioned data depicts the storage as on the first day of the month

TABLE 9: Live storage of water in Cholavaram reservoir in Chennai Metropolitan Area from 2011 to 2020 (in MCM)[59]

Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	23.1	24.2	13.3	4.8	3.48	20.3	2.32	14.5	1.35	1.92
February	23.7	14.01	11.2	2.6	3.19	15.09	1.95	12.7	1.35	2.03
March	21.8	8.4	2.5	2.2	2.12	10.6	0.7	11.2	1.35	2.03
April	19.1	2.8	2.1	1.4	1.81	7.1	0	2.8	1.18	2.03
May	17.6	2.43	1.1	0.1	0.5	3.3	0	1.98	0.3	2.03
June	6.1	2.3	0	0.08	0	2.3	0	1.92	0.02	2.03
July	2.5	2.406	0	0	0	2.2	0	1.72	0	-
August	2.6	2.406	0	0	0	2.06	0	0.7	0	-
September	3.4	2.406	0	0	0	1.95	0.6	0.02	0	-
October	3.9	2.6	0	0	0	2.8	1.01	0.2	1.5	-
November	19.3	6.1	4	1.3	0	2.03	5.09	0.5	5.4	-
December	23.6	9.3	9.3	17.2	16.8	2.03	16.8	1.1	2.7	-
Average	13.89	6.61	3.62	2.47	2.32	5.982	2.37	4.1	1.26	-

The above-mentioned data depicts the storage as on the first day of the month.

58 Details available at http://123.63.203.150/public/lake.htm, last accessed on September 20, 2021

59 Details available at http://123.63.203.150/public/lake.htm, last accessed on September 20, 2021

TABLE 10: Live storage of water in Red Hills reservoir in Chennai Metropolitan Area from 2011 to 2020 (in MCM)[60]

Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	91.6	74.5	61.2	61.3	44.7	81	12.7	44.8	26.6	69.5
February	92.1	78.4	62.6	56.4	49.3	80	8.6	38.7	20.3	82.2
March	87.9	72.8	61.9	63.3	51.9	76.7	20.3	33.8	14.7	71.8
April	76.5	64.8	48.8	61.6	42.5	66.4	18.2	47	8.5	-
May	64.08	51.5	35.5	49.4	38.4	53.2	11.8	50.3	3.5	-
June	62.4	37.3	23.2	42.6	28.5	45.6	4.7	40.4	0.08	78.7
July	53.3	34	13.4	36.2	19.5	34	0.5	31.7	0	-
August	49.04	39.02	9.5	26.2	12.1	30.6	0	26	0	-
September	57.1	38.9	16.2	25.2	6.8	19	2.3	20.1	0	-
October	83.7	43.5	27.6	29.5	2.3	18.6	3.8	13.5	1.5	-
November	86.7	53.4	37.7	27.5	0.7	11.6	17.3	22.9	23.7	-
December	85.1	55.7	52.3	37.9	79	7.5	44	31.2	46.4	-
Average	74.12	53.65	37.49	43	31.3	43.6	12.01	33.3	12.1	-

The above-mentioned data depicts the storage as on the first day of the month.

TABLE 11: Live storage of water in Chembarambakkam reservoir in Chennai Metropolitan Area from 2011 to 2020 (in MCM)[61]

Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	88.6	79.9	35	24.7	27.4	89.2	15.2	52.1	2.8	47.9
February	87.2	76.9	27.7	20.3	21.1	85.4	9.5	47.9	1.4	43.8
March	77.1	67.6	40.9	22.3	20.6	80.8	4.5	42.6	0.6	56.1
April	62.5	56.3	50.2	21.1	24.4	67.3	13.1	34.4	0.2	-
May	48.2	44.5	40.2	25.9	22.6	65.3	8.1	33.9	0.05	-
June	51.5	33.3	28.6	35.7	16.1	65.4	2.6	34.3	0.02	56.9
July	56.1	21.4	21.4	31.2	14.4	55.9	1.3	25.6	0	-
August	69	31.7	15.7	24	9.1	44.2	2.3	17.7	0	-
September	80.5	39.7	12.6	17.9	4.6	32.4	5	12.6	0	-
October	79	33.9	18.9	20.3	4.1	27.5	6.2	9.5	0.3	-
November	77.4	33.7	21.2	34.2	6.4	16.1	17.4	6.6	2.1	-
December	75.6	32.3	27	33.6	88.9	6.7	49.8	5.2	21.2	-
Average	71	45.9	28.2	25.9	21.6	49.6	11.25	26.8	2.3	-

The above-mentioned data depicts the storage as on the first day of the month.

60 Details available at http://123.63.203.150/public/lake.htm, last accessed on September 20, 2021

61 Details available at http://123.63.203.150/public/lake.htm, last accessed on September 20, 2021

The data on live water storage of the four reservoirs were collated and represented in Figure 13.

» It can be seen that throughout the years (both monsoon and non-monsoon months) in the last decade, the live water storage underwent an extremely erratic pattern. The storage levels did not increase in proportion to the increasing average annual rainfall intensity. This can be attributed to the inconsistent rainfall pattern over the years with increased dry period. Consequently, the groundwater levels were depleted, which in turn reduced the storage levels of the reservoirs. The second major reason for depleting water storage levels is mismanagement of the rainwater in CMA, which is mainly due to the following two reasons**:**

- Indiscriminate construction of storm water drains and dumping of large quantities of rainwater into the ocean every year, instead of channelizing it into these reservoirs.
- Encroachment/construction of factories and infrastructure in the catchments of these reservoirs are unregulated; therefore, much of the rainwater goes into the ocean as it does not find space to recharge groundwater or fill up the reservoirs or get used in excess by these factories. This limits the amount of water that enters the reservoirs for public consumption.

» The live water storage of Red Hills reservoir sharply decreased from 2011 to 2013. Post 2013, there had been an undulating pattern with rise and fall in storage till 2019.

» Live water storage of Poondi and Chembarambakkam reservoirs also endured a sharp decline from 2011 to 2015, followed by an undulating pattern till 2019.

» Although the live water storage of Cholavaram reservoir went through a slight decline post 2011 till 2014, but it remained more or less the same till 2019.

» The anomaly observed was the sharp increase in water storage in 2016. The cause of this could be the early arrival of monsoon that year, taking the annual rainfall to 546.65 mm.

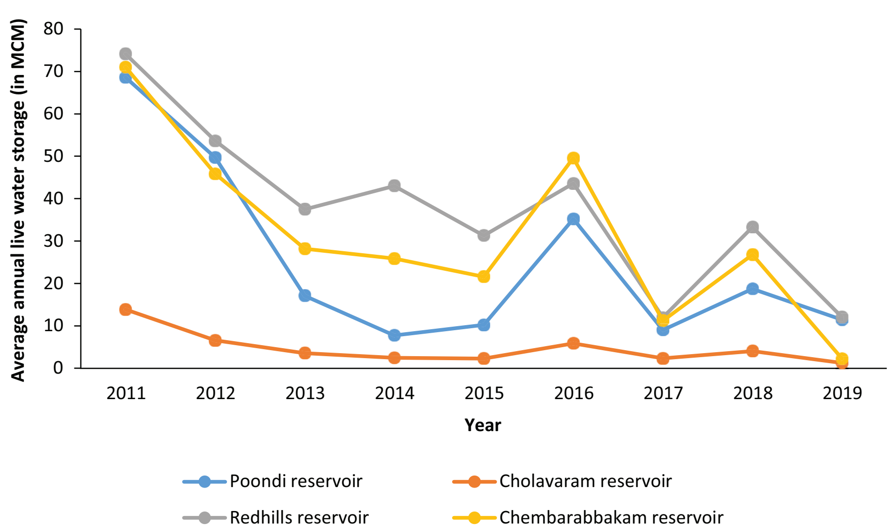

FIGURE 13: Average annual live water storage in reservoirs located in Chennai Metropolitan Area from 2011 to 2019

» The overall graph gives a picture of declining water storage levels which led to annual rising water shortages in dry months in the CMA.

» A positive point to be noted here is that the rising water storage levels post 2015, though inconsistent, can be credited to the efforts of desilting of these waterbodies, which has helped in improving the water storage levels.

Table 12 shows the month-wise live water storage of Veeranam reservoir located in Cuddalore district (180 km. from CMA) from 2011 to 2019.

TABLE 12: Live storage of water in Veeranam reservoir in Chennai Metropolitan Area from 2011 to 2020 (in MCM)[62]

Months	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	27.6	25.8	14.1	21.6	33.8	13.8	7.1	22.8	41.1	33.1
February	12.9	40	3.5	36.6	39	12.9	1.9	11.5	37.9	41.1
March	2.1	38.7	0.7	30.1	35.6	0	0	3.1	28.6	39.2
April	0	20.3	6.7	20.5	23.7	0	0	0	16.6	-
May	0	10.8	1.5	28.4	22.3	0	0	0	33.8	-
June	0	14.1	0	29.7	36.3	0	0	0	21.4	7.6
July	0	3.1	0	22.1	27.3	0	0	0	10.1	-
August	14.3	2.7	0	13.2	18.5	0	0	0	2.7	-
September	19.9	0	32.8	17.3	27.3	0	0	38	35.4	-
October	19.4	0	13.4	26.4	26.1	0	0	22.8	35.9	-
November	19.4	24.6	19.9	29	27.6	0	12	15.9	33.4	-
December	19.4	12	28.4	23.7	16.2	15.7	20.3	33.4	38	-
Average	11.25	16	10	24.8	27.8	3.5	3.4	12.2	27.9	-

The above-mentioned data depict the storage as on the first day of the month.

In Veeranam reservoir, throughout the years (both monsoon and non-monsoon months) in the last 10 years, live water storage underwent a slight erratic pattern. The live water storage in the reservoir had been through an undulating pattern between 2011 and 2019, with highest annual average in 2014, 2015, and 2019 and extremely low levels in 2016 and 2017. This can be attributed to the inconsistent rainfall pattern over the years with increased dry period which depleted the groundwater levels, and in turn, affected the storage level of the reservoir**.** However, the consistent efforts of the authorities over the last 5–6 years to enhance rainwater management in the region, such as desilting waterbodies across the state, yielded some good results. This can be seen in Table 12, which shows the average live water storage of the Veeranam Lake shot up to 27.9 MCM in 2019, the highest in the last 10 years. Such interventions are required in CMA to enhance the storage levels of the reservoirs.

[62] Details available at http://123.63.203.150/public/lake.htm, last accessed on September 20, 2021

Groundwater

The unavailability of freshwater from surface sources due to inconsistent rainfall patterns and rapid population growth in the city shifted the attention on other sources of water supply. Wells were dug up along the aquifers where groundwater reserves were found in abundance. Traditional dug wells and borewells in the domestic household also increased in CMA.

There are several well fields identified in CMA whose water is mostly used directly (without extensive treatment) for agricultural, industrial, and domestic purposes. These are Poondi, Tamaraipakkam, floodplains, Kannigaipair, Panjetty, Minjur, Southern Coastal Aquifer, Kidilam, and Paravanar river beds. As Chennai receives heavy rainfall, water from monsoon rains replenishes the groundwater periodically.

TABLE 13: Groundwater yield information of well fields located in Chennai Metropolitan Area[63]

Name of Well Field	Number of Wells Yielding Water	Designed Yield (MLD)	Average Yield from Wells in 2005 (MLD)
Tamaraipakkam	2 out of 30	50	1.6
Panjetty	1 out of 13	41	0.08
Minjur	5 out of 9	34	3.1
Poondi	4 out of 12	27	1.2
Floodplains	0 out of 5	14	0
Kannigaipair	0 out of 5	14	0.01
Southern coastal aquifers[64]	-	10	5
Total	**12 out of 74**	**190**	**10.99**

By 2005, only 12 of the 74 wells were active, and yielded just about 11 MLD as compared to the designed yield of 190 MLD.

In the last two decades, overexploitation of groundwater and its inadequate recharge has lowered the water table. The yielding capacity of the groundwater in CMA has gone down drastically as depicted in Table 14.

TABLE 14: Groundwater yields in Chennai Metropolitan Area[64]

Groundwater Source	Yield in 1996 (MLD)	Yield in 2006 (MLD)
Northern well fields	148	100
Southern coastal aquifers	10	5

[63] Excreta Matters Vol. 2, State of India's Environment, A Citizen's Report, Centre for Science and Environment,2012

[64] K.R.Sivaraman and Dr. S. Thillaigovindarajan, Chennai River Basin Micro Level Report, 2020

[65] Excreta Matters Vol. 2, State of India's Environment, A Citizen's Report, Centre for Science and Environment, 2012

Table 15 shows the block-wise groundwater development in CMA. Based on the development stage, blocks are classified into different categories.

Stage of Development	Category
Greater than 100%	Over exploited
85%–100%	Dark area
65%–85%	Grey area
Less than 65%	White area

Minjur was taken under the over-exploited category as the groundwater exploitation in the area is extremely high. Poonamallee belongs to the dark category. St. Thomas Mount and Cholavaram areas were categorized as grey areas. Water extraction in areas such as Puzhal, Villivakkam, Sriperumbudur Kattankulathur, and Kunrathur is less, thus they were categorized as white areas.

TABLE 15: Details of block-wise groundwater development in Chennai Metropolitan Area [66]

Block	Total Area (km^2)	Total Annual Groundwater Recharge (Mm^3)	Net Annual Groundwater Availability (Mm^3)	Existing Gross Groundwater Draft for All Uses (Mm^3)	Stage of Groundwater Development (%)
Minjur	478.30	123.72	111.35	147.31	132
Cholavaram	193.69	98.40	88.56	68.43	77
Puzhal	60.41	34.87	31.38	16.01	51
Villivakkam	175.78	60.65	54.59	28.72	53
Ponnamalle	156.13	72.01	64.81	57.39	89
Sriperumbudur	365.69	134.03	120.62	23.74	20
Kundrathur	270.38	87.66	78.90	45.26	57
St.Thomas Mount	236.51	41.61	37.45	23.85	64
Kattankulathur	361.76	83.40	75.06	45.49	61

The net groundwater availability of the Chennai district basin for 2013 was less than 2011, as seen in Table 16. All the 20 firkas of the Chennai district were found to be in over-exploited category.

TABLE 16: Groundwater availability and draft information of Chennai district[67]

District	2011		2013	
	Net Groundwater Availability (ham)	Groundwater Draft (ham)	Net Groundwater Availability (ham)	Groundwater Draft (ham)
Chennai	1707	3780	1497	2768

[66] State Ground and Surface Water Resources Data Centre 2003

[67] Report on AQUIFER MAPPING AND GROUND WATER MANAGEMENT, Chennai Aquifer System, Tamil Nadu, CGWB, March 2017

The top of the aquifer zone which is favourable for groundwater recharge in Chennai starts at a depth of 3 m below the ground level near the sea coast. The rechargeable depth varies from 4 m near Santhome and Ekkattuthangal to 23 m in Perambur. Aquifers are shallow near coastal areas. The south-eastern region of CMA including Adambakkam, St. Thomas Mount, Alandur, Velachery, Taramani, and a part of Guindy, Medavakkam, and Perungudi has a majority of crystalline rock formation, making the region impervious in nature.

Chennai comprises the rock formations that are heterogeneous in nature. Groundwater quality in Chennai changes both seasonally and depth wise. Groundwater is alkaline in shallow aquifers with pH values ranging from 7.8 to 9. High contents of chloride and sulphate are also found in water in the region, making water unsuitable for drinking purposes. Groundwater quality is good in some areas of Besant Nagar, Kotturpuram, Anna Nagar, Kilpauk, and Nungambakkam. Some areas of the city including Adyar, Shasthri Nagar, K. K. Nagar, Ashok Nagar, Raja Annamalaipuram, and Mylapore have the problem of excess iron content in groundwater. Groundwater pollution is common in industrial areas in north Chennai. The quality of groundwater could be improved by dilution with the help of artificial recharge, resulting in reduction of the concentration of salts.

4.2 Water and Wastewater Treatment Infrastructure

To meet the city's water demand, water stored in the reservoirs requires infrastructure for a safe and continuous supply to the end user. In this regard, to meet the minimum water quality standards, the city has several WTPs where the water tapped from the reservoirs is treated and further supplied to the city.

Also, there are wastewater treatment plants where wastewater from the city is collected and treated. In the process, maximum suspended solids are removed before the remaining water is discharged back to the rivers.

4.2.1 Water Treatment Plants

Current Scenario

In Chennai, water supply infrastructure is managed by the Chennai Metropolitan Water Supply and Sewerage Board. Water from Poondi and Cholavaram reservoirs is finally drawn from Red Hills reservoir, which gets treated at Kilpauk, Puzhal, and Surapet WTPs before being distributed to CMA. Two new lakes Chembarambakkam and Veeranam were identified in early 2000 to draw water from them and treated it at Chembarambakkam and Vadakuthu WTPs, respectively.

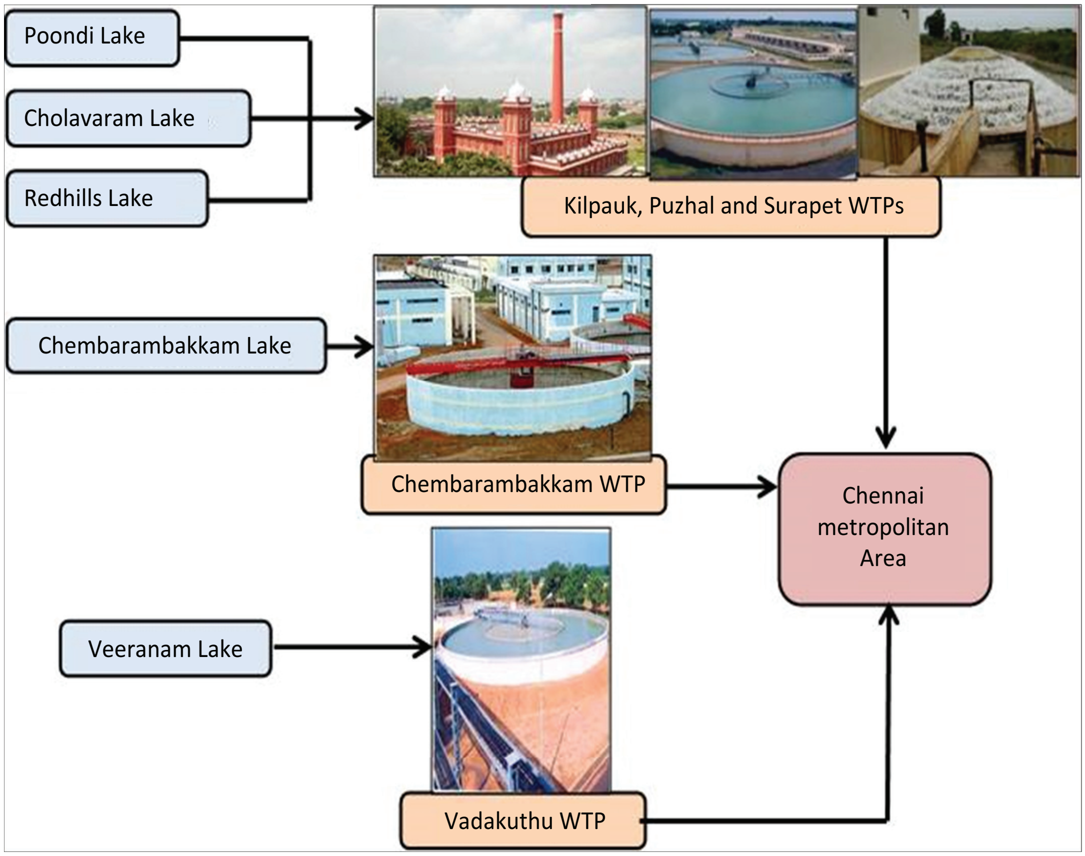

FIGURE 14: Water treatment plants in Chennai Metropolitan Area[68, 69, 70, 71, 72]

There are five WTPs in CMA with combined water treatment capacity of 1294 MLD, as given in Table 17.

TABLE 17: Water treatment plants in Chennai Metropolitan Area with their treatment capacities [73]

S. No.	Water Treatment Plant	Capacity (MLD)
1	Kilpauk	270
2	Puzhal	300
3	Surapet	14
4	Chembarambakkam	530
5	Vadakuthu	180
	Total	**1294**

68 Details available at http://chennai.citizenmatters.in/chennai-kilpauk-water-works-history-madras-6331, last accessed on September 21, 2021

69 Details available at https://mapio.net/pic/p-19808620/, last accessed on September 21, 2021

70 Details available at http://icrier.org/pdf/chennai_CMWSSB_Delhi_Feb2013.pdf, last accessed on September 21, 2021

71 Details available at https://www.water-technology.net/projects/chembarambakkam/, last accessed on September 21, 2021

72 Details available at http://mohua.gov.in/upload/uploadfiles/files/CMWSSB_Chennai_PPT_0.pdf, last accessed on September 21, 2021

73 Details available at http://icrier.org/pdf/chennai_CMWSSB_Delhi_Feb2013.pdf, last accessed on September 21, 2021

4.2.2 Sewage Treatment Plants

Historical Background

The sewage system in Chennai was designed for the first time in 1910 for a projected population of 6.6 lakhs in 1961. The system was improved and redesigned in 1958 for a projected population of 25.5 lakhs in 1976 and 27.2 lakhs in 1991 after the formation of CMA. The sewage network was such that it allowed the inclusion of storm water too. Furthermore, the city was divided into five zones with each zone having its own independent collection, conveyance, treatment, and disposal of the wastewater system.[74]

Current Scenario

Wastewater infrastructure in Chennai is managed by the Chennai Metropolitan Water Supply and Sewerage Board. The wastewater generated from the domestic and industrial sectors in Chennai finds its way to sewage treatment plants (STPs) and common effluent treatment plants (CETPs) via wastewater drains and sewer networks.

The infrastructure for transporting wastewater comprises 5200 km of sewer lines and 1894 km of open drains mainly carrying domestic wastewater and storm water. Open drains are mostly unlined, and wastewater flows under gravity towards the sink. The sewerage network comprises pipes of reinforced concrete cement with diameters varying from 250 mm to 2500 mm. Currently, the sewerage network in Chennai covers 98% of it area. Chennai has a total of 12 STPs, which are spread over five zones, that is, Kodungaiyur (zones I and II), Koyambedu, Nesapakkam, and Perungudi. The flow and treatment details of STPs are given in Table 18.

TABLE 18: Sewage treatment plants in Chennai Metropolitan Area[75, 76]

S. No.	Sewage Treatment Plant	Designed Capacity (MLD)	Actual Flow (MLD)	Main Treatment Process[77]	Amount of Water into Waterbodies After Treatment (MLD)
1	Kodungaiyur - Zone I	80	214.86	Activated sludge process	187.35
2	Kodungaiyur - Zone II	80			
3	Kodungaiyur - Zones I & II	110			
4	Koyambedu - Zone III	34	120.4	Activated sludge process	105
5	Koyambedu - Zone III	60			
6	Koyambedu - Zone III	120			
7	Nesapakkam - Zone IV	23	99.3	Activated sludge process	99
8	Nesapakkam - Zone IV	40			
9	Nesapakkam - Zone IV	54			
10	Perungudi - Zone V	54	74.46	Activated sludge process	95
11	Perungudi - Zone V	60			
12	Alandur - Zone V	12	12.5		

74 Details available at https://chennaimetrowater.tn.gov.in/watersupplysystem.html, last accessed on September 21, 2021

75 Details available at https://chennaimetrowater.tn.gov.in/seweragesystem.html, last accessed on September 21, 2021

76 Why Chennai Stinks? Citizens efforts to understand and solve the sewage problem, an initiative of Arappor Iyakkam

77 Details available at http://www.cmdachennai.gov.in/Volume1_English_PDF/Vol1_Chapter06_Infrastructure.pdf, last accessed on September 21, 2021

During the sewage treatment process, bio-gas is generated, which is further used to power the plant's operations. This incidentally reduces greenhouse gas emissions into the atmosphere and provides for carbon trading. CMWSSB has adopted a Clean Development Mechanism which leads to energy cost savings of approximately INR 45.46 lakhs per month.[78]

4.2.3 Water Meters

Water metering is the process of measuring the water use. It helps in cutting losses due to theft and ageing infrastructure and also makes the end user use water judiciously. More the coverage of metered water connections, more efficient is the revenue collection by the municipality. Due to its numerous benefits, water meter installation is increasing in Indian cities both by municipalities and private entities.

As data on CMA is not available, metered connections data for Chennai district was analysed.

Until 2019, there was no system in place to account for the water being supplied and used. The water meters provided earlier were faulty or damaged, or recorded incorrect readings. People's opposition to install the meters also hindered the coverage of the water meters in the city. Due to this, the CMWSSB had been incurring huge monetary losses.

Under the focus area 'Smart Water' in Smart Cities Mission, CMWSSB proposed to install AMR (Automatic Meter Reading) meters across the city with data capture by a wireless system using long-range gateways. It was envisaged that these installed meters will help in regulating the water distributed to consumers, useful for charging them accordingly.

In first phase (by January 2020), 600-odd digital water meters were installed in commercial areas in Adyar, Velachery, Thiruvanmiyur, and Besant Nagar. These areas fall under Zone 13.[79] Also, it was aimed at replacing the old manual meters with the new ones. In the second phase, it is planned to install the meters covering all domestic households.

4.2.4 Water Quality of Waterways Carrying Wastewater

The major waterways in Chennai that carry wastewater are River Cooum and Adayar, Buckingham Canal, and Otteri Nullah**.** These waterbodies are facing continuous degradation due to untreated sewage discharge, population increase, dumping of municipal garbage and construction waste, and the encroachment of their banks.

Chennai's drainage system comprises two rivers, five major waterways, and several minor drains, which are as follows:

» River Cooum in city limits – 17.98 Km

» River Adayar in city limits – 12.20 Km

» North Buckingham Canal – 17.00 Km

[78] Details available at https://chennaimetrowater.tn.gov.in/seweragesystem.html, last accessed on September 21, 2021

[79] Details available at https://www.newindianexpress.com/states/tamil-nadu/2019/sep/09/soon-chennaiites-water-bill-will-be-based-on-their-usage-2030914.html, last accessed on September 21, 2021

- Central Buckingham Canal – 7.00 Km
- South Buckingham Canal – 24.00 Km
- Otteri Nullah – 10.84 Km
- Virugambakkam–Arumbakkam Drain – 6.36 Km

These waterways function as flood carriers and have heavy flows for about 2 months during monsoon. In the remaining part of the year, these waterways majorly carry treated, partially treated, and untreated sewage from about 311 outfalls meant for storm water discharge. This results in the accumulation of large volumes of sludge and formation of sand bar in the mouth of the rivers. Consequently, there have been significant problems for flood protection system, storm water drain networks, and public health, leading to overall environmental degradation.

The water quality of rivers in the city has degraded and is in need of immediate interventions. The sewage disposal network needs to be improved so that harmful effluents are prevented from reaching the waterways. This would require a detailed study to fill in the gaps and generate solutions to improve the quality of these waterbodies.

4.3 Inferences

Surface Water Source

- The region is going to experience a staggered pattern of rainfall over the coming years due to rapidly changing climate, thus making it difficult to predict the rainfall intensity and period. This factor along with decreasing groundwater holding capacity and rainwater mismanagement would affect the water storage capacity in the reservoirs, which would fluctuate throughout the year. Therefore, the authorities have to emphasize on tapping alternative sources of water such as treated STP water and adoption of water-efficient technologies to cope up with the challenges of water scarcity. Adaptation strategies would also be required to avert the rising flood risks due to excessive rainfall.

Groundwater Source

- Over exploitation of groundwater sources to meet the growing water demand has resulted in depleting water table of well fields located in CMA. It can be estimated that if the built-up expansion is not controlled and water flow is not properly managed, the groundwater levels and quality will keep on decreasing in near future. However, the state's efforts in recent years towards rejuvenation of waterbodies in the region have helped in enhancing the reservoirs' water levels slightly.

A point to be noted here is that this analysis is based on the groundwater recharge potential and extraction data which is a decade old. Due to non-availability of the latest reliable record of groundwater availability and extraction data, there has been a huge roadblock to understand and analyse the water use by the city from various sources.

Water Metering

» Due to the non-availability of the latest data on water meters coverage in CMA, computing water use and losses was challenging. Although, the study on CMA under Smart Cities Mission suggests that the coverage of water meters had been poor in the region until 2019**.** Therefore, to overcome this issue, authorities have proposed and are in the process of installing water meters across the city under this mission. This shall help in efficient monitoring of water use and losses, thus making it a significant step towards building a water-secure future.

Water Quality of Waterways Carrying Wastewater

» The quality of rivers (Adyar, Cooum, and Kosasthalaiyar) flowing across CMA is deteriorating due to discharge of untreated domestic sewage, construction debris, and industrial wastewater in them. The lakes in the region are also extremely polluted, which if rejuvenated could provide a fresh potential alternative source to meet the rising water demand.

5. Potential Risks in Water Management

5.1 Urban Water Cycle

Water is continuously cycling around, through and above the Earth in a natural water cycle that has existed for billions of years. As water moves between the land, ocean, rivers, and atmosphere, it changes from solid to liquid to gas. This natural water cycle is our planet's way of recycling water, and is essential for life on Earth. It can be defined as a conceptual model describing the storage and circulation of water between the biosphere, the atmosphere, the lithosphere, and the hydrosphere. The stages of natural water cycle include environmental evaporation, condensation, precipitation, infiltration, runoff, and transpiration. Water can be stored in the atmosphere, oceans, lakes, rivers, streams, soils, glaciers, snowfields, and groundwater aquifers. Circulation of water among these storage compartments is caused by the processes including evapotranspiration, condensation, precipitation, infiltration, percolation, snowmelt, and runoff, which are also referred as the water cycle components.

The combined effects of urbanization, industrialization, and population growth affect natural landscapes and hydrological response of watersheds. Although many elements of the natural environment are affected by the anthropogenic factors with respect to pathways and hydrologic abstractions (or sources of water), the principal structure of the hydrological cycle remains intact in urban areas. However, the hydrologic cycle is greatly modified by urbanization impacts on the environment and the need to provide water services to the urban population. This includes water supply, drainage, wastewater collection and management, and beneficial uses of receiving waters. Consequently, the hydrological cycle has become more complex in urban areas with many anthropogenic influences and interventions. Thus, the resulting 'urban' hydrological cycle is termed as urban water cycle.

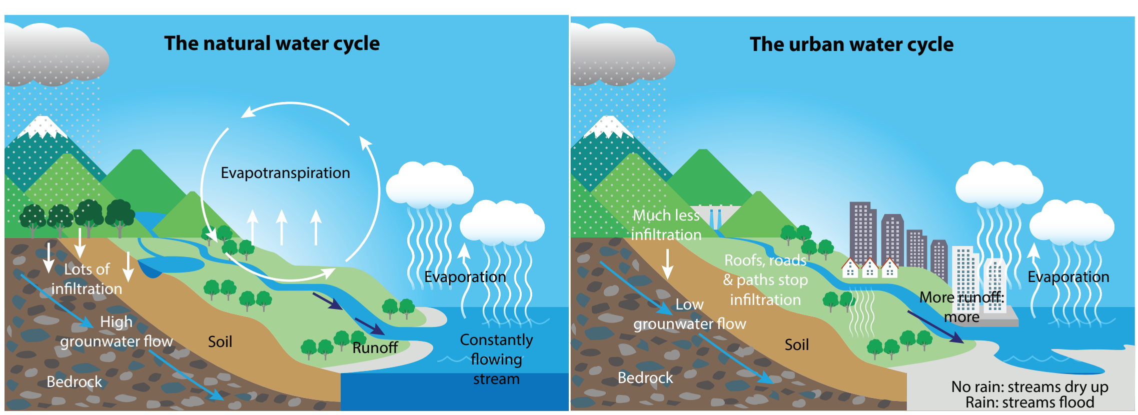

FIGURE 15: Natural and urban water cycles

The main stages of urban water cycle for CMA are as follows:

1. **Source:** The major source of water supply in CMA is surface water, which is used to meet the domestic and non-domestic water requirements of residential, commercial, industrial, agricultural, and vegetation spaces. The major sources of water supply in the region are Poondi, Red Hills, Chembarambakkam, Cholavaram, and Veeranam lake reservoirs.

Groundwater is another important source for meeting the water supply demand of CMA. It is extracted through wells found in individual households and bore wells in designated well fields. Water from bore wells is supplied through tankers to different areas in CMA. However, groundwater in the region is weakly regulated, which results in the exploitation of the groundwater resources.

In addition to this, rainwater harvesting is also done at some places to mostly meet the non-domestic water requirements. Besides, the untapped rainwater is discharged into the waterways as untreated runoff.

Seawater (desalination plants) is also being utilized, though in less quantities, to meet additional water requirements of Chennai city.

2. **Treatment, Storage, and Distribution:** Water from the reservoirs is transferred to various WTPs built across the metropolitan area for treatment. The treated water is then distributed and stored in several large water storage tanks. This treated water is then supplied from these water service reservoirs to the respective zones through a network of pipes consisting of different diameters. According to CMWSSB, the total coverage of water connections in Chennai is 99%.

3. **Use:** The supplied treated water from water service reservoirs is then used for residential, commercial, public, agricultural, and industrial purposes in the city.

4. **Collection:** The wastewater from residential, commercial, industrial, and public spaces is then collected and conveyed by sewer systems to wastewater treatment plants. Wastewater from vegetation and agricultural land is collected and conveyed through storm water drains into Adyar and Cooum Rivers, Otteri Nullah, and Buckingham Canal.

5. **Wastewater Treatment and Discharge:** Wastewater from vegetation and agricultural land is discharged into the waterways through storm water drains. It also helps in groundwater recharge. Wastewater generated from the city goes into various public STPs for treatment through sewer drains after which the treated wastewater is discharged into various waterways carrying wastewater. Due to lack of sufficient STPs and CETPs, a significant amount of domestic and industrial effluents is being discharged into Adyar and Cooum Rivers, Otteri Nullah, and Buckingham Canal, making them heavily polluted, which ultimately pollutes the sea (Bay of Bengal).

   However, some private entities such as private residential townships have installed their own centralized STPs for wastewater treatment. They reuse the treated wastewater for non-domestic purposes including flushing and landscape water requirements, thus preserving the region's natural waterways from being polluted.

Furthermore, wastewater from industries is treated in CETPs after which it is discharged into the waterways. A significant amount of untreated wastewater is directly discharged into the waterways especially Adyar and Cooum Rivers, making them heavily polluted.

Urban Floods

It is imperative to mention that increasing flood risk in this coastal region has been a matter of concern for quite some time. Rising sea levels and increased storm water runoff during heavy rains are some of the reasons that can be attributed for this rising menace.

The urban water cycle of Chennai Metropolitan Area is shown in Figure 16.

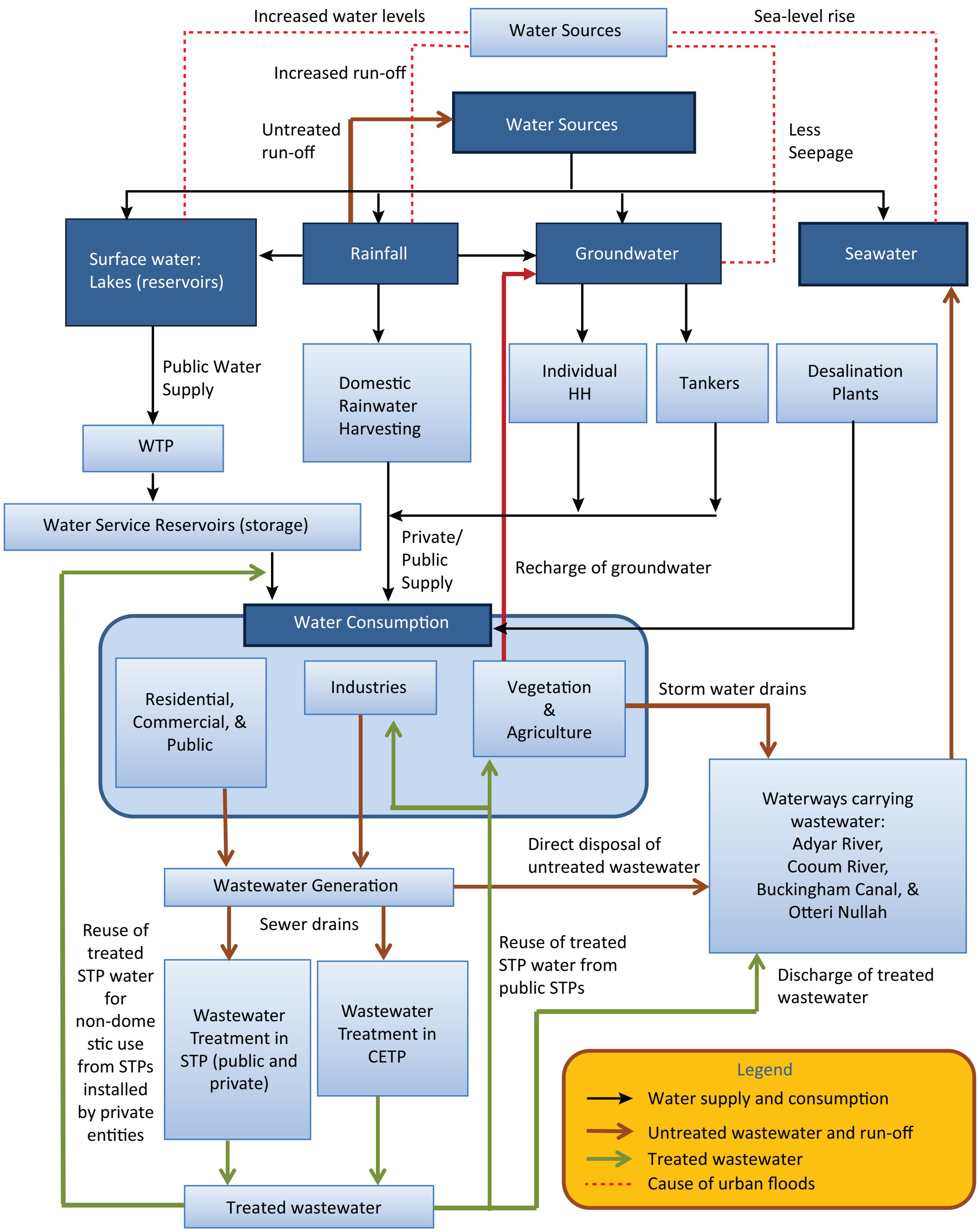

FIGURE 16: Urban water cycle of Chennai Metropolitan Area

5.2 Water Demand and Supply

The sustainability and quality of water in any city is closely linked to the quantity and quality of the basic infrastructure facilities that support it.

Water demand is generally classified as domestic water demand and non-domestic water demand. Domestic water demand covers the use of water for drinking, washing, bathing, flushing, etc. Non-domestic water demand includes the water demand for industries and other uses.

In this study, the researchers have considered only the domestic water demand (for residential, commercial, institutional, and other public spaces) for computation. Industrial and irrigation water demand were excluded due to non-availability of the data.

Table 19 shows the water demand and supply statistics for 2011 and 2019. Quantities were listed considering the water supply for 2011 and water demand for 2019. Some of the attributes for 2019, such as population and total water demand, were computed by the author by considering exponential growth in population due to non-availability of the data. Taking this as reference, water demand estimation for 2025 was computed.

Table 19: Water supply and demand in CMA for 2011, 2019, and projections for 2025

Parameters	2011	2019
CMA population	8,653,521[80]	10,372,643[81]
Per capita average water supply	96 lpcd[82]	96 lpcd[83]
Total water supply (extracted from surface water and desalination plants) (MLD)	831[84]	995[85]
Actual water demand of city (MLD)	1730[86]	2,074[87]
WTP installed capacity (MLD)	1294[88]	1294[89]
Wastewater generation	(80% of 1730) = 1384	(80% of 2074)= 1659
STP installed capacity (MLD)	558[90]	727[91]

[80] District Statistical Handbook Chennai District 2016-17, Department of Economics and Statistics, Government of Tamil Nadu

[81] Computed by the author by considering exponential growth in population

[82] Computed by the author by considering exponential growth in population

[83] Computed by the author by considering exponential growth in population

[84] Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

[85] Computed by the author by considering exponential growth in population

[86] Computed by taking 200 lpcd water demand from National Building Code (NBC) 2016, IS1172 (1993) Code of basic requirements for water supply, drainage and sanitation, for communities with more than 1 lakh population and full flushing systems

[87] Computed by taking 200 lpcd water demand from National Building Code (NBC) 2016, IS1172 (1993) Code of basic requirements for water supply, drainage and sanitation, for communities with more than 1 lakh population and full flushing systems

[88] Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

[89] Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

[90] Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

[91] Chennai Metro water website

Table 19: Water supply and demand in CMA for 2011, 2019, and projections for 2025

Parameters	2025
City population[92]	11,182,610
Total water demand (MLD)[93]	2236.5
Per capita average water demand (in lpcd)[94]	200
Groundwater extraction (MCM)	-
WTP installed capacity (MLD)[95]	1294
Required WTP installed capacity (MLD)	Increase to 2348.3 MLD[96]
Wastewater generation	(80% of 2236.5) = 1789.2
Required STP installed capacity (MLD)	Increase to 1878.6 MLD[97]

Scenario in 2011

1. In 2011, the average per capita water supply in CMA was 96 lpcd. The per capita water supply varied from 25 lpcd to 250 lpcd, which does not fit in the suggested standard of National Building Code of 150–200 lpcd.,[98,99] This shows that there has been inequitable distribution of water in the city. The suburbs got around 40 lpcd. The situation was worse in slums where supply was as low as 25 lpcd.

2. The total water supply to CMA was 831 MLD, which was very low as compared to the total water demand, which was 1730 MLD (considering average water demand of 200 lpcd).

3. The water treatment plants (WTPs) are inadequate for the population, considering the average water supply of 200 lpcd.

4. The quantity of wastewater generated in CMA was around 1384 MLD. Out of this, approximately 558 MLD was treated in the treatment plants. The remaining wastewater was being let into the streams thereby contaminating it. This reflected the scarcity of STPs in the city.

92 Computed by the author by considering exponential growth in population

93 Computed by taking 200 lpcd water demand from National Building Code (NBC) 2016, IS1172 (1993) Code of basic requirements for water supply, drainage and sanitation, for communities with more than 1 lakh population and full flushing systems

94 Computed by taking 200 lpcd water demand from National Building Code (NBC) 2016, IS1172 (1993) Code of basic requirements for water supply, drainage and sanitation, for communities with more than 1 lakh population and full flushing systems

95 Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011 Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

96 Computed by the author, required capacity is 5% (peak load) of total water demand in addition to water demand

97 Computed by the author, required capacity is 5% (peak load) of wastewater generation in addition to wastewater generation capacity

98 Details available at https://www.cag.org.in/blogs/chennai-water-secure, last accessed on September 21, 2021

99 Meeting the challenges in water and sanitation, the Chennai experience, CMWSSB 2011

Scenario in 2019

1. Due to significant increase in population, the total domestic water demand of the city surged to 2074 MLD from 1730 MLD in 2011.
2. The installed capacity of WTPs was 1294 MLD. This treatment capacity was inadequate for the population, having 2074 MLD of total domestic water demand.
3. The quantity of wastewater generated in CMA increased to 1659 MLD. The installed STP capacity also increased to 727 MLD. As this was insufficient, the remaining wastewater was let into the streams, thereby contaminating them.

Expected Scenario in 2025

1. CMA is going to experience a rapid rise in population by 2025 to stand at around 11,182,610. Thus, the water demand of the city would spiral to 2236.5 MLD.
2. The installed capacity of WTPs, that is, 1294 MLD (as of 2019), is inadequate for the population having total domestic water demand of 2236.5 MLD. The capacity would have to increase to 2348.3 MLD.
3. The quantity of wastewater generated in CMA is estimated to increase to 1789.2 MLD in 2025. The current STP infrastructure (727 MLD installed capacity) would fail to treat the wastewater to be generated, thus polluting the natural water ways. The installed capacity would have to increase to 1878.6 MLD.

5.3 Inferences

Surface Water

CMA has already started facing water shortages in the last few years, which would continue till 2025 due to rapid increase in population (estimated to reach 11 million). Improvements in the living standards and access to sanitation facilities have led to a corresponding increase in water demand. Along with this, the five main reservoirs – Poondi, Cholavaram, Red Hills, Chembarambakkam, and Veeranam, run dry during summer months. This has resulted in over exploitation of groundwater resources in the region. There has been large-scale withdrawal of groundwater by private water vendors during droughts as the levels of surface water sources reduce drastically. According to CMWSSB, 99% households in Chennai get piped water supply. However, the frequency of water supply reduces drastically in summer months, forcing people to purchase water from private tankers and packaged bottled water. Areas with no piped water supply receive water through Chennai Metro Water or private tankers. This clearly indicates that CMA will be water stressed in the coming years.

Groundwater

As no survey or assessment has been done on the groundwater table and extraction of complete Chennai metro area, partial data were used for its analysis in this study.

Water Storage, Transmission, and Distribution

There is an inequitable distribution of water in different areas of the region (50–250 lpcd, varies from suburbs to slums).[100] CMWSSB is unable to supply the required amount of water in the entire region due to lack of water infrastructure. As a result, slum areas and suburbs in CMA are completely dependent on tanker water supply. Also, there is an inadequate municipal water supply as compared to the water demand of CMA.

Frequent leaks and bursts in old water pipes have been reported across CMA (especially in Chennai district), resulting in unaccounted water loss. Also, there is no record of the available unaccounted water (non-revenue water). Therefore, water lost through leakages is completely unaccounted. The high levels of non-revenue water are detrimental to the financial viability of water utilities, as well to the quality of water itself.

Water Treatment Plants

The installed capacity of WTPs, that is, 1294 MLD (as of 2019), is found to be insufficient for the population having total domestic water demand of 2236.5 MLD in 2025. Hence, there is a need of enhancing the water treatment capacity.

Sewage Treatment Plants

As of 2019, the current number of STPs in Chennai and there capacities were found to be insufficient to treat the total sewage generated here. As a result, a significant amount of untreated sewage was directly discharged into the city's rivers and other waterbodies, making them heavily polluted. As the sewage generation is going to increase in coming years with the population, more partially/non-treated sewage will be discharged into them. This raises serious concerns about the degrading quality of the water sources used for human consumption.

[100] Details available at http://icrier.org/pdf/chennai_CMWSSB_Delhi_Feb2013.pdf, last accessed on September 21, 2021

6. Recommendations for Sustainable Water Management

To achieve sustainability in water management in cities, it becomes imperative to study and analyse all the aspects related to it. It should cover micro-scale green development measures such as rainwater harvesting, macro-scale water source management, water/wastewater/storm water infrastructure, and landscape preservation. This is known as integrated urban water management (IUWM), a water management approach that has become quite popular in the last decade. IUWM is based on designing solutions that are not isolated in nature but are interconnected water management clusters. This study followed this approach to recommend the most appropriate and practical measures to the identified potential risks, discussed in the previous chapter, for water management in CMA.

6.1 Upgradation in Urban Water Cycle

A suggestive upgradation model of the water cycle for the CMA is shown in Figure 17, where the lacunas of existing water management of the city was tried to be filled. This is based on the projections computed for 2025 in the last chapter.

1. Identification and filling up of data gaps

While finding the best solutions for poor water management in CMA, the study encountered various hindrances due to non-availability of data. Thus, research should be conducted to collect appropriate data to fill the missing gaps. For example, data on water meters coverage, water losses through leaks, groundwater extraction, etc., were missing. Furthermore, there is inadequate data on groundwater availability and extraction for the metropolitan area. Thus, challenges related to regulating groundwater use are being faced, resulting in groundwater exploitation.

2. Modifications in existing water infrastructure

» **Water Transmission and Distribution:**

1. Efficient leak detection and rectification works in the water supply pipelines (especially in the Chennai district) can help in controlling the water loss and also covering the newly added areas.

   Equitable distribution of water supply in all areas (including suburbs and the slums) of the metro with 24X7 pressurized water supply should be ensured.

   There should be an increase in decentralized water reservoirs to provide sufficient water to people to meet their daily water requirements.

» **Water Treatment Plants:**

There is a need of enhancing the treatment capacity of existing WTPs. The installed capacity of WTPs, that is, 1294 MLD (as of 2019) is insufficient for the population having 2236.5 MLD of total domestic water demand in 2025. The water treatment capacity needs to be enhanced to 2348.3 MLD.

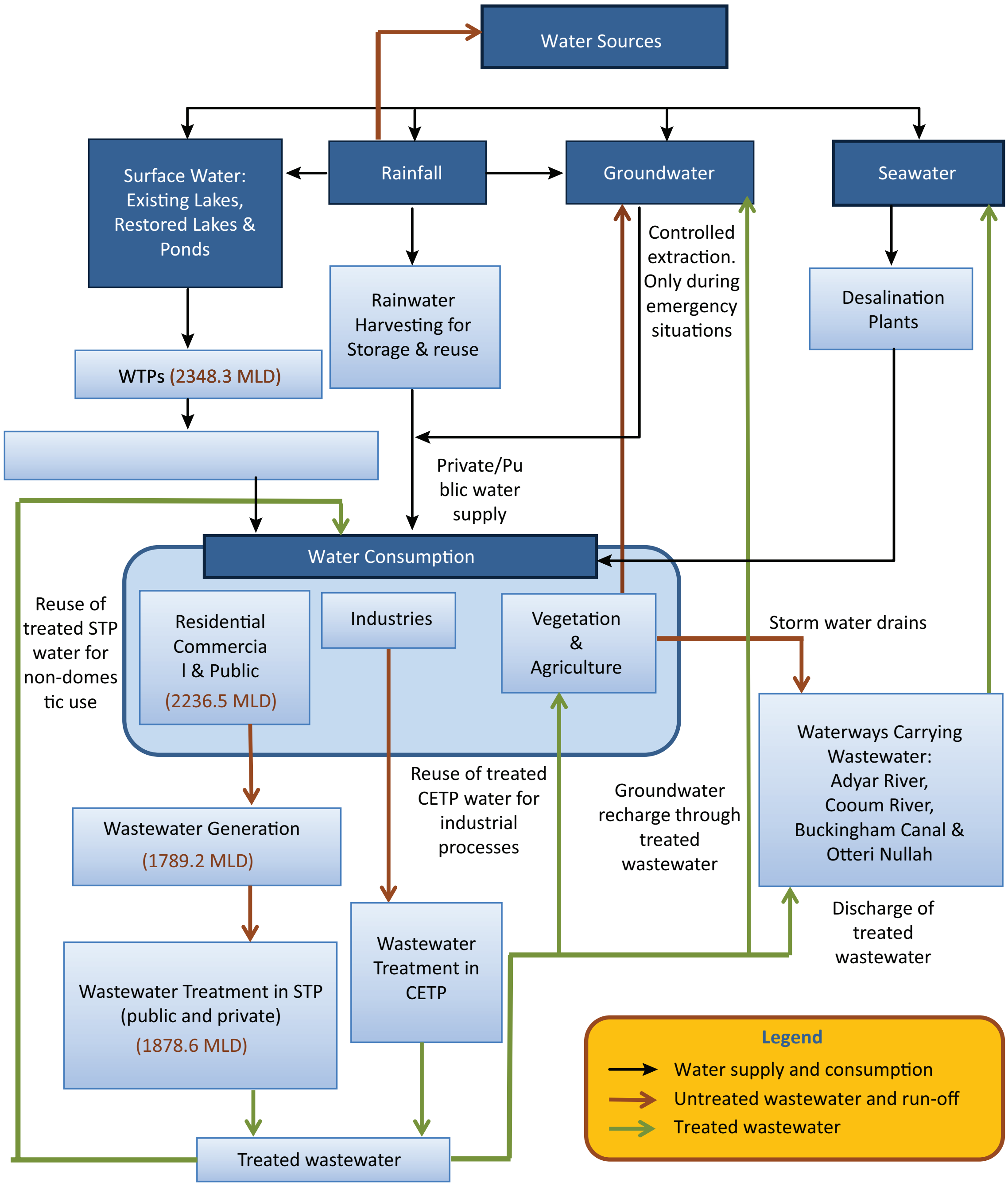

FIGURE 17: Upgraded urban water cycle of Chennai Metropolitan Area for 2025[101]

[101] Projected values in the upgraded water cycle have been computed and shown in Table 19

- **Sewage Treatment Plants:**

  The capacity of public STPs (~1878.6 MLD) should be increased to treat the entire sewage generation of the city in 2025. The quantity of wastewater generated is estimated to increase to 1789.2 MLD in 2025, which the current STP infrastructure (727 MLD installed capacity) would fail to treat.

  There should be a metro-wide sewerage network (including slums and the suburbs), covering each and every household which shall ensure complete collection of sewage.

  The use of biogas that is produced in sewage treatment plants for generating power to run the plants' operations can be made mandatory for all the existing as well as future STPs. This reduces energy cost and contributes to reduction in GHG emissions, providing for carbon trading.

- **Water Metering:**

  There should be 100% coverage of metered connection across CMA to ensure fair revenue collection and controlled water usage.

- **Water Quality of Waterways Carrying Wastewater:**

  Zero discharge of untreated wastewater from CMA into the waterbodies such as Adyar and Cooum Rivers should be ensured to protect them from polluting and maintain their natural goodness. Also, complete wastewater from CMA should be treated in STPs, ensuring there is no direct untreated wastewater discharge into the waterbodies.

3. Potential Water Sources for Use in Future

CMA has ample reliable water sources and is not a water-scarce region. However, the city gets limited water supply tapped from various lake reservoirs. The water scarcity faced by the city during certain periods of the year is due to poor management of its water sources. To meet the increasing water requirement, a significant amount of water is being transported from long distances (Veeranam Lake in Cuddalore district, 230 kms away from Chennai), fulfilling partial water requirements of the users. This incurs a huge financial cost and is also energy intensive as it requires a massive water supply and transport infrastructure. Therefore, the emphasis should be on the identification and assessment of potential water sources in nearby areas. There are potential alternative water sources, which if tapped would efficiently help in overcoming the water scarcity issue.

- **Seawater source:**

  Chennai has a geographical advantage of being a coastal city; thus, it could utilize the seawater after treatment from desalination plants to meet its increasing water demands.

- Restoration of the dying waterbodies (lakes and ponds) in CMA can help in adding potential freshwater source for the region. Over the years due to rapid urbanization, lakes in the region got degraded and currently are in a dire condition. There are eight large waterbodies in the city including Ramapuram Lake, Madipakkam village pond, Madipakkam Lake, Kolathur pond, Vannan Kuttai near Jaladiampettai, Pallikaranai, Puludivakkam Lake, and Pudhuchery Keni that are in a process of being restored. Also, there are 16 small waterbodies including Chitteri, Uthukulam, near Medavakkam, PTC quarters pond, Chinnakeni kulam near Karapakkam, Odaikeni kulam, Sappathi Kuttai, Karumanchavadi Kulam, Udayar Palayam

FIGURE 18: Nemmali seawater desalination plant located at the coast of Bay of Bengal in Chennai

Nagar (Kalaivanar Nagar Pond) and J J Nagar Lake.[102] A study should be conducted to check these waterbodies' revival potential and use them as drinking water sources.

Encroachment of agricultural/vacant land around lakes (waterbodies) should be stopped as these areas play a crucial role in providing water for irrigation purposes and recharge structures.

Artificial waterbodies/reservoirs could also be constructed to not only increase the freshwater availability but also enhance the groundwater table of the region.

FIGURE 19: Madipakkam Lake and restoration of Ramapuram Lake in Chennai[103, 104]

» **Groundwater sources:**

Controlled groundwater extraction should be ensured in the region and a check on its level and quality should be done by studying it at regular intervals. In fact, groundwater use should be completely restricted owing to its decreasing levels and should only be used during emergency times.

Monitoring and ensuring the strict implementation of the regulations under the Chennai Metropolitan Area Groundwater (Regulation) Act, 1987 should be done.

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102 Details available at https://www.deccanchronicle.com/nation/current-affairs/081117/tamil-nadu-24-lakes-identified-for-restoration.html, last accessed on September 2021

103 Details available at https://www.thenewsminute.com/article/success-story-how-ngo-and-local-residents-joined-hands-rejuvenate-madipakkam-lake-58489, last accessed on September 2021

104 Details available at https://www.newindianexpress.com/cities/chennai/2018/oct/29/chennai-restoration-work-begins-at-ramapuram-lake-1891198.html, last accessed on September 2021

» **Treated wastewater source:**

The treated water from STPs and CETPs can be a potential resource for saving the freshwater. Thus treated water from STP and CETP that is discharged into the rivers could be reused for non-domestic purposes in industries, commercial areas, etc. This shall also help in reviving the heavily polluted Adyar and Cooum Rivers, which could become a potential water source once they achieve the required water quality.

To carry out its successful implementation, installation of STPs and reuse of the treated sewage for flushing, gardening, construction, etc., in upcoming residential housing and commercial projects should be promoted. Dual plumbing lines should be planned to reuse treated sewage water for non-domestic applications.

To ensure 100% no direct untreated wastewater discharge into the waterbodies, capacities or the number of STPs and CETPs should be increased, if required.

Treated water from CETPs should be reused by industries in CMA.

» **Rainwater harvesting systems:**

Use of rainwater harvesting systems for storage and reuse should be promoted. This could be done by promoting the installation of localized rainwater storage systems at the individual level in new buildings for domestic purposes. This would help in reducing potable water supply and runoff, and shall contribute in the reduction of water-related infrastructure cost and water bills.

Chennai is one of a few cities in India that have successfully implemented the rainwater harvesting strategies as pushed by the Indian government in the last decade. RWH systems should be made mandatory in CMA. This shall not only help in recharging aquifers but also reduce tanker water demand as less number of wells will run dry during drought.

Localized tapping of rainwater by developing humanmade waterbodies should be carried out. Channelizing of storm water through drains before merging with river takes a lot of time; as a result the water gets evaporated or contaminated along the way. Instead, this water could be fully utilized by these local humanmade waterbodies to improve the groundwater recharge. Also, this reduces groundwater contamination due to natural percolation of rainwater.

Treated wastewater from STPs could be discharged into these local waterbodies to enhance the groundwater levels.

4. Implementation of flood resilience measures

Frequent floods in CMA during monsoons can be controlled by keeping a check on increased encroachments (concrete structures), which block the flow of rainwater runoff. Rules and regulations need to be strictly implemented to control the rapid expansion in CMA of residential areas and automobiles and IT industries. Such expansions lead to disappearance of rainwater catchment areas due to increased concretization of land. Furthermore, mitigation measures, including creating an ecological buffer zone, could help in limiting the damage caused by floods.

5. Capacity building and training

Capacity building and training of existing and new recruits of government staff, municipalities, boards, and other parastatal working in water supply and its management in the city should be done to strengthen work practices and thereby improving their overall performance.

6.2 Stakeholder Engagement for Sustainable Water Management

An effective implementation of the measures discussed in the last section to enhance water sustainability in Chennai requires a robust stakeholders' involvement. This is important as it ensures that the water management plans for the city takes into consideration the local requirements, interests, and experiences of all the stakeholders. It bridges the gap between experts, implementers, and policymakers. Also, to make a sustainable change w.r.t. water management, it is essential that all the stakeholders cooperate and collaborate with each other while carrying out their responsibilities towards water management efficiently. Table 20 consists of the ways by which the stakeholders' participation could be enhanced to ensure sustainable water management in the city.

TABLE 20: Stakeholders and their responsibilities to ensure sustainable water management

S. No.	Stakeholders	Roles and Responsibilities
International Level		
1.	International, regional and multilateral organizations	» Provide funds for city water management projects and conduct promotional programmes » Provide technical assistance and documentation » Create knowledge exchange platforms
National and State Level		
2.	National and state governments	» Develop policies and legal frameworks that enable and strengthen sustainable water management in cities
3.	Standardization bodies such as Bureau of Indian Standards, CPHEEO, etc.	» Develop new standards related to water consumption and management w.r.t changes in technology of the water infrastructure » Identify gaps and renew the standards

TABLE 20: Stakeholders and their responsibilities to ensure sustainable water management

S. No.	Stakeholders	Roles and Responsibilities
City Level		
4.	Urban local bodies, municipalities, city administration and state water regulatory authorities	» Promote and design a roadmap to follow sustainable water management initiatives and specific solutions for their implementation » Enhance citizen engagement and sensitize them with the benefits of sustainable water management practices » Strengthen monitoring and tracking of city services by defining key performance indicators (KPIs) and evaluating them
5.	City services companies	» Provide expertise to collaborate with municipalities and information and communication technology (ICT) companies to develop integrated collaborative models for smart water management » Develop smart and KPI-based city service models
6.	Utility providers	» Deploy sustainable water management practices such as smart water management
7.	ICT companies (start-ups and software companies)	» Provide the ICT infrastructure to support and integrate smart water management services » Provide technical solutions through research and innovation » Develop financially sustainable business models to enable smart water management implementation
8.	Urban planners	» Inclusion of water management plan in studies and city planning processes as a part of a broader approach » Give guidance to concerned stakeholders on city planning needs
9.	Non-government organizations	» Raise awareness regarding citizen concerns related to water availability » Increase public awareness on urban water issues
10.	Academia, research organizations and specialized bodies	» Conduct research and advice and assist city managers and policymakers on the measures to achieve sustainable urban water management in the city » Drive research and innovation in city's water management field

TABLE 20: Stakeholders and their responsibilities to ensure sustainable water management

S. No.	Stakeholders	Roles and Responsibilities
Building/Site Level		
11.	Citizens and citizen-related organizations like RWAs	» Participate actively in city's urban water management projects » RWAs and end users should take necessary documents from the facility manager, such as plumbing, WTP drawings, AMC, etc., during handing over the property » Practice water-saving measures at an individual level
12	Construction sector	Refer Section 6.2.1
13	Industries	» Adopt Integrated Water Management Framework (refer Section 6.2.2)

Disclaimer: This is an indicative list and not an exhaustive list.

6.2.1 Role of construction sector in ensuring sustainable water management

Scarcity of water has hampered all industries including the construction sector in South India in some way or the other. Water is needed in large quantities in the construction industry for various purposes. Reducing water consumption and improving water efficiency in buildings is a major step towards sustainable water management. Key opportunities to reduce water use on-site are as follows:

- Use of gunny bags, ponding technique, or curing compound.
- Use water-reducing admixture in concrete mix.
- Meter and monitor water consumption during construction. Tracking of water usage over time provides information of where it is being used and helps in identifying leaks or inefficiencies.
- Use of treated wastewater and/or captured storm water to offset main supplies or tankered water supplies. Abstracted water would incur lower cost and reduce the need to treat water that does not have to be of a potable standard.
- Using water-efficient taps and fixtures in temporary offices developed at construction sites, delivers quick savings with high returns on investment.
- Finalize a water-efficient plant and equipment when discussing options with suppliers/ subcontractors to ensure water efficiency in construction projects. Some key considerations are shown in Table 21.

TABLE 21: Water-efficient plant and equipment

S. No.	Plant	Saving	Considerations
1	Dust suppression (general)	~90%	» Avoid high capacity 'rain guns' and hoses » Choose misting/atomizing systems, which use less water and are more effective » Consider using non-potable water (ideally rainwater harvested on-site)
2	Dust suppression (vehicles)	~90%	» Avoid using high-pressure water jets diffused by a splash plate » Choose misting/atomizing systems, which use less water and are more effective
3	Road sweeping	~30%	» Avoid using an open hose » Ensure that operators are trained in water-efficient practices, vehicles have adjustable spray bars/nozzles, and any stand-alone washers are of high pressure (low flow) with trigger controls » Consider water recirculation systems
4	Wheel washing	~40%	» Avoid manual wheel washing (except when the need is very limited) » Choose drive-on recirculating systems with a sensor-controlled shut off (where demand is on-going)

6.2.2 Role of industries to ensure sustainable water management through integrated water management framework

Given the state of resource availability, use, and competing demand, the critical challenge lies in foresight of the issues and preparedness to respond to them for sustainable business operations. The management of water resources need a multifarious approach for not only improving the in-plant water-use efficiency, but also to look beyond the paradigm of *in situ* water management. This involves critical extrinsic factors such as source vulnerability, climate, allocation, access, competing use (irrigation, domestic, and industrial), regional water quality and availability, regional policies and regulations, socio-economic setup, and importantly, the stakeholders (government agencies, local community, etc.) including the industrial value chain. With growing demand, competing use, and scarcity scenarios in the region, there may not be enough water to meet societal, environmental, agricultural, or industrial needs. Besides, with the growing awareness, industries have a reputational stake if perceived as mismanaging their water resources or impacting on others directly or indirectly. Thus, there is a need of a holistic approach to manage water resources, necessitating formulation of an integrated water management framework, as a first step, with responsive corporate water policies and programmes to respond to the potential challenges related to water within and outside the plant boundaries.

The following generic framework was developed for industries and businesses across the board who want to better manage their water footprint and ensure efficient water management.[105]

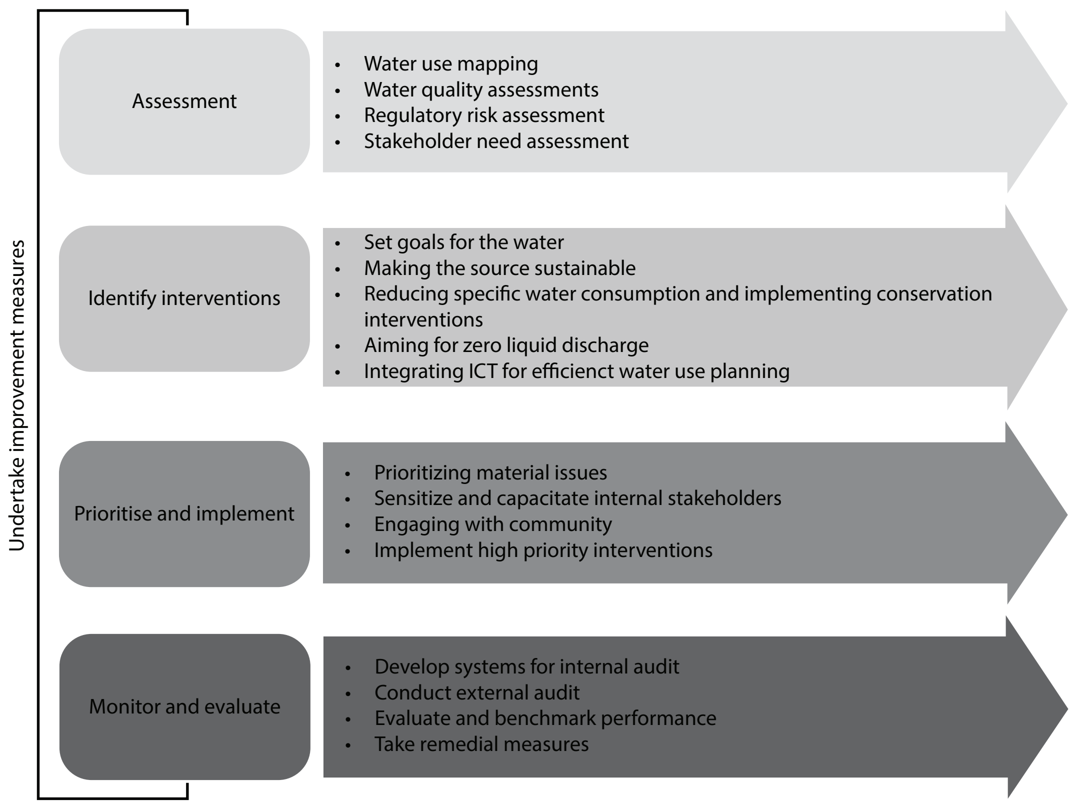

FIGURE 20: Approach for institutionalizing an integrated water management framework

1. Assessment

» **Water Use Mapping:**

To begin with, industries should map their water use, starting from the source to the end point, which is generally the discharge point. This should include all possible information related to the capacity, source, infrastructure type, age, leakage if any, and storage structures. Along with this, information related to water and effluent treatment plants of the industry, including the type of treatment options, capacity, O&M (Operations and Management) schedule, etc., should also be documented.

Identification of alternate sources of water for the industry and all the pertinent information related to the available sources of water should be done.

[105] Details available at http://cbs.teriin.org/pdf/researchreports/Integrated_water_management.pdf, last accessed on September 9, 2021

» **Water Quantity and Quality Assessment**

Industries should document the overall water consumption in the industry, based on the inflow and outflow from the industry. Similarly, water quality of the inflow and outflow should be assessed and documented by the industries.

For a detail assessment, specific water use in various processes or product manufacturing should be assessed to understand the water cycle of the industries. Based on this, a baseline for water consumption should be established for the year of assessment and recorded properly. This would help in assessing the future water needs of the industry.

The water availability should be considered at the watershed level. The surface and groundwater availability in the watershed should be assessed. Also, future water availability considering the climate change effects should be considered.

Besides, it is important to assess the water footprint of the industry. A water footprint is a way of assessing potential environmental impacts related to water. It also helps in identifying opportunities to reduce water-related potential impacts of products at various life-cycle stages, and with processes and organizations.

» **Regulatory Risk Assessments**

Industry should list down all the applicable regional regulatory and policy framework and programmes. Besides the applicable standards and norms specific to the industry, they should consider the applicable regional regulations, restrictions, notifications, as well as government policies and programmes cross-cutting various sectors such as water, land use, agriculture, urban/rural development, industrial development, sensitive zones, environment and ecosystem, etc. Also, the effectiveness of the policies on groundwater extraction, wastewater disposal, and capacity building should be assessed.

» **Stakeholder Need Assessment**

Industry should assess their relationship with the following important stakeholders to understand their water-related concerns:

Local communities: There are several areas of concern for a community when an industry is set up in their vicinity. Issues such as adequate availability of clean water for drinking, sanitation, and cooking are very important to be considered for the communities operating around the facility. Communities become non-cooperative if the industry operating in the region depletes or pollutes the groundwater table. Therefore, it is critical to gauge the needs of the local communities while engaging them for smooth operations of the organization.

Regulators: The regulators are also an important stakeholder, therefore it is quintessential for organizations to engage with regulatory bodies while staying abreast with the latest regulatory and compliance related developments for the industry.

Other competing industries: It is important to build a rapport with other competing industries operating in the same watershed and drawing water from the common source. The competition for water increases many-folds if all the industries are water-intensive units. Thus, there can be a decrease in the availability of water share. Also, due to the existence of industries in a region, the common source of water gets contaminated with untreated effluent from the industries. If the source of water is groundwater for all industries in a watershed then the situation becomes more serious, as it is a limited source, and as per the hydro-geological set-up of the area, its yield can be a limiting factor.

Therefore, it is important to know the water demand, use, and discharge practises of the competing users in a common watershed, and accordingly, adopt sustainable practices.

2. Identify interventions

» **Source Sustainability**

The most important aspect for a plant's operation is sustainability of the water source. The source should be able to provide good quality and quantity of water to sustain the plant's operation. Depending on the source type, a plant can take necessary actions to enhance its sustainability. Also, it is important to know if the source is shared with some other user or not. If the source is shared by many stakeholders, then it is a common responsibility of all to protect the source and to enhance its sustainability. In this, industries can take a lead.

Industries should ensure that the source of water for them is well-maintained and all the important aspects including its level, quality, etc., are recorded regularly. An alternate source of water for the industries should also be identified and characterized as a contingency measure. An important exercise in this regard is to conduct a Source Vulnerability Assessment (SVA).

SVA is a systematic examination process to assess a water system's sensitivity to potential threats (un-checked exploitation, pollution, etc.). The assessment helps in identifying the crucial challenges to the system in managing risks that arise as a consequence of such threats. Usually, an assessment of this sort takes into account the water balance of the system at the watershed scale (water supply/allocation and demands), policies and legal frameworks to support water resources conservation and management, and the hydrological variations due to changing climate and other environmental factors.

» **Reducing specific water consumption and implementing water conservation interventions**

Reduction of specific water consumption is very important to reduce the water footprint. This can be done by adopting various water conservation measures by following the priority order of potential options at the industry level. Eventually, this helps in reducing water stress at the watershed level as it reduces freshwater intake of industries. Specific water consumption level should be brought down using various techniques to a level that can be set as a benchmark for future reference of the industry.

Water audit is one of the key processes to be taken up by the industries to identify leaks, water flows, and then take necessary measures to reduce losses and increase efficiency. Regular water audits should be done by industries to ensure prevention and mitigation of leakages and unnecessary water loss. Apart from reducing water loss, it is important to focus on the aspects of water conservation. Below are some of the interventions that can enable in situ and ex situ water conservation.

a. *In situ* conservation

Rooftop rainwater harvesting: It is both an economical and eco-friendly technique of collecting rainwater and utilizing it for immediate and future use. Thus, it helps in reducing stress on public water supply and other sources. The implementation of this intervention involves site assessment, estimation of rainwater harvesting potential, designing a rainwater harvesting system, implementation, and operation and maintenance.

Wastewater recycling: This involves setting up of a system for recycling wastewater generated in the industry through appropriate treatment methods. This water can be reused for different purposes in the industry. Wastewater recycling can be planned in a centralized or decentralized manner depending on site conditions. Recycling provides an opportunity for zero discharge or even positive water balance for the plant. Wastewater should be recycled at source to reduce pollution load at the effluent treatment plant (ETP), ensure material recovery, and reduce treatment costs, besides reducing the overall water demand of the plant.

Reduction in leakages/losses and process optimization: Often a significant scope for potential water savings lies in optimization of water use in various processes such as cooling towers, boilers, etc. Besides, in many cases, leak detection coupled with metering and regular water audits helps in reducing leakages/losses in the network or process, thus, saving water and reducing freshwater intake.

b. *Ex situ* conservation

Watershed-level rainwater harvesting: This involves setting up of surface water harvesting interventions or watershed structures such as check dams, gabions, bunds, percolation tanks, storage ponds, etc. In addition to storing rainwater during monsoons, it helps in groundwater recharge.

Artificial recharge of groundwater: Water from surrounding streams and drains are collected through constructed streams, which further run through a human-made filtration system from where it flows into a shallow aquifer, thus, recharging the groundwater. There are several groundwater recharge technologies, such as shafts, that can be adopted.

» **Zero liquid discharge**

The effluent discharged from industries is equally or even more important factor than inflow to industries as it can be a challenge or an opportunity for water security. If discharged untreated, it can lead to pollution of water and land bodies, but if treated and reused it can decrease pressure on the existing water sources in a watershed. Therefore, it is important to ensure that a multiple-stage ETP is installed in the industrial facility for treating the industrial waste so that rivers/waterbodies remain contamination-free.

» **Efficient Water Use Planning**

For effective water use, it is important to integrate ICT tools in planning, which includes Management Information System, Decision Support System, etc. An ICT system can be used for controls and monitoring. They can be simply put to use for avoiding water wastage and providing regular information for better management of the resource, automation of systems, etc. In addition, ICT is the driving force behind innovation, as it is helpful in transforming business models and value chains. With the growing technological advancements, economically feasible options are available. All the industries should include ICT tools for management of water resources in their plant.

3. Prioritize and implement

» **Prioritizing Material Issues**

It is important for organizations to earmark and identify specific issues within the ambit of water management that are of higher relevance to them. After identification, organizations must be able to assign them priority levels according to their impact on the business. In this way, it becomes easier for organizations to identify higher priority tasks first, while being able to mitigate the risks associated with them.

» **Sensitize and Capacitate Internal Stakeholders**

Engagement and involvement of employees is critical for the successful implementation of effective water management and conservation interventions. Employees must be sensitized and trained for the implementation of the measures.

» **Engaging with community**

One of the foremost elements of efficient water management planning involves engaging communities and other stakeholders regularly. All the water-positive actions taken up by industries should be showcased to locals and the responsibility of ensuring water security at the watershed level should be shouldered with them. It is important to return back to nature what is taken from, thus, the efficient use of water by avoiding losses and conserving water through different methods not only benefit the plant, but also the surrounding watershed.

» **Implementing high-priority interventions**

Once all the aforementioned issues are addressed, the highest priority interventions should be with the internal stakeholders and the community at large.

4. Monitor and evaluate

After taking the necessary actions, it is important to monitor and evaluate the implemented actions regularly to learn from their benefits and weaknesses and to fix the issues, if any, on time. This helps in strengthening the system and understanding the overall benefits accrued by the industry.

It is suggested that industries can hold internal audits to evaluate the implemented plans twice a year as well as an external third-party assessment once a year. Evaluating and benchmarking the water performance on a regular basis is the key to a successful and integrated water management plan.

Remedial measures from the evaluation and monitoring must then be undertaken to sustain continual improvements in the system while the organization tries to optimize its water use and management performance.

6.3 Micro-level Assessment and its Importance in Assessment of City Water Sustainability

The report showcases the water statistics of the CMA region as published by the government and reliable public sources. However, the basis of arriving at these values is not clear. The reported values could be based on the assessment of water actually supplied by the public sector and the private sector or they might have been derived based on the water supply norms fixed by the government agencies for various socio-economic strata of the city. In either case, the values may not represent the 'real water demand' of the city. An assessment based on actual water supplied does not account for the water lost through leakage or wasted otherwise. Furthermore, these losses become a part of the presumed water requirement, which is not the 'real demand' of the city. Similarly, an assessment based on water supply norms does not account for the drivers of water demand including social, economic, demographic, and geographical factors.

During this study, a primary survey was carried out in selective residential townships in CMA to assess water demand and water-use patterns. A rapid water assessment study was conducted in two residential townships of Mahindra World City (MWC), Chennai to examine the water consumption pattern in the domestic sector in the region. The study revealed that water demand is influenced by a number of intersecting cultural, climatic, demographic, infrastructural, social, and physiological factors. Greater penetration and use of modern appliances in urban households influence water consumption.

6.3.1 Findings of Micro-level Assessment for Chennai Metropolitan Area

A variety of approaches were used for collecting and analysing different types of data. These approaches were drawn from the methods and techniques used in quantitative and qualitative research. Questionnaires and interviews were used for obtaining data on the following aspects: socio-economic and demographic attributes of respondents, sources of water, behaviour related to water use, water consumption pattern, and water conservation practices.

One common observation found in the audited townships of Chennai (Nova and Iris Court) was the high potential to reduce the freshwater demand (water source: Groundwater from well fields in MWC) by using measures such as rainwater harvesting systems and reusing treated STP water.

Treated wastewater use

Nova and Iris Court townships use treated STP water for non-domestic purposes (landscaping and flushing), which can potentially reduce the total freshwater demand by 23% and 17.8%, respectively. [106, 107]

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106 Study conducted on Rapid Water Audit of Nova Township, MWC, Chennai, TERI 2019

107 Study conducted on Report on Rapid Water Audit of Iris Court Township, MWC, Chennai, TERI 2019

According to the water sustainability study of CMA, the region has a huge potential to reduce its freshwater demand by reusing treated STP/CETP water. Simultaneously, it can reduce pollution in its rivers by restricting direct discharge of untreated wastewater. Furthermore, there are two important inferences from both the micro (township level) and macro (CMA level) studies. First, 100% reduction in the wastewater discharge from the townships into the local waterbodies and its treatment for reuse in various non-domestic purposes (flushing, irrigation, backwash) is required. Second, installation of water meters to record the use of treated STP water in non-domestic applications and outflow of wastewater generated from the site could enhance the efficient use of treated STP water.

Rainwater harvesting systems

As rainwater harvesting is one of the most important techniques for water conservation and reuse, this aspect was studied in the audited townships as well. It was found that the townships had underground water tanks to store and reuse rainwater for landscape and at times for flushing (mixed with treated STP water) purposes. However, as the water needs in non-domestic applications are met by treated STP water in the townships, the rainwater could be used for groundwater recharge through recharge pits.

According to the water sustainability study of CMA, rainwater has a potential to become an alternative water supply source to the region with the help of rainwater harvesting systems. It can be used for enhancing groundwater levels by tapping and directing it to the human-made/natural waterbodies. Therefore, two important inferences from both micro (township level) and macro (CMA level) studies can be made – first, the installation of rainwater harvesting techniques at the private level for storage and reuse and for improving the groundwater level and quality should be promoted. Second, meters should be installed to record rainwater use, thus enhancing its efficiency. As CMA experiences acute water shortage in summer months, rainwater harvesting techniques can be very fruitful in overcoming the problem.

6.5 Effective Implementation of Recommendations

Many recommendations suggested in Sections 6.1 and 6.2 to achieve sustainable water management against the identified potential risks in Chapter 5 can be seen as an extension to already existing proposed measures by the concerned authorities. However, their implementation was found to be missing on ground. In fact, despite having an extensive National Water Policy in place and existence of various state- and centre-level institutions, water resource development and management has not been very satisfactory in the region. Thus, a few questions arise such as whether the policy recommendations and institutions till now really been effective in providing safe and sufficient water to all for all types of purposes, be it domestic, industrial, and irrigation? Has it been instrumental in improving water management, protecting natural water resources, and maintaining the water quality?

To answer these pertinent questions, a list of areas that need immediate interventions to strengthen the implementation of these suggested recommendations are given in Table 22.

TABLE 22: Suggested interventions to strengthen the implementation of the recommendations

S. No.	Identified Issue	Required Intervention
1	**Governance and institutional challenges** The water resources management and formulations of projects and plans are fragmented, uncoordinated, and follow a top–down approach, which results in weak implementation. This is primarily due to two main reasons, which are as follows: First, the presence of multiplicity of institutions sharing the responsibility leads to non-accountability in performance. Second, in the top–down approach, the decision-makers are not well-versed with the local settings and micro-level ground realities, which often results in poor decision-making	**Development of an Integrated Water Resource Management (IWRM) along with bottom–up approach** IWRM is a process that promotes the coordinated development and management of water, land, and other related resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of the vital ecosystems and the environment. It is a cross-sectoral policy approach, designed to replace the traditional, fragmented sectoral approach towards water resource management. As the local nature and needs of water-related services, resources, and management vary, it is ideal that the task of managing them is handed over to institutions in a decentralized manner. A bottom–up approach for an institutional framework with the active involvement of local stakeholders is essential for effective planning and execution of any programme aimed at water management in the region.

TABLE 22: Suggested interventions to strengthen the implementation of the recommendations

S. No.	Identified Issue	Required Intervention
2	**Lack of high-level political commitment** Most attempts at building political commitment are targeted at national governments because the budgets, laws, policies, and regulations that can sustain a water management programme in the long run often flow from governments. However, even if it appears that the political commitment established by the national government is sufficient to sustain a programme, the commitment may still evaporate with elections and a new leadership or simply because of shifting priorities and policy concerns.	**Decentralization of water governance structure** First, there should be a sustained political will and a strong commitment for the implementation of the designed water-related plans and policies, which can translate into prioritization through different layers of government and effective course correction. However, due to change in the leadership, the commitment may change. Therefore, it becomes important to decentralize and delegate the decision-making powers to local levels of governance, which largely would remain unaffected by the election results. The political devolution is also required because it is unlikely that political commitment can be effectively built or sustained by focusing on any single type of stakeholder. Rather, there is a need to consider all the actors involved in the policy space, for example, urban local bodies, urban planners, utility providers, industries, citizens, nongovernmental organizations, etc., who are needed to support the programme and its transition.

TABLE 22: Suggested interventions to strengthen the implementation of the recommendations

S. No.	Identified Issue	Required Intervention
3	**Inefficiency in creating water-related databases** Databases of the quantity and quality of water and the consumption patterns of various sectoral users are necessary to take effective decisions. One of the biggest challenges in the water management sector in India is the lack of adequate scientific data needed for water budgeting, allocation planning, and water management decision-making. Adequate information flows are not available because the bodies administering the water resources seldom have the financial and technical capacity necessary for undertaking the exercise of collection and analysis of a large amount of data. This is because the process of urbanization is dynamic and cities are spiralling and becoming more complex. Hence, any capacity enhancement is prone to quick depletion. Processes, technologies, and innovations take their toll on knowledge and skills based on older models.	There are two possible processes by which the databases can be strengthened, which are as follows: First, there is a constant need to update and convert capacity building into an on-going process for the water-administering bodies. It is time to reimagine capacity building by creating a municipal capacity building management system for all stakeholders, including municipal employees, councillors, and citizens. This system could be involved in conducting a training-need analysis, creating quality training materials, and arranging for field training. The system could assess the need for lateral hiring of professionals and engaging private institutions, research agencies, and corporates for capacity enhancement. Also, to conduct training, an urban local body needs funds. The system could create blocks that would work towards collaboration with national and international funding agencies and tapping into CSR. The other alternative can be to engage external stakeholders, including NGOs, research institutes, private entities, etc., who have expertise in water-related areas and can play an important role in populating data and its management, research and analysis, and infuse new ideas.

Conversely, India's effort in initiating adoption of water-related technologies and innovation in the country especially on the digital water management is noteworthy. This creation of innovation and implementation cycles is expected to reduce gaps between research and practice in various fields. India is a rising economic power and an increasingly important locus of innovation. Spurred by competition unleashed by liberalization of once stifling regulations, India's private sector firms are fast improving the quality of their products and services and rapidly expanding their global presence. Efforts are on to use digital technologies, drones, radar and satellite technologies, artificial intelligence solutions, and many more, which shall play a critical role in water resources and their management in the country.

Indeed, there is a long list of technological trends and advances that are likely to benefit rapid and effective adaptation of the water sector, as follows:

» Cybernetics, artificial intelligence, and instantaneous information technology (smarter internet)

» Nanotechnology

» Cost-effective energy technology (solar, space-based energy, algae as fuel)

» Biotechnology (genetic engineering) to help feed the populace and save endangered species

» Space-based environmental monitoring systems and instantaneous feedback to predictive models even to remote areas

» Geoengineering to reverse global warming (e.g., giant reflectors in orbit; greening deserts; iron fertilization of the sea; aerosols in the stratosphere)

» Effective and reliable prediction of most weather and climate events

» Renewable energy replacing fossil fuels entirely – low-carbon societies

» Desalinization (in conjunction with cheap fusion energy) becoming cost-effective and providing water for most large coastal urban areas and megacities

» Vastly improved sanitation and wastewater treatment technologies and recycling

» Biotech approaches to pest control for improved agricultural yields

» Ecological engineering to preserve habitats, reverse species extinctions, and combat invasive species

» Mapping groundwater resources and sustainable extraction levels

Computer based optimization and simulation models incorporated with interactive graphics, audio based decision support systems will continue to help us in identifying plans, designs, and policies that maximize the desired impacts and minimize the undesired ones as well as making clearer the trade offs between the two.

Science, technology, and innovation strategies are the integral parts of sustainable development strategies. Many innovations in sustainable water management are high risk and with uncertain returns. Government financing and policies for innovation, supported by public–private partnerships, can be designed and implemented to reduce risks and promote research and development and diffusion and transfer of technologies.

The Mahindra-TERI Centre of Excellence (MTCoE) is a joint research initiative of Mahindra Lifespaces (MLDL) and The Energy and Resources Institute (TERI). It focuses on developing science-based solutions for India's future built environment, with a view to reduce the energy footprint of the real estate industry.

The overall scope of the project includes standardization and measurement of building material, thermal and visual comfort study, development of performance standard matrices, guidelines and numerical toolkits and water related activity for sustainable water use in habitats.

The activities related to the sustainable use of water in habitats, includes both macro and micro level analysis in terms of water efficiency, conservation and management within a premise by end users in Indian cities. The study identifies potential risks associated with water sources, governance, infrastructure and demand & supply and provide recommendations to combat those risks.

MTCoE is located at TERI Gram, Gual Pahari, Gurugram, Faridabad, Haryana.

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