CHENNAI: STATE OF WATER

A PLATFORM FOR INTEGRATED WATER GOVERNANCE IN METROPOLITAN CHENNAI: DEVELOPING FUTURE SCENARIOS AND STRATEGIES THROUGH PARTICIPATORY SIMULATIONS

AUTHORS

Auralice Graft, Dr. Ashwin Mahalingam, A. Ramachandran, Akshaya Ayyangar, O. Hemasree, Devashish Mankar, Naveen Sai U and Dr. Parama Roy.

With guidance from Dr. Balaji Narasimhan and Dr. Indumathi Nambi

FUNDERS

TATA TRUSTS

Chola

IITMAANA
IIT Madras Alumni Association of North America

TECHNICAL PARTNERS

OKAPI

FIELDS of VIEW

ABOUT THE ORGANIZATIONS

Funders

Tamil Nadu State Land Use Research Board

TN SLURB was established as a permanent body by the State Planning Commission in 2011. TN SLURB evolves formal interactions with various stakeholders and arrives at various policy options besides enabling the State Planning Commission to host seminars/ workshops and to commission studies on sustainable land water resource management. The objectives of TN SLURB range from assessing land resources and assigning priorities for land-use changes to building databases and utilizing such databases for improved integration.

Cholamandalam Finance

Cholamandalam Finance has been carrying out CSR through AMM Charities Trust (renamed AMM Foundation). Over the decades, the foundation has been extensively engaged in public health and education initiatives in the communities of its operational presence. The foundation now manages four schools, a polytechnic college and four hospitals. They further support initiatives in eco-conservation and environmental protection through afforestation, soil conservation and promoting rain water harvesting. The organization's continued investments in clean practices and processes that often go beyond statutory requirements reflect its commitment to the environment.

Tata Trusts

The Tata Trusts are among India's oldest philanthropic organizations. The trusts own two-thirds of the stock holding of Tata Sons, the apex company of the Tata group of companies. The wealth that accrues from this asset has enabled the trusts to play a pioneering role in transforming traditional ideas of charity and introducing the concept of philanthropy to make a real difference to communities. Through grant-making, direct implementation and co-partnership strategies, Tata Trusts support and drive innovation in the areas of natural resources management; education; healthcare and nutrition; rural livelihoods; enhancing civil society and governance; media, arts, crafts and culture; and diversified employment. The trusts engage with competent individuals and government bodies, international agencies and like-minded private-sector organizations to nurture a self-sustaining ecosystem that collectively works across all these areas.

IITMAANA
IIT Madras Alumni Association of North America

IIT MAANA

IIT Madras Alumni Association of North America (IITMAANA) is the parent organization of all IITM alumni in the USA, Canada and Mexico. IITMAANA engages in charitable activities to promote both education and social entrepreneurship, including the promotion of social and educational objectives of the Alumni, students, and faculty of IIT Madras. They provide financial and technical collaboration and support for cutting-edge applied & industrial research for the global marketplace. In addition, they facilitate the alumni's efforts in taking up activities that are geared to improve society at large and contribute to national development.

Technical Partners

Okapi Research & Advisory

Okapi is an IIT Madras-incubated research and consulting group focused on strategies for addressing the institutional voids that handicap collaboration and innovation in delivering sustainable development. It works with government, corporate, philanthropic and community-based clients, primarily but not exclusively in India, to help them reach environmental and human development goals. Its current work focuses largely on infrastructure and service governance, in sectors ranging from energy to urban infrastructure and at scales from social enterprise development to national policy. It also has a growing portfolio of projects focused on developing scenarios as a tool for anticipating, preparing for and influencing the future; including adoption of new technologies and science-based approaches across sectors.

Fields of View

Fields of View is a Bangalore-based non-profit organization that uses simulations and games as visual representations to engage specific groups or diverse stakeholders on a wide range of issues from framing and defining vague but pressing policies to solving "wicked problems". Tools such as Agent-Based Models enable policymakers to explore multidimensional implications of their decisions prior to implementation. The visualization process broadly functions as a means to deepen participation in social, economic and environmental problems that require solutions through involving multiple actors including the general public. The interdisciplinary team works with academia, civil society and the government around complex public policy problems ranging from urban poverty to waste management.

The Indian Institute of Technology, Madras/Centre for Urbanization, Buildings and Environment (CUBE)

CUBE, a centre of excellence being raised as a society in IITM, is an applied research centre founded to address the practical challenges being faced by urban built environment through development and deployment of innovative technology and policy-based solutions in partnership with academia, government and theprivate sector. Its mission is to innovate and translate academic research into actionable solutions. Its primary focus is on housing and construction, smart cities, urban planning, transportation and environmental sustainability

EXECUTIVE SUMMARY

This is a report about water in Chennai. It aggregates and analyzes existing research around the current state of water in the Chennai Metropolitan Area, and also presents select primary research findings. Its overall purpose is to describe current conditions, trends and vulnerabilities, aiming to articulate risk and certainty variability while filling a critical gap in the information available to policymakers and other stakeholders seeking to promote effective outcomes, in particular as they shape resilience. This is the second of five policy-oriented reports that make up the Context Development stage in a project titled “A Platform for Integrated Water Governance in Metropolitan Chennai: Developing Future Scenarios and Strategies through Participatory Simulations.”

Our report is organized primarily around a city water assessment framework, examining water source and availability; water supply, demand and balance; drainage and sanitation; water-sector investments and vulnerabilities, risks and threats. Key findings from the section on water source and availability are that an estimated 1000 million litres are currently available to Chennai every day, and they are consumed by residences, businesses, institutions and industry. This water is sourced essentially from rainfall, which falls in varying intensity over the course of each year, and across years. Variation in rainfall can be extreme and is a major consideration in Chennai water-sector planning. Rainfall replenishes river flow and other surface sources, as well as groundwater tables. Chennai water is also sourced from desalination plants, which treat seawater and – to an almost negligible extent – from treated waste water. Regarding groundwater, our analysis of these levels against rainfall patterns over almost eight years indicates considerable variation – both temporal and spatial – in recharge rates, indicating a potentially high risk situation in some areas of Chennai.

Our study of water supply, demand and balance in Chennai provides important learning points while also shining a light on key information gaps. For example, demand is clearly projected to rise as the city’s economy, population and boundaries expand. It is also clear that supply will most likely be impacted by the range of climate and urban threats facing the city area. Missing, however, are exact amounts of water supplied. This is because supply is on the whole not metered; it is measured instead in terms of amounts of water released, which at present is estimated at 1000 million litres per day (MLD). Similarly, no definitive number appears to exist for water demand. Estimates range between 1050 and 2248 MLD. Because these numbers are unknown, whether (and the extent to which) there is balance in the water sector is also unclear and this has significant implications for policymaking and strategy development. Regardless, information that does exist seems to not always inform development planning. For example, we analyzed the links between projected demand for water and the number of environmental permissions granted, and found that on-the-ground water needs are not necessarily considered when clearance for new projects is granted.

Further, we find that Chennai is investing heavily in its water sector. There is broad recognition that city area water balance, if it exists at all, is precarious. Steps and measures to improve and protect whatever balance exists are being planned and implemented by a range of entities including Metrowater, Chennai's water utility, other water-related government departments, the non-profit sector, civic associations, the private sector and, in some cases, partnerships between these different groups. Investments are varied in scale, ranging from multi-crore desalination plants and sewage treatment plants, to tiny-budget efforts, including smartphone applications and social media flood-mapping tools.

It is unclear, however, whether these investments will be adequate in the face of a multitude of climate and urban risks. It appears likely that achieving sustainability in Chennai's water sector will be difficult. To begin with, there is wide disagreement among stakeholders about how to achieve sustainability. Some argue it is best secured by means of increased desalination capacity, while others see this as an overly expensive option that will also produce severe environmental outcomes. Chennai should return instead, it is argued, to traditional water-capturing systems that are managed at the local level. Along the same lines, some government officials express certainty that flood risk can be reduced to close to zero by completing ongoing storm water drain repairs, while others we spoke with dismissed such repairs as practically inconsequential. Many, including officials we spoke with at Metrowater, see wastewater reuse as a highly promising means to achieving sustainability, and dismiss currently ongoing plans to improve on this as inadequate. Others are emphatic about a "mental block" among Chennai-ites against wastewater reuse.

Our study also suggests that current investments do not appear to adequately consider climate and/or urban risks. For example, our analysis indicates that ongoing waterbody restoration efforts could better integrate with the overall water ecosystem. In some cases, these efforts, while well-intentioned, often involve clearing debris from a lake or pond while failing to target the channels leading into that waterbody, and failing to recognize the extent to which those channels are often themselves receptacles of solid or sewage waste. The result is that such restoration efforts are likely to quickly become undone by new refuse flowing into the waterbody. In short, such plans would do well to factor in clearly obvious risk areas.

Also, we found a need for improved coordination across multiple water-sector plans and organizations. For instance, a number of master plans outline intentions to improve Chennai's water-sector. A close reading of these, however, highlights a failure in many cases to recognize other ongoing efforts, and an urgent need to coordinate between these efforts. In general, insufficient coordination appears to define water-sector governance in Chennai, as emphasized by several officials we met.

At a broad level, our research, including a modelling exercise that analyzes built-up area and surface flows in the Adyar basin, leads us to conclude that continued business as usual in Chennai's water sector will likely mean plummeting groundwater levels and increasing run-off, among a range of other dangerous outcomes. These in turn could well result in a multitude of social, economic and environmental problems for the city area. Such concerns, however, are certainly offset to some degree by the number of highly qualified and well intentioned stakeholders investing in this sector with an aim to improving and sustaining water balance.

TABLE OF CONTENTS

ABBREVIATIONS

ADB	Asian Development Bank
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
CGWB	Central Ground Water Board
CMA	Chennai Metropolitan Area
CMCDM	Chennai Mega City Development Mission
CMDA	Chennai Metropolitan Development Authority
CNRM	Centre National de Recherches Météorologiques
CPHEEO	Central Public Health and Environmental Engineering Organization
CRRT	Chennai Rivers Restoration Trust
EC	Environmental Clearance
EFI	Environmentalist Foundation of India
EIA	Environmental Impact Assessment
GCC	Greater Chennai Corporation
GDP	Gross Domestic Product
GIS	Geographic Information System
GoTN	Government of Tamil Nadu
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modelling System
IAMWARM	Irrigated Agriculture Modernization and Water-bodies Restoration and Management
IMD	India Meteorological Department
IS	Indian Standard
ISTP	Information System Technology Planning
ISWD	Integrated Storm Water Drain
IT/ITES	Information Technology/Information Technology Enabled Services
JICA	Japan International Cooperation Agency
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KL	Kilolitre
Kms	Kilometres
L	Litres
LPCD	Litres per Capita per Day

MAWS	Municipal Administration and Water Supply
Mcft	Million cubic feet
MIDS	Madras Institute of Development Studies
MLD	Million Litres per Day
mm	Millimetres
MoEF	Ministry of Environment and Forests
NGO	Non-Governmental Organization
O&M	Operations and Maintenance
OECF	Overseas Economic Cooperation Fund
OMR	Old Mahabalipuram Road
PWD	Public Works Department
RWH	Rainwater Harvesting
SEIAA	State Environmental Impact Assessment Author-ity
STP	State Industries Promotion Corporation of Tamil Nadu
SWSM	Sewage Treatment Plant
Tmcft	Sustainable Water Security Mission
TN	Thousand million cubic feet
TNSAPCC	Tamil Nadu Tamil Nadu State Action Plan for Climate Change
TNSCB	Tamil Nadu Slum Clearance Board
TN SLURB	Tamil Nadu State Land Use Research Board
TNUIFSL	Tamil Nadu Urban Infrastructure Financial Services Limited
TUFIDCO	Tamil Nadu Urban Finance and Infrastructure Development Corporation
TWIC	Tamil Nadu Water Investment Company
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UPE	Urban Political Ecology

LIST OF FIGURES

LIST OF TABLES

FOREWORD

Chennai, the fourth largest city in India, on the one hand aspires to sustain its growth and development and, on the other is increasingly facing environmental limitations in multiple forms (water scarcity, floods, droughts, sea-level rise and loss of greenery, wetlands and other natural resources/habitats). Okapi Research & Advisory, the Center for Urbanization, Buildings & Environment (CUBE) at IIT Madras and Fields of View, funded by Tamil Nadu State Land Use Research Board, Cholamandalam Investment and Finance Company Limited, IIT Madras Alumni Association of North America (IITMAANA) and Tata Trusts, have initiated a project titled, "A Platform for Integrated Water Governance in Metropolitan Chennai: Developing Future Scenarios and Strategies through Participatory Simulations". This project is an attempt to develop a process of **planning and decision-making** that can help integrate concerns and actions around urban growth and environmental management, particularly with respect to water-related vulnerabilities, so that Chennai may develop as a sustainable and resilient city.

This process of *integrated planning and decision-making* encompasses a three-step methodology:

I. **Context Development:** This involves using primary and secondary research to gather background information on current trends of the city's development, its state of water and emerging tensions, particularly with respect to institutional and governance-related challenges.

II. **Scenario and Tool Development:** This involves agent-based model development to present multiple scenarios based on varied decisions and actions undertaken by different public, private and civic agencies.

III. **Strategy Development:** Finally, scenarios and games will be used to enable multiple actors to design strategies that can help address current challenges characterizing the city's development and its intersection with water-related risks.

The specific outcomes of this work will include:

1. **Five policy-oriented reports**

a. *Chennai: Urban Visions* – A report on the city's socio-economic drivers, their visions and the overall trajectory of development.

b. *Chennai: State of Water* – A report on the current state of water and associated risks.

c. *Chennai: Emerging Tensions in Land, Water and Waste Governance* – A report on institutional and decision-making challenges related to how land, water and waste is dealt with in the context of rapid urban development and need for greater water resilience.

d. *Building an Integrated Governance Platform* – Drawing on grounded experience, a report on challenges and good practices around data collection, workshop facilitation and project design to facilitate replication of similar scenario-based integrated governance platforms.

e. *Shaping Public, Private, Community Actions for Transformative Change* – A comprehensive, grounded, tactical strategic blueprint to guide, public, private and civil society actions to transform the system.

2. **An agent-based model** to help assess implications of specific land, water and waste-related decisions on the Chennai Metropolitan Area (CMA)'s water vulnerability scenario.

The reports and the agent-based model will offer the essential integrated/interdisciplinary knowledge and practical tool and guidance for planners and policy makers to make informed decisions for a more sustainable water resilient Chennai. The first phase of work has synthesized existing data and collected some primary data to set the stage for stakeholder engagement and deliberation in the following two steps of the integrated planning process, namely, the scenario and strategy development phases. This work is presented in the first three reports: 1. Chennai: Urban Visions; 2: Chennai: State of Water; and 3: Chennai: Emerging Tensions in Land, Water and Waste Governance. The overarching thought that binds the three reports is grounded in Urban Political Ecological (UPE) scholarship rooted in the work of David Harvey (2000; 1996; 1989; 1973) and Neil Smith (1996; 1984; 1980 with Keefe).

Since our core purpose in this project is to develop a process of integrated and participatory planning that can make Chennai more resilient towards water-related risks, a common question is whether such integrated planning falls within the scope of urban planning or environmental planning? We often think of urban/human issues and environmental/natural issues as distinct, and hence tend to differentiate urban planning and governance from environmental planning and governance. However, UPE scholars contend that our cities and the state of their resources including land, water, vegetation, air, etc., are a result of the complex interaction between existing environmental conditions and human processes. For instance, flooding in Chennai in 2015 was not simply a natural disaster. Rather, as one activist described, "it was in the making since 1990s". Land-use change due to fast urbanization and economic development lead by human decisions and actions across CMA, interacted with the hydrological and climatological dynamics, leading to the city to come to a stand-still in December that year.

The UPE approach can be summarized in terms of its three core tenets. Each of these tenets provides a theoretical and analytical basis for examining our cities and its environment.

Tenet 1: Understanding city and its environment as a manifestation of the dialectic interaction of social and environmental processes

Counter-intuitive to the traditional and popular expectation of finding nature outside the city's boundaries (Keil, 2003) and necessarily contentious understanding of "pristine nature" vs. "destructive humanity" (Braun, 2002), the UPE approach focuses on the dialectic/two-way and symbiotic relation between nature and society (Swyngedouw, 1996; Swyengedouw and Kaika 2000; Cronon, 1991; Keil and Graham, 1998). It enables us to think of the urban environment as a product of interaction between human elements of planning decisions, policies, infrastructure funding, investment and ownership practices, public engagement, local politics, etc. and nature (Kaika 2005; Swyngedouw and Heynen, 2003; Braun and Castree, 1998). As such, in our effort to present an understanding of the current state of waterbodies in Chennai, we pay attention not only to the physical/environmental aspects of rainfall, local topography and drainage patterns, but also engage with social aspects of urbanization and planning and policies around water and waste management to highlight the complex two-way society-nature interaction (see the State of Water report). This dialectic interaction is evident, for instance, in the extent to which rapid encroachment on waterbodies impacts the quality and quantity of water while this state of water itself poses threats to future development of the region in absence of sustainable solutions.

Tenet 2: Excavating socio-political power play in production of city environment

UPE recognizes the existence of the deeply uneven power relations through which the contemporary city environment is produced (Heynen et al., 2006). Harvey explains that urbanization is a process of contestation for achieving control over society's scarce resources.

In this struggle, it is usually those with relatively more socio-economic power who win, letting the marginalized fall further back in the struggle. This explains the continued inequality in distribution of resources like drinking water, which are scarce to start with in a city like Chennai (Janakarajan, 2013; Srinivasan et al., 2010). However, this power play is not only driven by economic power but also by social, political and institutional power, which plays an equally important role in determining who benefits from and who is threatened by the state of the socio-natural condition of a city. As such, uncovering these intricate power relations remains an extremely important part of our three reports as we attempt to explain the process of peripheralization of the water problem in Chennai (in the State of Water report), the limited incorporation of citizens' inputs, especially those of marginalized ones, in urban planning and policy-making (in the Urban Visions report) and the interaction between various government agencies with differential power and jurisdiction, divided responsibilities across sectors and geographies and blurred accountability shaping urban-water governance ecosystem in Chennai (in the Emerging Tensions report).

Tenet 3: Understanding the present through a historical-geographic perspective

The UPE framework highlights that a proper understanding of the present state and plans to modify the future towards sustainability requires a historical geographic perspective. In other words, to understand the present and predict and/or modify the future, we need to look at the past trajectory. Similarly, for a complete picture, it is essential to pay attention to social and ecological processes interactively shaping our cities at various geographic scales/spaces. As such, in our analysis of the present state of urban development, water resources and governance we have time and again highlighted how past events have shaped or have been transformed by current trends. In the Urban Visions report, for instance, we describe the historical trajectory of development of Chennai as the fourth largest city in India, underlying political-economic shifts and implications for the city's environment. Similarly, in examining the role and relation of agencies involved in governing Chennai, we have paid particular attention to how these agencies work at various scales and with what implications, specifically in the Emerging Tensions report. As such, each of the three reports in the Context Development phase of our work emphasizes on different aspects of the human-environment interaction process that ultimately shape Chennai and its waterscapes (See Figure 1).

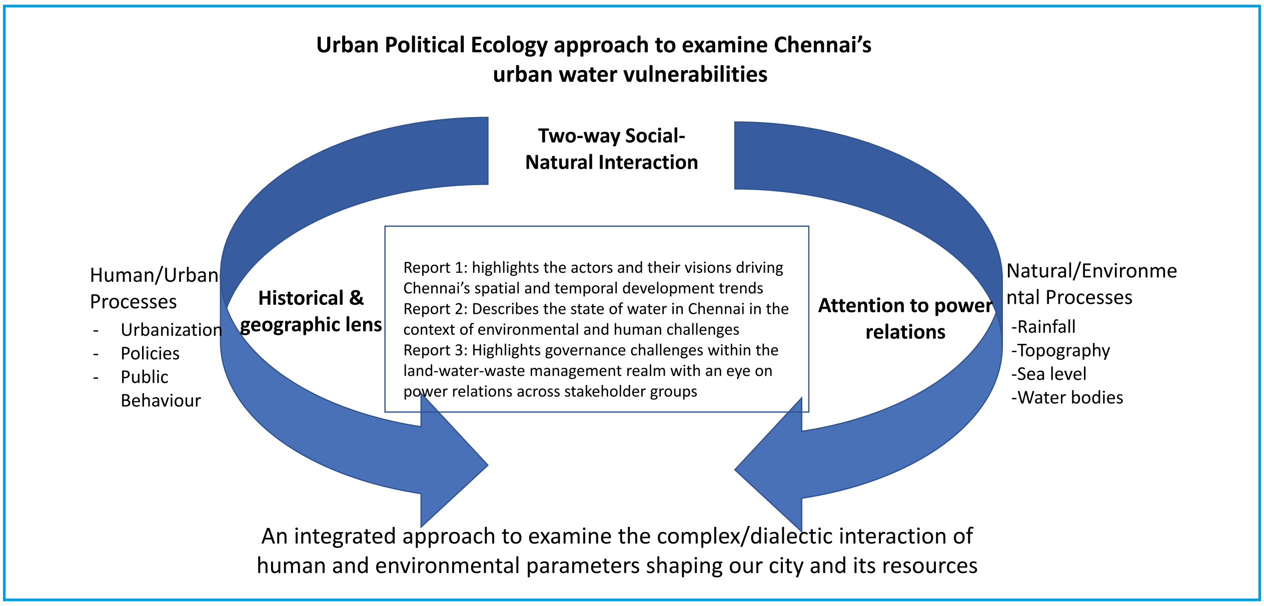

Figure 1: Urban Political Ecology approach

The following report, Chennai: State of Water is the second of three reports that together make up the context development component of the Chennai Scenarios project. This Chennai: State of Water report provides a detailed snapshot of the current state of water in the Chennai Metropolitan Area. The report aggregates and analyses existing research and information, and also presents select primary research. Overall, trends and knowledge around Chennai water are highlighted, with a focus on environmental elements as well as the human and environmental factors that influence the state of Chennai's water – including rapid urban land transformation and ineffective waste management on the human side, and climate change and sea-level rise on the environmental side.

Counter-intuitive to the traditional and popular expectation of finding nature outside the city's boundaries and necessarily contentious understanding of "pristine nature" vs. "destructive humanity" the UPE approach focuses on the dialectic/two-way and symbiotic relation between nature and society.

CHAPTER 1: INTRODUCTION

CHAPTER 1 : INTRODUCTION

Increasingly, water dominates news from cities around the world. Stories about acute water shortage in Sao Paolo, Brazil, and Melbourne, Australia, are upstaged by an imminent “Day Zero” in Cape Town, South Africa: the day on which municipal water supply in this drought-stricken city may be shut off entirely. Flood inundation and extreme rainfall events are also regular news features, as are stories about an increasing awareness around water as a critical resource; about efforts – many of them successful – to innovate water management systems or revive traditional ones.

Water dominates news from the city of Chennai, India, as well. The widely covered December 2015 floods were a prime example. Today, Chennai news produces a steady stream of water-related coverage – from analyses of flooding causes and projections about future events, to impending water shortages. One recent article suggested that Chennai’s water situation may be even more dire than Cape Town’s. Stories highlight water-sector problems, while others are more hopeful, outlining plans to develop new technologies, infrastructure investments or programmes to reclaim and rejuvenate waterbodies.

These stories from Chennai tell a broader tale of the metropolitan area’s inherently difficult relationship with water. No perennial source flows through the region and, as a result, the city relies almost entirely on monsoon rains for its water supply. Added to this, most supply falls during the northeast monsoon, meaning there’s only about a month each year when Chennai receives most of its water supply – making the collection and storage of that water key to year-round availability. At the same time, demand for water in Chennai is ever increasing: as the city expands, a multiplying population and growing economy are thirsty for larger and larger amounts of it. To complicate all of this, Chennai’s topography and location on the coast mean it is particularly vulnerable to flooding and water-related shocks. Other risks include water quality and groundwater levels.

Chennai’s difficult relationship with water may be growing more complicated. There are signs that the area water catchment may not be behaving as it used to. Monsoons in 2017 distributed almost 30 percent more rainfall than average (India Meteorological Department [IMD], 2017) but late in the year, a time when reservoirs are typically full, they were at 4915 million cubic feet (mcft), less than half their full capacity of 11,257 mcft (lake levels on 1 December 2017, Metrowater website). There could be a simple explanation for this. Rainfall may have just fallen nearer to the coast, missing reservoir areas. Or it could indicate that something is amiss with the catchment area.

This report explores possibilities such as these, while painting an overall picture of the current condition and trends in Chennai water, along with sector risks, threats and vulnerabilities. It also illustrates the need for more integrated actions across multiple sectors for Chennai's sustainable future: while much information is available on Chennai's water situation– from scientific and unscientific research to master plans, and policy and media reports – few in-depth analyses of that information exist. There is also a shortage of definitive roadmaps for how to achieve sustainability. Risk and certainty variability are rarely articulated in a clear fashion, meaning there's a critical gap in the information available to policymakers and other stakeholders as they choose instruments to promote effective outcomes shaping resilience. This report aims to help fill that gap.

Background: Chennai Urbanization and Growth

Key to understanding Chennai's state of water is to know the rapid urbanization that has characterized the city's growth in recent decades. This expansion has innumerable effects on all aspects of Chennai's water sector. Chennai urbanization is discussed in detail in our accompanying Chennai: Urban Visions report. For this report,we provide a brief summary. Chennai growth is reflected in its increasing size: city area jurisdiction expanded from 174 sq. kms in 2011 to 426 sq. kms, with notified plans to further expand into a proposed mega region covering 8878 sq. kms. It is also reflected in the growing numbers of people living there: the population of the CMA almost doubled between 1981 and 2011, expanding from 4.6 million to 8.7 million (Census, 2011). Some of this population growth is explained by increasing rural-urban migration in Tamil Nadu, a state that the 2011 census described as India's third most urbanized – with most urbanization occurring in Chennai (Sivakumar, B., 2011).

This rural-urban migration is driven in part by Tamil Nadu's higher-than-national-average education levels: 80.9 percent of the state population was literate in 2011, increasing from 73.45 percent in 2001 (Government of India Census Data, 2016), and Tamil Nadu was ranked number one among Indian states with almost 100 percent Gross Enrolment Ratio in primary and higher primary education (Ragu Raman, A, 2018). These education levels enable more people to make the transition away from agricultural employment. Simultaneously, Chennai's better education facilities lead to increased migration (Kolappan, B., 2015).

Economic terms also describe Chennai growth: the city area economy is currently India's fourth largest, with a GDP per capita growth that was the highest in India in 2000-2014 (Raghavan,S., T.C.A., 2015). The World Bank ranked Chennai ninth among Asia-Pacific super rich cities, its tally having increased from 390 to 130 over 15 years (India Today, 2016). Major drivers of this growth are Chennai's manufacturing sector and its "new economy" – or IT and ITES (IT Enabled Services) – industries. The manufacturing sector is made up of large industries, including petrochemical and chemical, as well as electrical and automobile-related industries, which give Chennai the moniker the "Detroit of India", or automobile capital of India – for the significant role it plays in automobile and automobile-part construction and export. Chennai's "new economy" industry makes it a preferred destination for many of the world's major IT companies; the city houses all top-ten IT Indian multinational companies (Chennai Development Plan, 2006), and it has been at the forefront of India's proactive attitude to the IT sector, introducing one of the country's first state-level IT policies in 1997. Outside the formal sector, an estimated 70 percent of employment takes place, driving the city's supply of goods, and livelihoods (Kennedy, L. et al., 2014). Major economic gateways into Chennai city are its two ports and an international airport.

This growth and economic activity requires development and built-up space–for homes, offices, IT parks, factories, godowns and hospitals. It also requires infrastructure to make things function. All of this underlies many of the issues raised in this report: pressures on water supply, for example; or increasing water demand, leading to water balance stress (explained in Chapter 3). It also explains some of the human factors influencing Chennai's water sector, including land-use changes, waterbody encroachment and growing amounts of mismanaged solid waste (discussed in Chapter 6). In sum, Chennai's growth and urbanization represent a key backdrop to this report on Chennai's state of water.

Framework and Methodology

This Chennai: State of Water report is a compilation and analysis of secondary information around Chennai water that is complemented with select primary research (Figure 2). The report is based on a city water assessment framework that maps the following issues:

Water source and availability – where does water come from, how and in what amounts?

Water supply, demand and balance – how, how much and to what extent do they equate?

Water drainage and sanitation – the systems and estimated quantities; includes waste water and solid waste

Solutions – what is being done to protect and enhance the water sector?

Water-sector vulnerabilities, risks and threats – what are the factors likely to influence the water sector in the future?

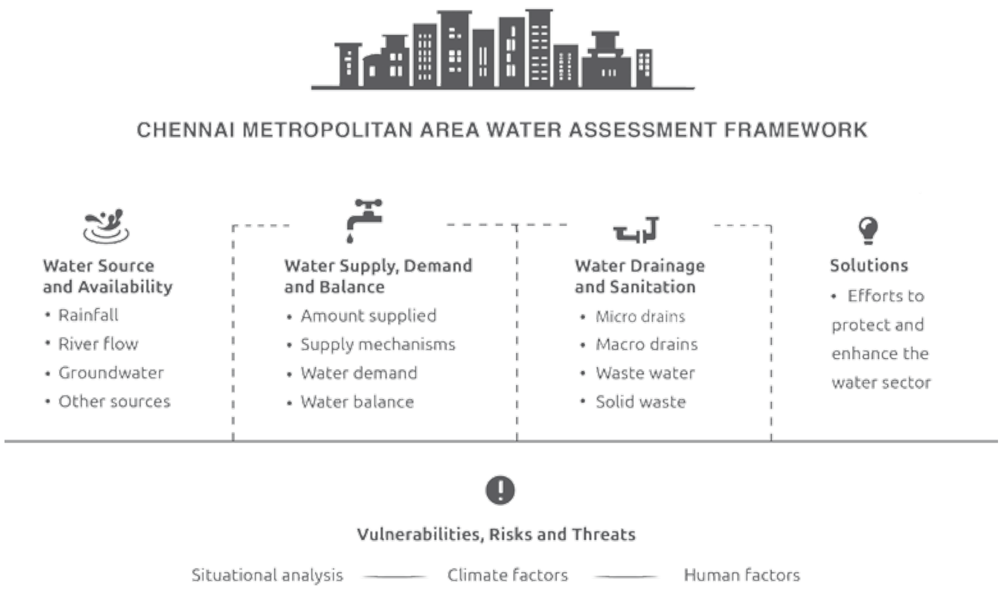

Figure 2: CMA water assessment framework

Adapted from Boggaram, Vittal & Bagath, Raj, 2017

These issues are mapped mainly using secondary research, of which a great dealis available. A range of research exercises, plans and documents exist on this topic. Overall, the quality of this literature is high. Many experts in the field also provided valuable insights and opinions. However, what this report aims to achieve is largely missing in the existing documentation, which is: a) a streamlining of that existing information with a view to providing a better understanding of Chennai's water management network and process, and b) analysis of this existing data. This report aims to provide that streamlined documentation while also beginning to fill the gap in analysis by analysing five research questions. The methodologies used for both our secondary and primary work are described here:

Secondary Research

The Chennai: State of Water report is divided into seven chapters. The first and last chapters serve as an introduction and conclusion. Chapter 2 discusses water source and availability in Chennai, including water storage structures and how they evolved over time. This includes a compilation of data on rainfall patterns; river flow; desalination; extent of grey-water recycling; groundwater levels and extraction from wells including private wells; reservoir and tank storage capacity; and inter- and intra-state allocations.

Chapter 3 presents water supply, water demand and water balance in Chennai. Questions we seek to answer are: “How does water reach consumers and in what amounts?” “What is the consumer demand for water?” “What are factors influencing demand?” And, “How do supply and demand equate?” “What are the gaps?” The first subsection describes the nature of institutional water supply and its dynamics. The second subsection presents different approaches to qualifying and quantifying water demand in Chennai, as well as the current and future projected figures available in secondary literature and quoted to us by officials and experts. Finally, the third subsection discusses water balance or water-sector sustainability.

Chapter 4 provides an account of Chennai’s drainage and sanitation systems to highlight where excess and waste water goes, as well as how solid waste is managed and the effects this has on the water sector. Micro and macro drainage networks are described, followed by the sewage system and the management of solid waste.

Chapter 5 details the investments being carried out in the water sector, grouped according to the entity making them. Entities include investments made by Chennai Metrowater, the Greater Chennai Corporation, the Public Works Department, multi-government groups such as the Chennai Rivers Restoration Trust and the Sustainable Water Security Mission, citizens and private-public partnerships. Also mentioned are several ongoing schemes to conserve water at the district level.

Chapter 6 highlights the vulnerabilities, risks and threats facing Chennai’s water sector, including situational vulnerability, climate risks and urban risks. Situational vulnerability focuses on Chennai’s geographic location, including its coastal geography and its topography – all of which mean inherent risks. Climate risks include predicted changes in rainfall, groundwater levels, sea levels and storm severity. Urban risks, on the other hand, are outlined in terms of land-use changes, waterbody encroachment, flooding and drought, water supply infrastructure, saline intrusion and water pollution.

The conclusion or "way forward" chapter summarizes the report's findings and presents five recommendations.

The key data sources for the secondary research are academic literature, policy documents, maps, organizational websites and reports. These are supplemented by in-depth interviews with key stakeholders such as government officials from relevant water and planning departments, department engineers, academics and civil-society experts.

Primary analysis

Five specific issues emerged from the process of compiling and analysing the secondary data and stakeholder interviews. These issues range from understanding the rationale for large lake restoration projects, or projection of water demand, to how urbanization is modelled vis-à-vis surface water flow. They were selected because they are likely to play an important role in the future state of water and, in a way, present emerging tensions related to water. Each issue/modelling exercise and methodology followed is outlined here:

Issue 1: How stable have groundwater recharge rates been over time?

We analysed the links between Chennai groundwater levels and rainfall patterns to understand the temporal and spatial change in recharge rates with the aim of answering questions such as: "Are recharge rates increasing/decreasing or are they constant over time and across different locations?" Theory suggests a particular area should have an approximately constant rate of recharge given a certain average groundwater level and a certain intensity of rainfall. We sought to understand if this is indeed the case for Chennai: whether selected areas have constant to increasing rates of recharge or if the opposite is true; that is, recharge rates have declined over time, and why that may be so.

Data collection and analysis: We gathered data on monthly groundwater levels from around 18 existing groundwater wells across the city. This data was collected from an in-house lab at the Environment and Water Resources Engineering department that has been studying groundwater levels in the city for many years. The well water levels were measured in relation to the ground level, i.e., the depth of the water level relative to the present surface level in each study location. Therefore, groundwater levels close to the surface indicate an active recharge and healthy groundwater levels in that location. The monthly recharge levels were compared to monthly rainfall data from January 2006 to December 2014. Rainfall data was gathered from a combination of sources including the IMD and local weather stations (KEA Weather Station). Based on this data, we were able to analyse the groundwater levels during specific months of the year – particularly the summer and monsoon months.

This analysis is presented in Chapter 2: Water Source and Availability to highlight the sectionon groundwater.

Issue 2: Does new water demand match Metrowater supply projections?

We matched the environmental clearances granted by the State Environmental Impact Assessment Authority(SEIAA) with water (and wastewater) requirements and demand projections made by Metrowater for a randomly selected sample year. This enabled us to determine if the agency in charge of water provision for the city (Chennai Metrowater) is prepared to meet future demand for water.

Data collection and analysis: Data was obtained on current and future water supply and demand, and the process of future projections through interviews with key persons at Chennai Metrowater. Data on environmental clearances granted and water requirements for each project was gathered from the SEIAA website. The information from Chennai Metrowater consisted of water projections for every five years starting in 2015 and going up to 2020. From this data, we picked the time period 2015–2020, and 2016 was picked as a random sample year. Care was taken to ensure that the right numbers were compared. Chennai Metrowater's projections are made for both existing and new projects. Therefore, yearly incremental increase in water demand was compared to water requirements of new projects that obtained Environmental Impact Assessment (EIA) clearance for 2016.

This analysis is presented in Chapter 3: Water Supply, Demand and Balance to complement the secondary research presented around water demand.

Issue 3: How do waterbody restoration efforts integrate with the water ecosystem?

We sought to understand the process and rationale behind the selection of waterbodies for restoration in a state government-funded project in the CMA. The Tamil Nadu state government, by means of the Chennai Rivers Restoration Trust (CRRT) and Tamil Nadu Urban Infrastructure Financial Services Ltd (TNUIFSL), plans to restore 42 waterbodies and 13 waterways (including the Adyar, Cooum and Kosathalaiyur rivers) in the CMA.

Data collection and analysis: The primary data source is project documents; these cover all project stages and include the initial inception report and the final master plan. The documents provided a thorough understanding of the project and enabled us to review the extent to which a scientific methodology was used when selecting the waterbodies.

This analysis is presented in the Chapter 5: Investments in the Water Sector as it complements some of the ongoing efforts to restore waterbodies.

Issue 4: Do EIA processes safeguard waterbodies against development?

We explored the framework of EIAs to study its potential impacts on waterbodies in the CMA. We asked questions such as: “What types of clearances have been granted?” and “Were they close to waterbodies, drains or ecologically sensitive areas?”

Data collection and analysis: Our primary data source was Tamil Nadu SEIAA’s frequently updated website, which provides a list of projects that were granted clearance as well as details about each project, including type, location and date of clearance (see Figure 3). From this list, geographic coordinates of projects for a sample year – 2016 – were extracted and overlaid on a map with waterbodies to determine proximity to the latter.

This analysis is presented in Chapter 6: Water-Sector Vulnerabilities, Risks and Threats to highlight some of the factors that complicate the encroachment of waterbodies and, specifically, the issue of enforcing rules against it.

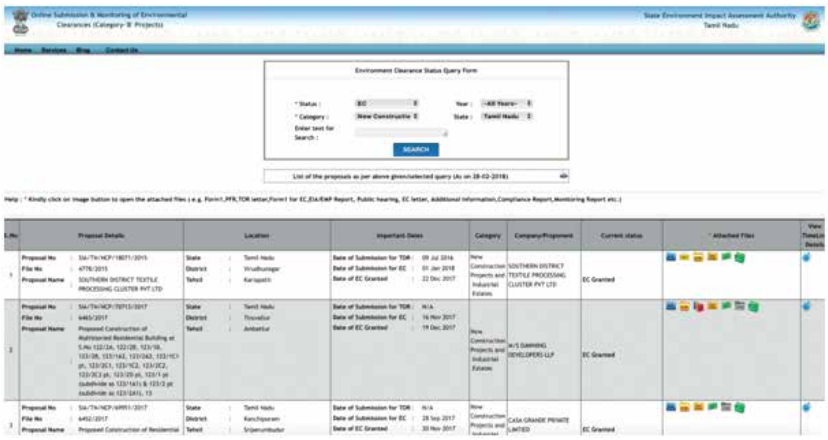

Figure 3: List of projects granted EIA clearance in Tamil Nadu
Source: State Environmental Assessment Authority, Tamil Nadu

Issue 5: Simulation impacts of urbanization on Adyar basin flow patterns

The impacts of urbanization on flow patterns in the Adyar basin for a period leading up to 2030 is studied. The Adyar basin comprises a network of interconnected natural and man-made waterbodies, including Chembarambakkam tank (one of the largest reservoirs), that supply water to Chennai city. The goal here was to analyse how surface water flow patterns will change as built-up area changes over time. As the city grows, surrounding areas have witnessed increased rates of urbanization, particularly in recent years. This has meant an increase in built-up area and, consequently, the impervious surface area. An expanded impervious surface area means increased prevention of water percolation into the ground, thereby increasing surface run-off and changing flow patterns in the event of rain.

Data collection and analysis: The above issue was studied using a combination of publicly available data and data gathered from interviews. Data on precipitation levels was gathered from the Centre National de Recherches Météorologiques (CNRM). CNRM produces atmospheric models including weather prediction models, hydrological and surface models at a global scale. This was complemented by publicly available data and interviews with government departments on land-use and land-cover change, inflow and outflow of tanks, and other relevant parameters. The hydrological modelling system 'HEC-HMS' was used to model results. Figure 4 provides an illustration of the model for the study area.

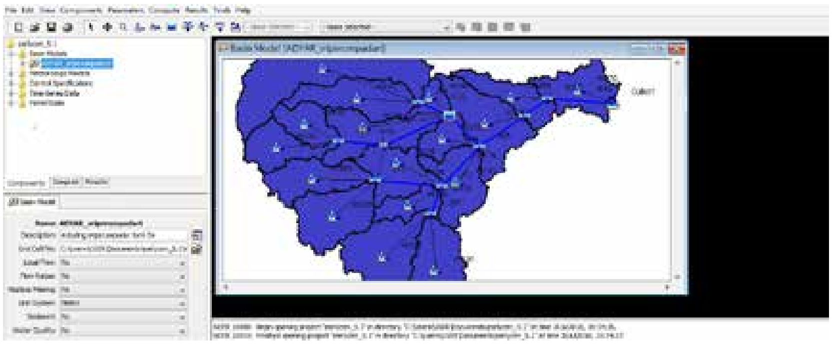

Figure 4: Interface of HEC-HMS model

The "HEC-HMS" model is designed to simulate hydrological processes in a watershed. It was designed by the Hydrologic Engineering Center of the US Army Corps of Engineers (USACE, 2010). Researchers feed in data on various parameters about the watershed, such as impervious surface, initial storage, lag time, time frame, precipitation, based on which simulations are run.

Results are in the form of peak discharge, date and time of peak discharge, base flow volume, direct run-off volume in each sub-basin. Using this software, researchers can analyse water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillwaydesign, flood damage reduction, and so on (Metrowater, accessed 28 Feb. 2018). The results of this simulation exercise are presented in Chapter 6: Water-Sector Vulnerabilities, Risks and Threats to underscore the extent to which urbanization impacts the water sector.

CHAPTER 2: WATER SOURCE AND AVAILABILITY

CHAPTER 2 : WATER SOURCE AND AVAILABILITY

Chennai, the capital city of Tamil Nadu state and one of India's major urban hubs, consumes large amounts of water every day. Where does this water come from and in what quantities? How is it captured? What are the mechanisms used to store the water, what is their total capacity and do they typically reach that capacity? Is any of this projected to change? This chapter answers these questions, highlighting the sources of Chennai water, including surface and groundwater, the systems that contain it, how they evolved over time and the amounts they produce, are capable of producing and are likely to produce in the future. Also presented are the results of an analysis exercise we conducted around the stability of groundwater recharge rates over time. Finally, we look at total water availability for Chennai, including future projections, both in terms of surface and groundwater, indicating potential stress points going forward.

Water Source

This section describes where Chennai's water comes from, the structures that capture and divert it and how they evolved over time. Water is sourced primarily from rainfall, and subsequently from river flow, groundwater and other mechanisms. The structures that capture and channel water to the Chennai city area are reservoirs, lakes and tanks, well fields and private wells, inter- and intra-state allocations, desalination plants and sewage treatment plants (STPs). Also, current levels, capacity levels and projected levels are presented. These projections show potential vulnerability areas in terms of future availability.

Rainfall

Chennai relies heavily on rainfall for its water supply. No perennial source flows through the region. Rainfall replenishes river flow, reservoirs, tanks and ponds, and also recharges aquifers. It is the primary source of all other sources. Most rainfall is received during the northeast monsoon, which falls during the winter months, a lesser amount during the summer southwest monsoon, and a still smaller amount during other rain spells throughout the year. The amount received during each spell varies from year to year. It can be as much as 63 percent during the north-east monsoon, with 32 percent during the south-west, and 5 percent during other spells (IMD, India) or as low as 47 percent received during the north-east monsoon, with 35 percent during the south-west monsoon and the remaining 18 percent during other summer or winter rain spells

(Tamil Nadu State Action Plan for Climate Change). Regardless of the exact amounts, the general pattern is the result of Chennai's (and most of Tamil Nadu's) positioning in the shadow of the Western Ghat mountain range (Figure 5).

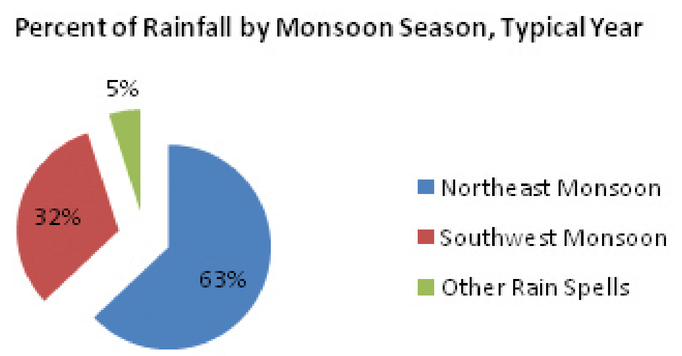

Figure 5: Percentage of rainfall by monsoon season
Source: India Meteorological Department

The actual amount of rain Chennai receives fluctuates year to year, sometimes to a large extent. Please see Figure 6 for a compilation of the amounts received between 1985 and 2016. This annual amount is as low as 624 mm and as high as 2570 mm. On average, Chennai receives approximately 1300 mm per year. This is actually high compared to the annual state-wide average of 940 mm, and is only slightly lower than the annual national average of 1360 mm.The extent to which rainfall quantities fluctuate also stands out in Figure 6. The gap between highest and lowest rainfall received in Chennai can be as large as 1946 mm, whereas it is 778 mm for Tamil Nadu and 523 mm for India (IMD, 2016 and Open Government Data Platform of India).

These patterns are significant in terms of Chennai water management and water-sector sustainability. They mean that a large part of annual water supply is received during a very brief period of time. The northeast monsoon can be as short as 37 days (Y.E.A. Raj, 2003). This means that water management systems must be adept at capturing and storing that water. The degree of fluctuation also means plans must accommodate the possibility that rainfall will be very low or very high some years. These patterns are also the basis of different arguments for how to achieve water-sector sustainability in Chennai. The relatively high annual average rainfall received underscores the opinion held by some that Chennai receives enough rainfall to sustain its water needs. Sunita Narain of the Centre for Science and Environment, for example, argues that Chennai's challenge lies more in its ability to capture and store water efficiently than in sourcing adequate amounts of water (Sunita Narain, 2017). On the other hand, others are of the opinion that the fluctuations in quantity received year to year are too dramatic to allow the city area to rely on rainfall. Metrowater (Chennai's water utility) officials, for example, point to these fluctuations when defending decisions to pursue additional water supply sources such as desalination plants or inter- or intra-state agreements (Government official from Metrowater, 2018).

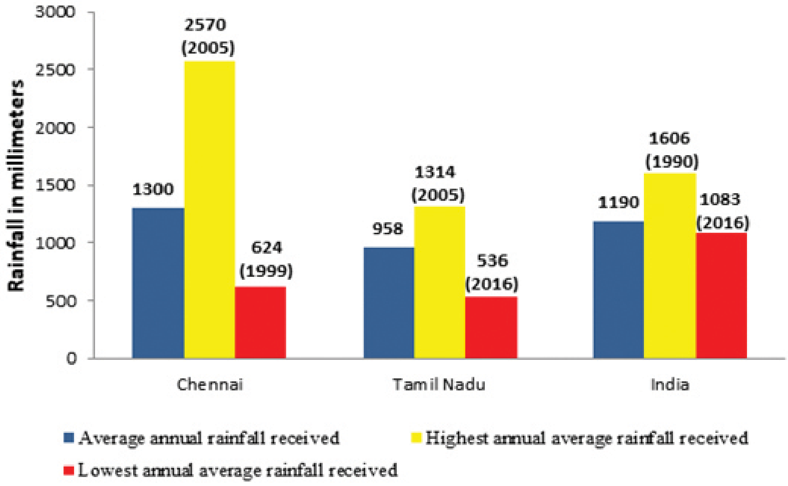

Figure 6: Annual rainfall received 1985-2016
Source: GCC, TNSAPCC & IMD

Looking ahead, the amount of rainfall Chennai receives is predicted to remain relatively constant until the end of the century, at which time it is projected to increase. However, the pattern in which it is received is predicted to change. Climate models suggest that rain will increasingly fall in big, brief spurts, with larger quantities received over shorter periods of time. This suggests that Chennai may experience more heavy rainfall spells like that of December 2015 when 539 mm of rain fell over eight days, which is almost three times the monthly average for December. A record-breaking 272 mm fell during 12 hours that month (Skyweather.com, 9 December 2015). Predictions that this may repeat have significant implications in terms of flood risk as well as water storage and management.

River Flow

Three rivers define the Chennai basin: the Kosathalaiyur, the Cooum and the Adyar. All three run west-to-east through different sections of the metropolitan area. The Kosathalaiyur is a primary supplier of Chennai's surface water. It is a 136-km river that originates to the west of Chennai, in Vellore district, and flows through Tiruvallur district, the northern fringes of the CMA, and eventually drains into the sea at Ennore creek. The Kosathalaiyur never enters into Chennai city boundaries.

The Cooum river also supplies surface water to Chennai. The Cooum originates in Tiruvallur district about 70 kms west of Chennai. It is substantiated by surplus water from the Cooum tank, 22 kms along, and then travels 18 kms through Chennai city before entering the sea near Madras University. The Cooum is a small river; it is classified as the smallest that flows into the Bay of Bengal (see Figure 7).

The Adyar is another river defining the Chennai basin; it traverses 15 kms of Chennai city. However, the Adyar does not contribute as a water source; it primarily serves a drainage function. This river originates in Guduvancheri village, about 25 kms from Chennai, but only becomes river-like after it receives surplus flow from Chembarambakkam reservoir. It then receives drainage from southwest areas of Chennai.

The amount of water carried by the Kosathalaiyur and the Cooum varies according to season and varies depending on rainfall. These rivers can run almost dry during drought periods and conversely may flood in times of heavy rain.

Figure 7: Chennai waterways
Source: www.downtoearth.org

Reservoirs, Tanks and Lakes

An estimated 320 reservoirs, tanks and lakes populate the Chennai city area. Historically, they all worked to capture and store Chennai water at a decentralized level. Waterbody systems were managed by the people living around them. The waterbodies were recharged primarily by rainfall (Sunita Narain, 2015). Today, four reservoirs, also sometimes referred to as lakes, and a network of smaller tanks, all linked by feeders and canals, capture and store water for Chennai. Canals allow for flow between the reservoirs or tanks when there is adequate pressure, or in case of excess water. Reservoirs are recharged primarily by river flow, which is diverted through a series of approximately 20 check dams, with some rainfall also contributing directly to recharge. This current system is centralized; it is controlled by the Public Works Department (PWD) and governed by Metrowater. Today's system serves the CMA; prior to 1969, when Metrowater acquired irrigation rights, it served regional agricultural water needs as per legal requirements (Nikku,2004).

Chennai's four main reservoirs are Cholavaram, Puzhal (also known as Red Hills), Poondi and Chembarambakkam. All four are fed by the Kosathalaiyur river. Cholavaram, Poondi and Chembarambakkam connect in a cascading system. All four reservoirs share similar attributes: they are each replenished seasonally, with flow occurring mainly during the northeast monsoon. They are typically shallow, and evaporation rates are therefore high, estimated in 2008 to be as high as 43 percent. Safe potential from Chennai's lakes, estimated at 95 percent probability, is only 142 million litres per day (MLD) (Second Master Plan for Chennai Metropolitan Area: 2026, 2008; Nikku, 2004). This is strikingly low when compared with the estimated 1000 MLD currently being consumed by Chennai.

Cholavaram and Red Hills are Chennai's oldest reservoirs. Initially, they served as irrigation tanks and were selected in 1872 for city water storage by the then-newly established PWD. To form the reservoirs, an anicut was constructed over the Kosathalaiyur at Tamaraipakkam, about 28 kms north-east of Chennai. Subsequently, a channel was dug to direct water supply to Chennai city. At that time, the system was designed for a projected population of 0.47 million. Poondi was constructed in 1944 with the aim of intercepting and storing more Kosathalaiyur river flow. Water from Chembarambakkam lake, which is situated 6 kms from Chennai, was first channelled into the city's water supply system in 2000 (Nikku, 2004; Second Master Plan for Chennai Metropolitan Area: 2026, 2008).

The total capacity of Chennai's reservoirs has been altered over time. Repeated efforts to increase capacity have been made over the years, including as late as 1991-1992. Currently, according to

Metrowater, the capacity of each lake is as follows (see Table 1). The third column represents actual daily storage levels (these are averages taken from Metrowater storage level data between 2003 and 2015).

Lake	Total capacity in mcft	Actual storage level in mcft
Poondi	3231	1176.03
Cholavaram	881	255.30
Red Hills	3300	1683.91
Chembarambakkam	3645	1337.96
Total	11,057	4453.20

Table 1: Present-day capacity of Chennai reservoirs vs. actual daily storage levels 2003-2015

Source: Chennai Metrowater

Together, Chennai's four main reservoirs have the capacity to store 11,057 mcft of water. However, they rarely attain that capacity. Table 1 indicates total capacity and actual daily storage averages (as calculated from data captured by Metrowater on the first of every month and averaged over the course of the years 2003-2015). According to one official we interviewed, Chennai reservoirs have reached their full capacity just two to three times in the last 15 years, the most recent being after record rainfall in December 2015 (Interview with TUFIDCO officials, 2017). Typically, the reservoirs store between 255 and 1683 mcft of water every day, depending on the year and the month. Total water availability from Chennai reservoirs is usually an approximate 350 MLD. One expert suggested that total surface water supply to Chennai cannot exceed 800-900 MLD (Interview with TUFIDCO officials, 2017).

Check Dams

Several smaller tanks, including the Red Hills tank, are also supplied by the Cooum river waters, which are diverted by two check dams, Paruthipattu and Kannapalayam.These check dams are an important element of Chennai's surface water management system. They are man-made mechanisms built across rivers or streams to divert and store river flow that would otherwise drain into the sea. Chennai's first check dams were built at the recommendation of a series of hydrological studies conducted by UNDP during the 1960s and 1980s. Check dams were originally intended to increase city water supply.

Today, approximately 20 check dams populate the Chennai area, including the Mettur dam, which provides 50 thousand million cubic feet (tmcft) to Chennai, and the Bandivakanur and Thirukandalam check dams. The Bandivakanur dam is new; it was constructed in 2013 by Chennai's PWD (Radhakrishna interview, TUFIDCO, 2017; Lakshmi, K., The Hindu, Feb.2017).

Check dams improve water supply, and they also help replenish aquifers, enabling more surface flow to filter down into the groundwater table that immediately surrounds the dam. Several studies indicate the extent to which this is successful. For example, one study by Anna University examined groundwater levels in 33 wells in the vicinity of a 260-metre check dam in Palleswaram, Tiruvallur district. It found that levels rose 4 metres over the course of five years (Lakshmi, K., The Hindu, Feb. 2017). Also, Anna University's Department of Geology conducted two more studies oncheck dams along the Araniar river, also in Tiruvallur district. Here, 19 monitoring wells were selected near a check dam, and groundwater levels were measured periodically from July 2010 (before the check dam was constructed) to July 2012 (after it became operational). Findings indicate a clear increase in groundwater potential as a result of the check dams, with levels increasing between 1 and 3.5 metres, and extending out approximately 2 kms from the check dam. About 63 percent of water stored in one check dam was found to result in groundwater recharge (Renganayaki, P.and Lakshmanan, E., 2013; Elango, L., 2014).

Groundwater

Groundwater is water that has percolated through the ground and is trapped in layers of porous rock beneath the earth's surface. Groundwater is commonly used as a source of fresh water, partially because the process of percolation purifies and filters the water, rendering it suitable for human consumption.Groundwater supplies Chennai's needs to varying degrees, depending on surface water availability. Chennai groundwater is pumped up at large scales by Metrowater through well fields and the hiring of private agricultural wells, and at smaller scales by individual well owners.

Well Fields

Well fields to serve Chennai with groundwater were developed in two locations: along a 20-km-long coastal aquifer to the south of the city, between Thiruvanmiyur and Kovalam, and to the north, from within the Arani-Kosathalaiyur basin. The southern aquifers were identified and developed in the 1960s-1970s. While they originally yielded approximately 6MLD, they are now rendered saline and no longer contribute to Chennai water supply at all.

The Araniar-Kosathalaiyur basin well fields were developed in two phases: the first in 1969 and the second in 1987. The first three, at Tamaraipakkam, Panjetty and Minjur, were recommended by a 1966-1969 UNDP study that identified an aquifer with the potential to abstract an estimated yield of 125 MLD by means of borewells. Initially, Chennai's PWD supplied this water to industries in the Manali area. In 1981, following Metrowater's 1978 assumption of control of these well fields, some water was also diverted to Chennai's water supply system – at first only in emergency situations and eventually on a permanent basis (Metrowater website, Water Supply System).

The second phase followed 1982-1985 UNDP/UNCTAD studies that identified three additional aquifers in the same Araniar-Kosathalaiyur basin, found to have the potential to abstract approximately 55 MLD. These well fields were developed in 1987 as part of a first Chennai World Bank-aided project. They are located at Poondi, Flood Plains and Kannigaiper (Metrowater website, Water Supply System).

The quantities tapped from these well fields vary, depending on surface water levels. The most recent data indicates that approximately 25 MLD is currently sourced this way (MAWS, 2016). This has decreased over time as a result of legislation to protect groundwater: it was approximately 85 MLD in 2013, (Metrowater Delhi presentation, 2013) and 111.5 MLD in 2000 (Munian, 2010), when well fields supplied approximately 25 percent of city needs (Biswas, Asit K. & Uitto, Juha I., 1999). Legislative requirements are defined by the CMA Groundwater (Regulation) Act 1987 and the 2003 statewide Groundwater (Development and Management) Act.

Hiring of Private Agricultural Wells

Metrowater also taps groundwater by purchasing it from private agricultural wells in the Araniar-Kosathalaiyur basin. This activity began in 2000 when a tripartite agreement was signed between Metrowater, Chennai's electricity board and farmers. Initially, 60 farmers subscribed to the agreement, with that number growing to 208 in 2011 and 245 in 2002 (Ruet, J. et al., 2006).

In 2006, 20 to 25 percent of Metrowater's total supply was sourced this way, constituting the largest share of groundwater extracted from all well fields (Ruet, J. et al., 2006). Tapping also increases during water crisis periods. Seventy-five private agricultural wells, for example, were hired during the 2003 drought to increase water yield by approximately 25 MLD (Munian, 2010, p. 137). Pumped water is conveyed through a well-field-pipeline network to Chennai city and other consumers, including industry. In fact, some studies of private agricultural well hiring, including Ruet et al. (2006), suggest that industry is the primary intended recipient of this method of water sourcing (Interview with TUFIDCO officials, 2017; Metrowater website, Water Supply System, accessed 7 May 2018).

Private agricultural well hiring to supply urban water needs is an India-wide phenomenon. It is sometimes classified as a variation of direct land acquisition for industrial or real estate needs – or as "appropriation through water resources". It is also found to negatively impact farmer livelihoods. One study examined 59 farmers in Chennai's peri-urban areas, including 32 who sold water from their agricultural well to Metrowater, Chennai's water utility. Farmers who sold their water were found to experience a 35 percent drop in cultivated land. Also, while their income was found to increase by up to 80 percent in a two-year period, any farmer either semi-dependent or dependent on the water seller experienced a sharp decrease in income over time (Ruet, J. et al., 2006).

Private Wells

Groundwater is also sourced from privately owned wells. These may be shallow wells, which are sunk, or tube wells or borewells, which are drilled– all of which occur at the owners' initiation and expense. Certain areas of the city require that a licence be obtained for these wells, as per the Chennai Metropolitan Area Groundwater (Regulation) Act 1987.

Supply by privately owned wells is common throughout India: a 2007 study of seven Indian megacities found that 25-80 percent of households in six cities relied on private wells for some portion of their water needs (Shaban and Sharma, 2007 as quoted in Srinivasan, V. et al., Oct. 2010).

Groundwater Over-Exploitation and Related Legislation

It is not clear how much groundwater Chennai uses. Currently, estimates suggest it is in the range of 350 MLD, which includes an estimated 25 MLD from well fields. What we do know is that the amount varies according to Metrowater availability. As Metrowater supply becomes restricted, groundwater extraction increases, and vice versa.

We also know that groundwater is a limited resource that, across India, is increasingly overexploited. The World Bank reports that for the past four to five decades, 80 percent of India's rural and domestic water supplies have depended on groundwater, with an estimated 253 billion cubic metres abstracted every year. This is high compared with other countries. In fact, India's groundwater extraction represents approximately 25 percent of global extraction (The World Bank, 2018). Categorization of groundwater extraction is done by block, and extent of over-exploitation is calculated by measuring percolation rates against the amounts of water extracted. A block is deemed overexploited when 100 percent or more of the water percolating into it is pumped. When 90 percent is pumped out, the block is categorized as critical. Other categories include semi-critical, safe or saline. In Tamil Nadu, 80 percent of groundwater resources are estimated as being used with increasing rates of over-exploitation. One report indicates the number of overexploited blocks is up from 21 percent in 1980 to 48 percent today (TNSAPCC).

Chennai's groundwater resources are overexploited as well. A study by India's Central Ground Water Board (CGWB) finds that Chennai groundwater is extracted at a rate of 185 percent, indicating the system is extremely overexploited. "The groundwater in Chennai is depleting between 10 cm and 20 cm per year," says a superintending hydrologist at CGWB (as quoted in Y. Kabirdoss, Times of India, 30 March 2017). Also, Chennai wellfields to the north of the city have been found to supply approximately 85 MLD when their safe yield is only 68 MLD (Janakarajan, S., 2013). Additionally, Chennai groundwater tables may be particularly slow to recharge as a result of a "thick clayey aquifer layer" underlying its reservoirs that prevents leakage and, as a result, percolation (Srinivasan, V., July2010). In addition to being overexploited, wellfields are also experiencing saline intrusion.

Legislation to curb groundwater exploitation in Chennai exists in the form of two Acts and a government order: the 1987 Chennai Metropolitan Area Groundwater (Regulation) Act, the 2003 statewide Groundwater (Development and Management) Act, and a 2010 order passed by the PWD that restricts groundwater extraction within 10 kms of the coastline (mainly to mitigate saline intrusion). The former outlines measures to protect groundwater and encourage recharge in the form of four rules which apply to the CMA: 1) permission required to sink wells, 2) registration required for existing wells, 3) licences required for extraction, use or transportation of groundwater and 4) permits or licences can be cancelled. The Act also calls for the implementation of specific schemes, for example that for rainwater harvesting where new site plans cannot be sanctioned unless they include a provision for rainwater harvesting structures (see page 57 for more on rainwater harvesting). The Act further restricts the capacity of pumps for drawing groundwater.

Distinct from this legislation is the statewide Groundwater (Development and Management) Act, which came into force in 2003 and was notified in 2013. This Act stipulates a series of rules intended to protect groundwater resources, safeguard against over-exploitation, and ensure proper development and management of these resources in the state. The Act also requires groundwater users in blocks that are deemed over-exploited or critical to register with groundwater authorities (Nikku, 2004;Second Master Plan for Chennai Metropolitan Area: 2026, 2008).

While some studies indicate positive impacts as a result of this groundwater-related legislation, overall it has been deemed difficult to implement and to enforce. A perceptible rise in groundwater tables as a result of CMA Groundwater (Regulation) Act rules has been determined, particularly when viewed in combination with community-scale tank and pond rejuvenation activities – which involve desilting waterbodies and clearing the channels leading into them. For example, one assessment indicates the intervention improves aquifer recharge from rainwater run-off from 9 to 27 percent (Srinivasan, October 2010).

However, enforcement and implementation have been difficult. It is clear, for example, that certain industries within the CMA continue to extract groundwater for commercial purposes even without permission (R.K. Srinivasan, 2006). Also, the statewide Act was so problematic it took 10 years to be notified (legally binding) – and was repealed almost immediately after that. One issue involved a lack of clear definition of terms, particularly around marginal and small farmers. Also, a rule requiring users of high-powered pumps (with one horse power or more) to obtain licences was deemed politically unacceptable (T. Ramakrishna, The Hindu, Sept. 2013). Overall, this groundwater-related legislation has little effect. “While there are many laws which can be used to regulate over-extraction, in the many years I have been studying the groundwater scenario in Chennai, I have never seen them implemented,” laments S. Packialakshmi of the Department of Civil Engineering, Sathyabama University (as quoted in S. Arasu, 26 October 2017).

Inter- and Intra-State Allocations

Chennai’s reservoirs are replenished primarily by the Kosathalaiyur and the Cooum rivers, but some additional flow is received from other, more distant rivers, according to several inter- and intra-state mechanisms and agreements:

Telugu Ganga Inter Basin Project

Perhaps the most ambitious agreement is this one between the governments of Tamil Nadu and its neighbouring state, Andhra Pradesh, to divert and share quantum surplus river flow from the 1400 m-long Krishna river, which originates in Maharashtra and flows through Karnataka and Andhra Pradesh. The Telugu Ganga project was originally designed to increase Poondi reservoir capacity, 400 kms away. The project would also supply irrigation water for Rayalaseema region in Andhra Pradesh (Nikku, 2004).

A defining idea behind the Telugu Ganga project was to enable Chennai to benefit from rainfall from both monsoon periods. As stated above, Chennai's geographic positioning means that it traditionally receives most rainfall during the northeast monsoon. The Krishna river, on the other hand, is largely replenished during the south-west monsoon. The Telugu Ganga project was devised as a way of diverting southwest monsoon rainfall to Chennai by means of the Krishna river and a network of canals connecting it to the Poondi reservoir (Nikku, 2004).

This project is decades-old and has yet to reach the potential it originally promised. It was initiated in 1976, approved in 1977 and formally inaugurated in 1983 with the expressed intention of increasing Chennai's storage capacity by 15 tmcft by 2002, which would increase supply by 995 MLD. However, implementation was delayed repeatedly, and the first phase was launched 13 years later in 1996 with a 200-MLD flow into Chembarambakkam reservoir (Anand, P.B., 2001). Further delays, budget constraints and water scarcity in the Krishna river basin have meant the amounts of water actually transferred remain small. In 2017, just 4-5 tmcft of water flowed into the reservoir through this project. As of 2004, the largest amount of water received was 7 tmcftin 2000-2001 (Ramakrishnan, T., 1996a). Before flowing into Chembarambakkam, water is first treated at a treatment facility that was constructed in 1996 and holds a total supply capacity of 530 MLD (Interview with TUFIDCO official, 2017).

The New Veeranam Project

This project, conceived initially in 1967 as the Veeranam project, was designed to increase Chennai's water supply by directing water from Veeranam lake in the Cauvery basin, Cuddalore district, 235 kms away. Implementation was fragmented, disrupted over more than 30 years by political, legal and financial constraints. Chennai received its first supply in 2004, by which time the project had been renamed the New Veeranam project. At that time, water was not supplied by the Veeranam lake, but by a network of 45 deep borewells just north of the lake that were dug in 2003 when the Veeranam lake had run dry but political will to make the project happen was strong. The wells were dug despite protests from local farmers who were concerned it would affect the local groundwater table (Sridhar, V., 2004).

The New Veeranam project supplies approximately 50-180 MLD of water to Chennai (Sriram, V., 2015). Supply is pumped alternately from the Veeranam lake and the network of wells, depending on the Veeranam lake water level. Water is treated at Vadakuthu treatment plant just north of the lake near Neyveli, and it is then routed through a pressurized pipeline, which ensures flow along the sloped terrain to Chennai and also reduces the chance of theft. Water is received at Porur water distribution station, near Chennai, from where it is distributed to the city through trunk mains and distribution centres. The project is somewhat less complicated to administer than the Telugu Ganga project because the source and destination of water are both under the control of one government (Srinivasan, V., July 2010).

Desalination

In an effort to reduce pressure on city drinking water availability, Metrowater, Chennai's water utility, set up two desalination plants: the Minjur plant in 2010 and the Nemmeli plant in 2013. Both apply a reverse osmosis process to brackish water as per IS 10500: 1991 (Bureau of Indian Standards). The Minjur plant has a capacity of 100 MLD. It is currently operational and supplies 95 MLD of potable water to 2.5 million residents in northern Chennai. The Nemmeli plant also holds a capacity of 100 MLD. It is fully operational and supplies approximately 85 MLD to the southern areas of Chennai city.

The two plants currently contribute 180 MLD to Chennai's water supply, or, according to one report, "close to one-third of the city's water supply" (Gopalakrishnan, S., June 2017). Plant officials describe this water as "safe, clean and potable" (Narayanan, Chitra, 2016). Others describe it as "high price water" (Interview with TUFIDCO official, 2017), because every kilolitre (KL) is estimated to cost INR 30 to produce, with Metrowater purchasing it from plants at INR 48.66 per KL (Lakshmi, K., April 2012). Compare this with the INR 50 per month per dwelling that unmetered residential consumers pay Metrowater to cover all their supply needs – including sewage charges (http://www.chennaimetrowater.tn.nic.in/tariff.html, accessed 18 April 2018).

In an effort to reduce pressure on city drinking water availability, Metrowater, Chennai's water utility, set up two desalination plants: the Minjur plant in 2010 and the Nemmeli plant in 2013.

Desalination is one approach to ensuring freshwater supply and addressing drought, particularly in coastal areas. The water-scarce nation of Israel, for example, operates five desalination plants along the Mediterranean Sea which currently supply over 25 percent of the country's water needs. Totally, 18,426 desalination plants serve water needs to 300 million people in 150 countries around the world (Pawariya, A., 2017). However, experts disagree on whether desalination is the appropriate measure in the Chennai context. Some argue that Chennai receives adequate rainfall to cover annual water demand, while highlighting the environmental and economic costs of desalination. They say that desalination's energy requirements heavily tax the environment and negatively impact marine life. They also underscore the economic costs: INR 533.38 crore to construct the Nemmeli plant, an amount that is suggested to be four times that which was originally quoted (Interview with TUFIDCO official, 2017). There are also the per-litre costs, as mentioned above. It is argued that Chennai should pursue efforts to recycle water instead – by reusing sewage, for example, or by harvesting more rainwater – by means of rooftop structures as well as by reviving the more than 300 lakes, tanks and ponds that historically served to capture and store city area water (Narain, S., 2017). Desalination in Chennai, according to Professor Janakarajan formerly of the Madras Institute of Development Studies (MIDS) and currently serving as president of SaciWATERs, is the "lazy option" (as quoted in Gopalakrishnan, S.,June2017).

On the other hand, it is argued that cities like Chennai with no perennial water source must pursue technological solutions such as desalination – or curb city growth entirely. This argument stipulates that rainfall is unreliable; it falls in large quantities some years but in very small amounts at other times. Desalination, it is argued, is the far safer option. Experts also downplay the costs of desalinated water, particularly in terms of price per litre: "Costs are nothing compared to bottled water. It costs 6 paise a litre, INR 60 for 1000 litres, against INR 15 for a litre of bottled water. Even a tanker, you pay 15 paise and you don't know how safe that water is" (Narayanan, Chitra, 2016).

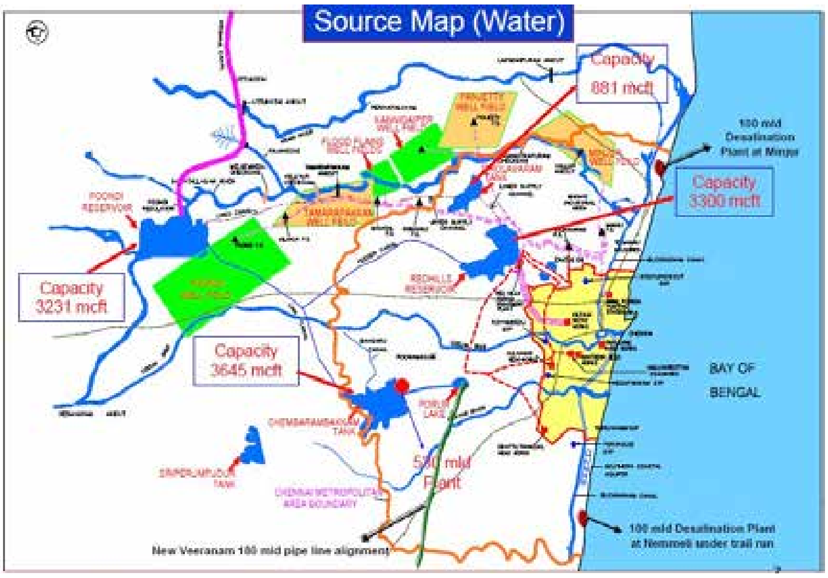

Figure 8: Water source map for Metrowater, Chennai's water utility

Source: Metrowater, 2013

Sewage Reuse

A minute amount of Chennai water is sourced from treated sewage; it is used entirely by select industries. Currently, just 23 MLD is supplied this way. Waste water is treated by Metrowater and sold at an estimated price of INR 11 per KL (Interview with TUFIDCO official, 2017). Madras Refineries and Madras Fertilizers are two examples of industries that operate using treated sewage. However, efforts to direct treated sewage to industry are by no means comprehensive. In fact, one 2010 report described them as having "stalled" due to poor demand from industrial consumers (Srinivasan, V., Oct. 2010). Indeed, many industries continue to operate on raw water (which is sourced by Metrowater but not treated for potability). Industries in Sriperumbudur, for example, continue to receive water supply from Chembarambakkam.

Sewage – or waste or grey water – reuse contributes significantly to water supply in many regions of the world. In some countries, such as Singapore, and cities such as Windhoek, Namibia, treated grey water is also used for domestic purposes. Experts, including those at India's Centre for Science and Environment, argue this solution needs further exploration in the Chennai context. They emphasize that, in addition to improving water availability, treated sewage can also boost water utility income. Metrowater, they indicate, can sell reused sewage and use revenues to improve their supply infrastructure (Narain, S., 2015). One Metrowater engineer we spoke with indicated that sewage reuse is Chennai's best option to meet growing demand. In fact, he pointed to the steps currently being taken to improve sewage treatment systems and predicted that, within 10-15 years, Chennai will rely heavily on sewage reuse for water supply, including for domestic purposes. However, others insist that sewage reuse for domestic purpose is unsuitable in the Chennai case; arguing that citizens have a "mental block" against it (Narayanan, Chitra, 2016).

Primary Analysis: *How stable have groundwater recharge rates been over time?*

Little is known about the dynamics of groundwater systems, particularly from a real-world perspective – where several factors, including soil profile, extent of pervious and impervious surfaces, and rainwater harvesting structures could influence the system either positively or negatively. Having this understanding is important because Metrowater relies on a combination of surface and groundwater sources for its daily water supply. Metrowater extracts approximately 25MLD from groundwater aquifers, and additional water supplies are extracted by means of private borewells drilled for residential and commercial purposes (MAWS, 2016). Also, groundwater is an important source of recharge for surface waterbodies and any change in levels is also likely to impact recharge.

We analysed the links between groundwater levels and rainfall patterns in Chennai to understand the temporal and spatial change in recharge rates, asking the question: are recharge rates increasing, decreasing or remaining constant over time and across different locations? In the case of a static system, a particular area should maintain approximately constant rates of recharge given a certain average groundwater level and a certain intensity of rainfall. The objective of our analysis was to understand if this is the case in Chennai or, if not – if recharge rates have changed (declined) over a period of time – then to hypothesize why this might be the case.

Data collection and analysis: We gathered data on monthly groundwater levels from 18 existing groundwater wells across the city. This data was collected from an in-house lab at the Environment and Water Resources Engineering Department that has studied city groundwater levels for many years. The water levels in the wells were measured with respect to the ground level, i.e., the depth of the water level relative to the present surface level in each study location. Therefore, groundwater levels close to the surface indicate an active recharge and healthy groundwater levels in that location. The monthly recharge levels were compared to monthly rainfall data from January 2006 to December 2014. Rainfall data was gathered from a combination of sources including IMD and local weather stations (KEA Weather Station). Based on this data, we were able to analyse groundwater levels during specific months of the year – particularly the summer and monsoon months.

Results: There is considerable variation in groundwater recharge rates, given constant rainfall. If the groundwater table were a closed system, one would expect a sinusoidal pattern in terms of recharge and use. However, this was not found to bethe case across all areas studied. Figure 9 to Figure 12 show monthly groundwater levels and corresponding rainfall levels in Vepery, Ayanavaram, George Town and Royapuram. In these areas, recharge rates are considerably lower than corresponding rainfall levels during annual recharge months – October to December. For example, in Vepery, monthly rainfall rose from 121mm to 560mm between point 33 (September 2008) and point 35 (November 2008) but recharge rates only rose by approximately 147mm during those same months. The opposite phenomenon can also be seen – where the rate of increase in groundwater levels is more than the rate of increase in rainfall (for example, during September to December 2014). Compared over time, groundwater recharge rates during the monsoon of 2006 appear to be higher than those during the monsoon of 2010, given initial similar rainfall and groundwater levels. Other areas including Ayanavaram, George Town and Royapuram also show this same variation. It should be noted that these areas are in the northern and older part of the city and have a high population density.

Further, from our data it can be observed that in these regions, average groundwater levels are around 500 to 600 mm below the surface and show a decreasing trend between 2006 and 2014. The variation and reduction in groundwater levels could perhaps be caused by indiscriminate construction leading to increased surface run-off and/or higher extraction rates due to an increase in the number of people relying on groundwater.

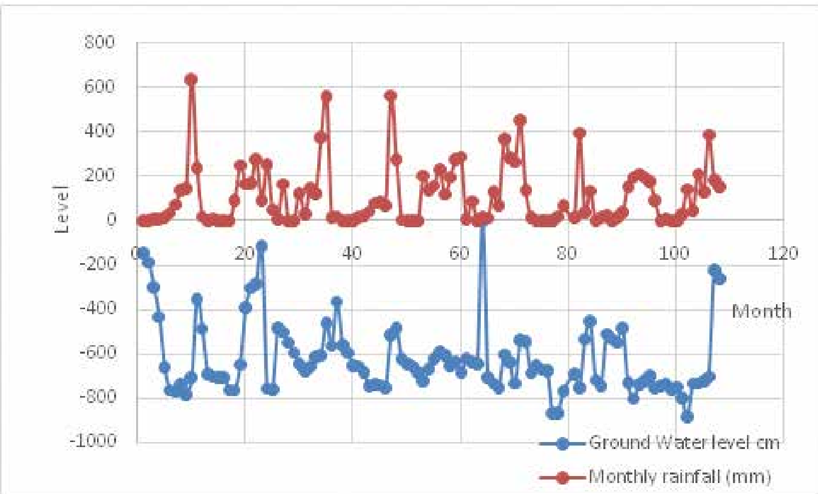

Figure 9: Groundwater levels vs. rainfall in Vepery

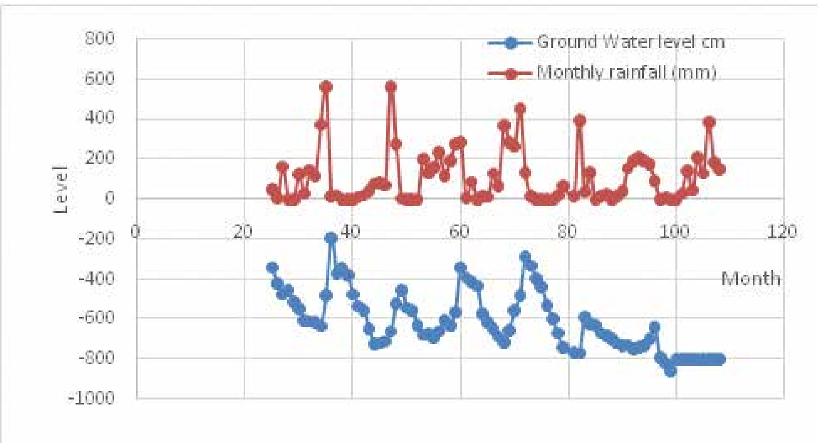

Figure 10: Groundwater levels vs. rainfall in Ayanavaram

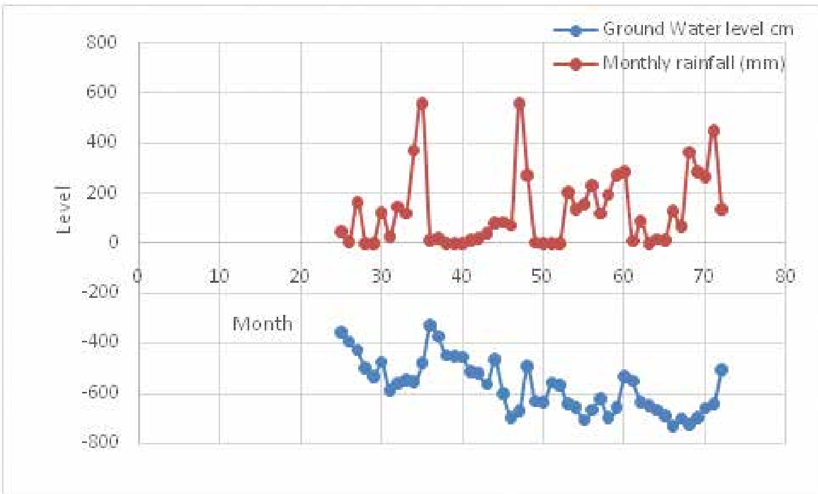

Figure 11: Groundwater levels vs. rainfall in George Town (Chennai Central)

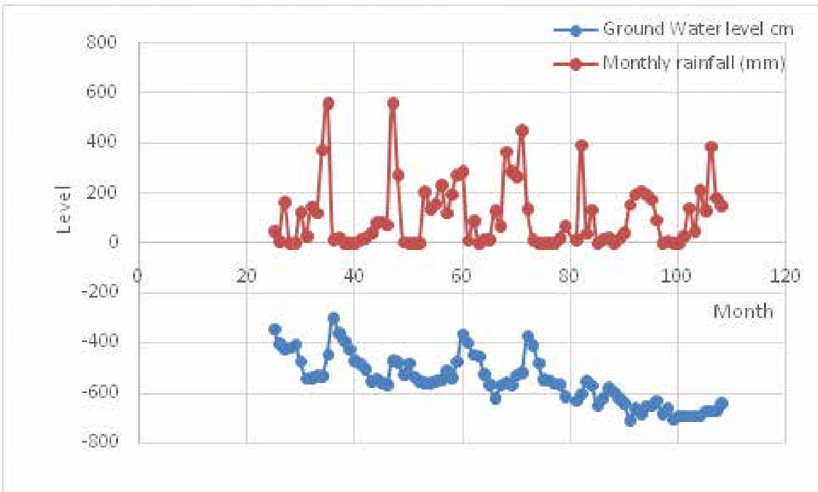

Figure 12: Groundwater levels vs. rainfall in Royapuram

In contrast, there are several areas in the central and southern parts of the city including Adyar, Mylapore, Saidapet, Lady Willingdon College (Triplicane) and Chepauk that show relatively higher recharge levels during the same study period (2006 to 2014), despite mismatches in the rate of groundwater recharge levels and rainfall levels during the monsoon months. In these areas, average groundwater levels are between approximately 200 and 400mm below the surface. Velachery is an exception to this trend. Here there is considerable variation in groundwater levels during the monsoon months and groundwater levels seem to be falling over the years (Figure 13).

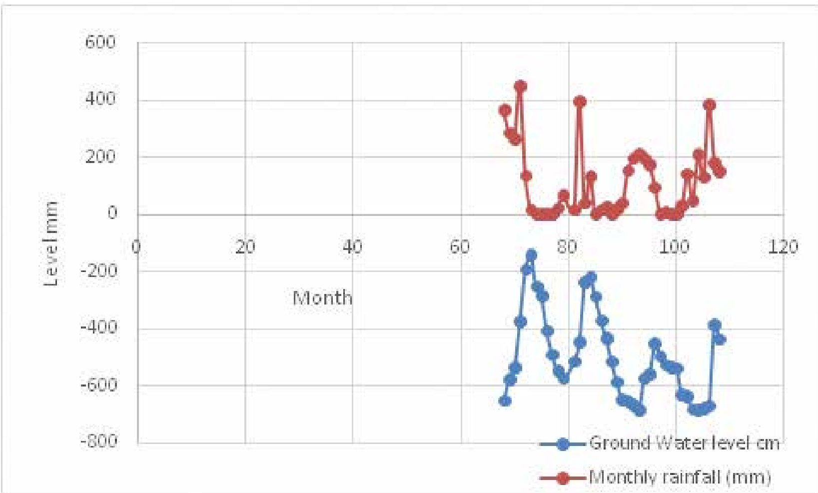

Figure 13: Groundwater levels vs. rainfall in Velachery

To conclude, there is temporal and spatial variation in groundwater levels and recharge rates, with some areas showing more variation than others. Areas such as Adyar, Mylapore, Saidapet, Chepauk and Triplicane in the central and southern parts of the city seem to have relatively similar crests and troughs of groundwater recharge and rainfall levels. However, other areas located farther north including Ayanavaram, George Town, Vepery and Royapuram, indicate an overall decreasing trend in groundwater levels and a considerable mismatch between recharge rates and rainfall levels during the monsoon months. Soil profiles may explain some of these observations, and differential strata could lead to a variance in groundwater recharge spatially. However, we observe spatio-temporal variations in other areas where rates of recharge seem to be decreasing. These areas represent higher risks because people rely on a system that is overexploited, perhaps due to indiscriminate construction resulting in prevention of infiltration and bringing in more people to rely on groundwater.

Total Water Availability

According to Chennai's water utility, total water availability for the metropolitan area is currently 1000 MLD. This is also the total amount currently being supplied. The amount includes surface water, groundwater and that received from other sources (such as desalination). 650 MLD is the estimated amount coming through Metrowater's piped supply, which includes 180 MLD from desalination. Last year (2017), during a drought period, availability was lower, with Metrowater piped supply providing just 400-450 MLD (Interview with Metrowater officials, 14 February 2018).Some experts we spoke with indicated this number may be high. For example, one Chennai water-sector expert indicated total availability (and supply) is just 550 MLD during normal years and may be 800 MLD (inclusive of all sources) during good years.

Variations in the total amount of water available to Chennai make it difficult to determine per capita water availability. India's Central Public Health and Environmental Engineering Organization (CPHEEO) indicates this should be 135 litres per capita per day (LPCD), and Metrowater officials state they aim to provide this. However, Chennai's Master Plan indicates the average per capita amount supplied is 90 LPCD with just 25 LPCD supplied to slum areas (Second Master Plan for Chennai Metropolitan Area: 2026, 2008). Chennai is also described as having the lowest per capita availability of water among India's large cities (Kennedy, L. et al., 2014).

Availability is predicted to change in the future. It is projected to be 1957 MLD in 2026, including 200 MLD from desalination, 180 MLD from sewage reuse and 240 MLD from groundwater sources (Second Master Plan as quoted in TWIC, 2017).

CHAPTER 3 : WATER SUPPLY AND DEMAND

CHAPTER 3 : WATER SUPPLY AND DEMAND

This chapter describes water supply and demand in the CMA, as well as water balance. How does water reach consumers? How much reaches them? To what extent do these numbers vary and are they projected to change? Similarly, what is the demand for water? What are factors influencing demand? How is demand quantified and qualified? And how do supply and demand equate? What are the gaps? These questions are addressed in the chapter below.

Water Supply

Three distinct systems constitute institutional water supply in Chennai city: utility supply, which is provided by Metrowater, self-provision, accessed through privatelydrilled wells, and a private market consisting of bulk supply and retail sales.

Utility Supply, Provided by Metrowater

Metrowater is Chennai's public water utility. It is a monopoly provider and operator of potable water, supplying Chennai's domestic consumers – by means of in-house and public connections – and other consumers, including industry. Surface water, groundwater and desalinated water, much of it stored in reservoirs or tanks, is first treated at one of three plants – Kilpauk, Red Hills or Chembarambakkam – and then supplied to 16 water distribution centres (also known as "head works"), each serving a different zone in Chennai (Refer Figure 14). According to 2013 Metrowater documentation, the utility supplies 729,389 consumers and 493,903 household connections across Chennai (including the city and additional municipalities) (Metrowater, 2013). All Metrowater-supplied water is treated for potability.

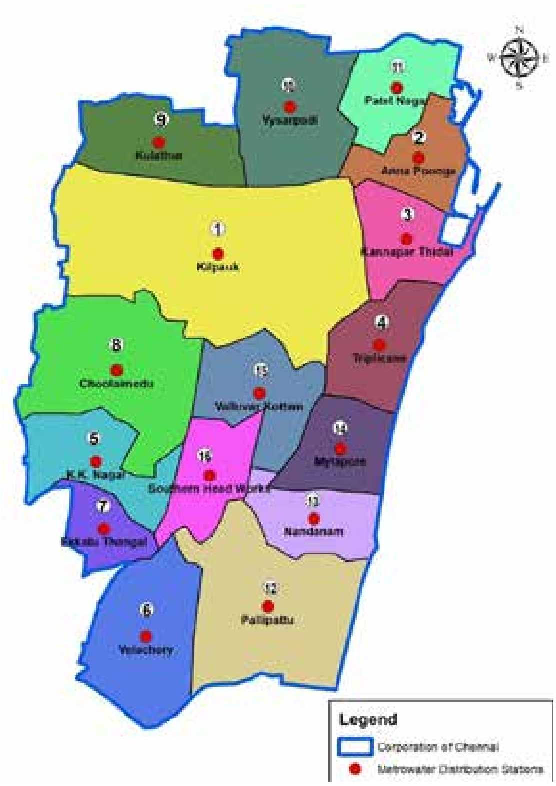

Figure 14: Area served by Metrowater
Source: Adapted from Metrowater

To ensure that water is potable, Metrowater treats all the water it supplies at source, and also monitors water quality on a 24-hour basis by testing samples at various distribution points. This is carried out according to standards outlined by the Government of India's CPHEEO. Occasionally, other stakeholders, including the Chennai Corporation, also participate in this sampling which, according to Metrowater officials, "makes the testing exercise more formidable". Results indicate that water is safe to drink "most of the time", with above-permissible levels of E-coli and other components found occasionally, but always treated immediately with corrective measures. Also, a "minor difference" in quality is found between water at source and that sampled at distribution centres. However, according to Metrowater officials, this difference is not significant (Interview with Metrowater executive officials, 14 February 2018). The difference may be explained by what one expert described as the "archaic pipes" that Metrowater supply passes through, which also pass very near to sewage pipes (SaciWATERs, 2018, personal communication). Regardless of these measures, many Chennai residents opt for bottled or canned water for drinking purposes anyway.

To ensure that water is potable, Metrowater treats all the water it supplies at source, and also monitors water quality on a 24-hour basis by testing samples at various distribution points.

This is carried out according to standards outlined by the Government of India's CPHEEO. Occasionally, other stakeholders, including the Chennai Corporation, also participate in this sampling which, according to Metrowater officials, "makes the testing exercise more formidable".

Metrowater supply comes primarily from surface water sources (Figure 15). 450 MLD of the estimated 650 MLD supplied by Metrowater today is described as coming from surface water sources (with 180 MLD sourced from desalination and 20-25 MLD from groundwater sources). Prior to 2004, groundwater sources contributed more – approximately 100 MLD – however,this was reduced as a result of over-exploitation (Chennai Metrowater website, accessed 8 May 2018, and interview with Metrowater official, April 2018).

Going forward, Metrowater's piped water capacity is projected to increase to approximately 1500 MLD – in light of plans to expand the city area (Interview with Metrowater executive officials, 14 February 2018). Fifty percent of this is to be sourced from desalination, 40 percent from surface water and 10 percent from recycled waste water (Interview with TUFIDCO official, 2017).

Importantly, the amounts supplied by Metrowater are approximate; exact figures are not known. Metrowater supply is on the whole not metered or billed for at the consumer end, meaning that actual tapped quantities are not recorded. A 2005 survey of 264 Chennai households found that just 1.1 percent of connections were metered (Munian, 2010). This is reiterated by Metrowater officials who say that metering exists for some water-intensive consumers such as certain industries, commercial buildings and marriage halls, but by and large not for domestic consumers. Efforts to implement metering across Chennai are ongoing. They include pilot projects to test metering in domestic buildings and residential areas in Anna Nagar, which were dropped because customers found the associated tariffs to be too high. The tariffs were INR 1500 per month, compared to the regular INR 50 per month (Interview with Metrowater official, 26 October 2017). More recently, pilot projects were initiated in a residential area in T. Nagar; these are ongoing. Programmes to add metering to 33,000 commercial buildings are also ongoing (Lakshmi, K., 5 April 2017).

Meanwhile, Metrowater records supply in terms of the amounts released from its distribution centres. The gap between this amount and what consumers actually receive is known as "non-revenue water" or "non-accounted-for water", and is the result of several factors including pipeline leakage, water theft or illicit water connections. Metrowater estimates non-revenue water in Chennai to amount to approximately 15 percent of supply (Government official from Metrowater, 2017 and 2018). Other reports where data was examined between the years 2002 and 2006 indicate that losses due to pipeline leakage ranged from 15 to 35 percent, depending on the city zone – indicating that the broader "non-revenue water" category, which also includes theft and illicit connections, may be higher than Metrowater estimates (Srinivasan, V., 2008).

Pipeline leakages affect water supply around the world. They are estimated to be as high as 50 percent in developing countries, and as low as 5 percent in the developed world. In the Chennai context, these leakages are the result of deteriorating infrastructure, poor-quality materials and gaps in operations and maintenance (O&M). Interestingly, pipeline leakage losses have one benefit: one Chennai-focused study finds they contribute to groundwater recharge – thereby indirectly contributing to supply. The study compared recharge as a result of rainfall with recharge as a result of pipeline leakages between 2002 and 2006. It found recharge as a result of rainfall to be significant during the monsoon months (July to December), while recharge due to pipeline losses dominated in the spring and summer months (January to June). During most periods, recharge as a result of pipeline losses accountedfor at least half of the total recharge in the city (Srinivasan, V.,doctoral thesis, 2008).

Access to Metrowater supply is available in some form to more than 95 percent of Chennai city households, while coverage in extended areas of the city is poor (TWIC, 2017). Water is supplied by way of a piped network and through non-piped connections.

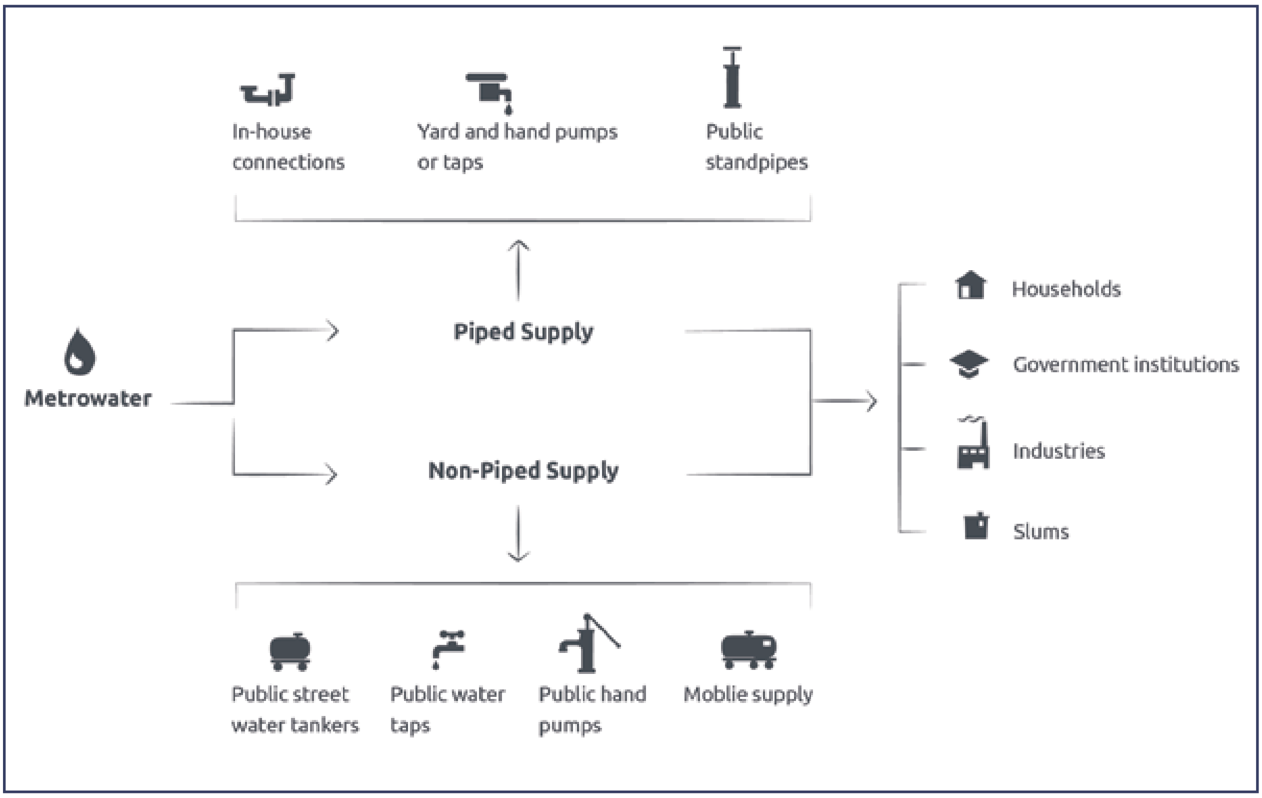

Figure 15: Metrowater supply

Almost 100 percent of city core areas are covered by Metrowater's piped network. This network supplies private piped in-house connections or taps and public standpipes. In-house connections are typically in the form of a tap or simply a hand pump (Munian, 2010, p. 182). Piped connections are typically not metered.

Piped supply to Chennai is generally very low, with an estimated less-than-two hours delivered per day in 2009 (Kennedy, L. et al., 2014). This is typical across the country: no Indian city supplies 24/7 piped water supply. However, Chennai ranks at the low end, and is described in one report as having the lowest per capita availability of all Indian megacities (Srinivasan, V., July 2010). The average cost of piped supply is not known, but it was estimated in 2009 at INR 13/KL (McKenzie, D. & Ray, I., 2009, as quoted in Srinivasan, V., October 2010). This is low compared to the cost of bottled water, which costs INR 10-12 per litre, or canned water which on average costs INR 18-30 per 12-litre can (Venkatachalam, L., 2014).

In terms of capacity and supply, Metrowater's piped network capacity is approximately 830 MLD. However, the amounts supplied are typically lower: in February 2018, Metrowater officials stated supply was 650 MLD. During a drought the preceding year, supply was as low as 400-450 MLD, and it was just 140 MLD during Chennai's 2003 drought (Interview with Metrowater executive officials, 14 February 2018). This includes water supplied to Chennai city, industries and several regional municipalities that come under Metrowater's mandate.

Metrowater's Non-Piped Supply, Including Mobile Supply

Non-piped supply is made available through common distribution points. These might be public water taps, public handpumps, public street water tanks or "mobile supply" – ortanker trucks. A study of 450 households across slum and non-slum areas in Chennai found that 68.6 percent depend on common distribution points for their water supply (Munian, 2010, p. 183).

When available water levels at Metrowater drop to below half of the aggregate demand, the piped supply system shuts down. At this point, the utility switches to "mobile supply", meaning that a "lifeline" amount of 90 litres per household per day (or 20 litres per capita per day, assuming an average household size of 4.5) is delivered by tanker trucks. Often, this task is contracted out to private entities, including non-governmental organizations (NGOs). A 2010 estimate indicates that Metrowater has contracts with approximately 500 such private contractors, and that approximately 10 percent of Metrowater's annual expenses are spent hiring and monitoring these tankers (Munian, 2010, p. 107).

One significant shutdown occurred during Chennai's 2004-2005 drought period, when piped supply stopped operating for almost a year and the entire city relied on mobile supply. Well owners drew so heavily from groundwater at this time that levels fell from 8 to 10 metres. At the peak of this drought, residential wells also went dry, and consumers turned to private tanker supply (see below for more information on Chennai's private water market). The situation was so dire that speculation abounded that the city might have to be evacuated. It was alleviated at last by a heavy monsoon in 2005 that replenished reservoirs and aquifers; and normal supply was resumed (Srinivasan, V., Jul. and Oct. 2010).

While "mobile supply" covers city water needs when Metrowater's piped supply shuts down, slum areas are almost always supplied this way. While some Chennai slum areas have access to street water taps, most have to rely on tanker truck supply. In addition, delivery of "mobile supply" to slum areas can be highly variable. For example, during the 2004 drought, many slum residents experienced irregular supply – even across demographically similar slums or those located close to each other. They also found that delivery relied on local politics and their own capacity to agitate for supply (Srinivasan, V., July 2010; Srinivasan, V., 2008).

Self-Provision: Privately Owned Wells and Borewells

Water is further supplied to the Chennai city area by means of privately owned wells. Households and industry dig and drill wells, including borewells, essentially to bridge gaps in Metrowater supply. Attempts have been made over the years to quantify the amount supplied to Chennai by such wells. For example, two household surveys of a stratified sample of 1500 Chennai households indicate that more than two-thirds of Chennai households supplement their water supply with private wells (Srinivasan, V., 2013). Another estimate suggests that about 60 percent of Chennai household needs are supplied by private wells (Janakarajan, S., 2013).

There are no official estimates for the number of privately owned wells. However, it is estimated that there are 420,000 in Chennai city alone. A large portion of households have private wells. Two extensive household surveys, conducted in 2004 and 2006 respectively, suggest that 60-70 percent of Chennai's households use private wells to supplement water (Veena,S.& Seema,K., March 2014). Also, many industries rely on privately owned wells to operate. The estimated depth of borewells is 300-500 feet (Lakshmi, K., May 2017).

Reliance on private wells varies over time, with Chennai turning to them more when piped supply is restricted. One study indicates that just 43 percent of households reported relying on private wells during wet periods, whereas all households reported relying on them during drought periods (Srinivasan, V., July 2010).

Private Market: Water Vendors

A private market also supplies water to Chennai, in large quantities–filling up overhead tanks or sump pits–or in smaller quantities, primarily at the retail level by packet, bottle or jerrycan for drinking water purposes. These large quantities are transported into the city by tanker truck. Estimates suggest that up to 10,000 such trucks populate highways around Chennai every day (Rajagopalan, K., 2013), each with a typical capacity of 12,000 litres (Anand, P.B., 2001). That's 120 million litres of water per day. Other research indicates that 400 water tanker companies are licensed in Tamil Nadu, which accounts for 50 percent of all licensees in India. Of these, 220 companies are said to operate in and around Chennai – indicating the size of the domestic water tanker market, and the extent to which Chennai dominates it (Kennedy et al., 2014). The water tanker truck market is informal and largely unregulated. However, tanker companies do require licensing as per the Chennai Metropolitan Area Groundwater (Regulation) Act 1987. Tanker truck water is typically untreated and not fit for human consumption (Munian,2010).

Private market water supply fluctuates according to Metrowater availability. However, one study of 450 households found that 16 percent accessed water through mobile tanker truck, and 45 percent purchased packaged water (Munian, 2010, p. 185). Another rough 2012 estimate suggests that up to 90 percent of residents in certain neighbourhoods of Chennai's Old Mahabalipuram Road (OMR) bought drinking water in cans or bottles, and that 55 percent purchase water from tankers because piped supply is unreliable or unavailable (Akshatha, M., Citizen Matters, 2017).India-wide, a 2005 study estimated that tankers met about 7 percent of the demand-supply gap for six cities across the country. The study found the market to be particularly significant during drought, and an important factor to consider when calculating household spending on water (Srinivasan, V., July 2010).

Tanker truck water is purchased from farmers who, in many cases, have shifted away from agricultural forms of livelihood to water production. Selling water to tankers is often more profitable than farming (Ruet, J. et al., 2002). At least one report suggests that

Metrowater purchases this water for INR 3 per cubic metre and sells it at INR 15 per cubic metre (Munian, 2010). Interviews with tanker drivers reveal that tanker water is sourced from peri-urban agricultural wells located within 0.5 km of major roads, and never from residential area wells (Srinivasan, V., July 2010).

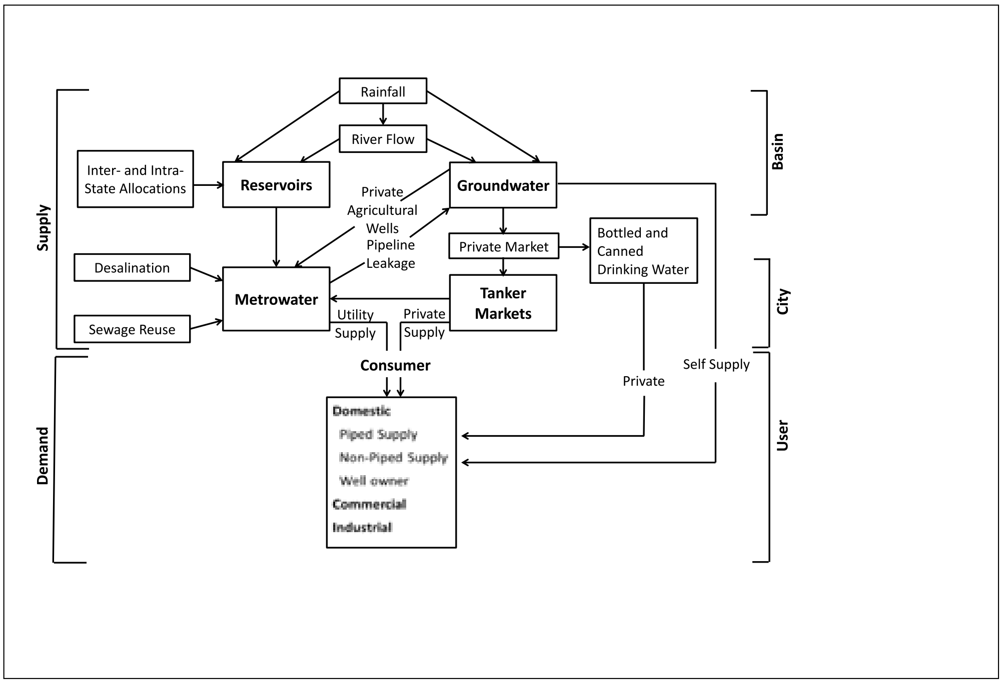

Figure 16: Water supply and demand in Chennai

Adapted from Srinivasan, V., Oct. 2010

Water Demand

This section presents information on water demand in Chennai. Exact figures are not known, because Chennai's water supply is largely unmetered (as discussed in the previous section). However, different approaches have been tested for qualifying demand, and these are presented. Also, varied estimates for quantified current demand are presented, as well as for future demand.

Qualifying Chennai's Water Demand

Demand for water in Chennai varies, and exact amounts are not known. Approaches to qualify demand vary as well. Below are some examples.

Defining Demand by Consumer Type

One approach to defining demand is in terms of consumer type, where consumers are defined by the mechanisms by which they receive water. The above section on water supply outlines these mechanisms (Figure 16). They include Metrowater supply (piped and non-piped), self-provision and private markets. Consumers defined as “domestic” have piped Metrowater connections, are unconnected and/or have private wells. Some consumers can afford sump or overhead tanks to intermittently channel piped supply into their tanks, increasing their demand. Consumers with private wells top up Metrowater supply as needed – often meaning they enjoy an effective 24/7 supply (Srinivasan, V. et al., July 2010). These private wells, however, are also associated with negative health outcomes such as mosquito breeding – which in turn leads to the spread of diseases such as malaria and dengue (Anand, P.B., 2001).

Industrial consumers are another demand category in this approach. Industries typically drill their own borewells and therefore tend to profit from a more stable water supply than most households (Munian, 2010). Industries also receive Metrowater supply. For example, some industries in the northern areas of Chennai have access to yield from Metrowater well fields that is pumped directly to them. Also, water sourced from hired agricultural wells is found to primarily serve industrial needs. Further, it is argued that Chennai industries receive favourable Metrowater treatment compared to the treatment received by domestic and other users. For example, Ruet et al. (2006) sees a clear partiality towards industry in their appropriation of water sourced from private agricultural wells. This is also reflected in government promises to provide 24/7 supply to Chennai’s IT corridor (although this promise remains unfulfilled).

Agricultural consumers are also mentioned in some literature as a category defining demand; however, in the case of Chennai it is negligible. Farmlands have mostly been urbanized, with farmers selling their lands to urban buyers. It is noted, however, that the management of agricultural water needs is still carried out by the PWD, and some experts we interviewed believe this should change to come under a consortium of Metrowater and others instead (Interview with TUFIDCO official, 2017).

Defining Demand by Variable

Water demand is also defined in terms of influencing factor. A study of Chennai’s residential demand finds that it is primarily a function of population – as it generally is around the world. As populations grow, so, too, the number of people and the need for more water. Chennai’s population growth is discussed in detail in the accompanying Chennai: Urban Visions report. In sum, it is on an upward trajectory and, as a result, demand for water in Chennai has been challenging supply capacity for years.

The same study of Chennai’s residential demand highlights other defining factors, including economic, sociocultural, environmental and technological factors. It finds that economics are not a significant variable when studying Chennai water demand: water is charged at a fixed rate of INR 300 for a half-yearly period, and as a result withdrawal has zero marginal cost. This fixed tariff method also impacts potability as a factor: when all water comes at one fixed price, consumers don't distinguish between water as cooking or non-cooking, drinking or non-drinking.

The study also indicates sociocultural factors as a variable in defining Chennai residential water demand. It cites studies showing that household size and educational background correlate with total demand. A larger house often means increased total demand – while also indicating decreased per capita consumption. Levels of education, and specifically the educational standard achieved by household heads, are also found to influence residential water demand: the higher the level of education, the more the demand for water.

In terms of environmental and technological factors, these are found to impact Chennai's residential demand for water. Environmental factors such as changes in rainfall, temperature and evapotranspiration are seen to enhance demand for water. And technological factors are seen to play a major role in reducing water demand. These factors include details of household appliances such as dishwashers, washing machines and water-conserving taps – as well as types of toilet flushes and showers which differ widely in the amounts of water they use (Munian, 2010).

Quantifying Chennai's Water Demand

Chennai water demand is also quantified. The results here are varied (Refer Table 2). For example, Chennai's Second Master Plan estimates total water demand for Chennai at 2248 MLD (Second Master Plan), while Metrowater's Master Plan Report indicates 1136 MLD (2015). A Metrowater official we spoke with calculated demand at INR 1.50 per litre per capita, meaning that with a current population of approximately 7,000,000, demand stands at 1050 MLD (Government official from Metrowater, 2017). Other estimates for the 174-sq.-km city area indicate total demand at 1200 MLD, while those projected for the expanded Greater Chennai Corporation (GCC) area, covering 425 sq. kms are an estimated 1600 MLD (Interview with TUFIDCO official, 2017).

Source of Estimate	Estimated Demand for Water (in MLD)
Chennai Second Master Plan	2248
TUFIDCO Officials	1200
Metrowater Master Plan	1136
Metrowater Officials	1050

Table 2: Estimates for current water demand in Chennai, with source of estimate

One household survey estimates the demand for potable water at 20LPCD – and generally assumes it to be inelastic – while demand for non-potable water is found to be a function of price, household income and family size (Srinivasan, V., 2008).

Consumer-specific amounts for Chennai water demand are estimated as follows: domestic consumers require 859 MLD, industrial consumers 86 MLD, and commercial consumers 988 MLD (Metrowater Master Plan Report, 2015).

All estimates are projected to increase throughout the city and Tamil Nadu state as populations grow and needs change as fuelled by economic growth. One projection for total water demand for the Chennai city area indicates it will be 1560 MLD in 2019 (Gopalakrishnan, S., June 2017). A 2013 Metrowater document predicts Chennai city future demand for freshwater sources is 686 MLDin 2031 and 710 MLD in 2041 (Metrowater, 2013).

Demand for privately supplied water is found to be particularly high. Narasaiah (as quoted in Rajagopalan, K., 2016) finds that 50 percent of low-income households in Chennai purchase water privately. It was found that some households spend more than 5 percent of their income on this water. Generally, urban demand for tanked water supply is found to be driven by two combined factors: inadequate piped water supply and unreliable groundwater supply in wells. A 2013 report, however, posits that, in the case of Chennai, the primary factor may be unreliable groundwater supply in wells (Srinivasan, V. et al., 2013). Research also indicates that Chennai-ites believe privately sourced water to be of higher quality, and purchasing water on this market has become part of Chennai's water consumption culture (Rajagopalan, K., 2013).

Primary Analysis: *Does new water demand as determined by recent developments match Metrowater supply projections?*

This analysis aims to understand if environmental impact assessment (EIA) permissions granted for new construction projects match with the water demand projections made by Metrowater, Chennai's water utility. Being the primary water supply provider for the city, Metrowater's mandate is to provide water for domestic as well as industrial purposes for the area within the Chennai Corporation limits (176 sq. kms). However, it has also extended its services to the surrounding urban local bodies (about 7.88 sq.kms in extension areas and Manali New Town) and has already initiated measures to provide services for the entire CMA. The recent CMA expansion from 1189 sq. kms to 8878 sq. kms puts more pressure on Metrowater as the primary water supply authority in the CMA as the city experiences both heavy rain from monsoons and droughts, and is generally considered a water-scarce region. Therefore, it is critical that the methodology followed to project future water demand is rigorous and exhaustive, taking into account water availability, all possible demand avenues and climate-related risks.

Data was obtained on current and future water supply and demand through interviews with key persons at Metrowater for the earlier CMA of 1189 sq. kms. Data on environmental clearances granted as well as water requirements for each project was gathered from the SEIAA website.

The SEIAA grants permissions for nine categories of projects including coal mining, industries, infrastructure and miscellaneous projects near the coast, new construction projects and industrial estates, non-coal mining, hydroelectric and thermal projects. It granted 12 environmental clearances for the year 2016 in the Chennai area under the "newconstruction and industrial projects" category which comprised residential, commercial and institutional projects. According to the project documents, total water requirement for these 12 projects is 2.95 MLD.

Water demand projections of Metrowater are made for five-year intervals from 2015-2020 up to 2045-2050. We picked 2016 as a sample year to compare yearly incremental water demand to water requirements of new construction projects that obtained EIA clearance. Metrowater's water demand projection is essentially total water demand that includes existing demand and additional demandfor residential, industrial and commercial sectors for every five years (Table 3). Therefore, to compare water demand projections with water requirements for new construction projects, the incremental water demand projected for each year from 2015 to 2020 had to be computed. This was done by estimating the percentage share of industrial and commercial water demand (12.6 percent) to total demand (which was assumed as constant for each year) and incremental demand per year for 2015 and subsequent years up to 2020. Based on these values, the yearly water demand for industrial and commercial sectors was estimated at 4.62 MLD for each year from 2015-2020.

Sector	Year							
	2015	2020	2025	2030	2035	2040	2045	2050
Domestic	416.0	603.8	617.4	629.3	642.2	655.0	666.0	679.7
Industrial	34.1	36.2	37.0	37.8	34.7	35.4	36.0	32.6
Commercial	26.0	19.0	19.0	19.0	19.3	19.7	20.0	20.4
Total	476.1	659.0	673.4	686.0	696.2	710.0	722.0	732.7

Table 3: Water demand projections by Chennai Metrowater (in MLD)
Source: Chennai Metropolitan Water Supply and Sewerage Board

Water demand projections for the industrial and commercial sectors are seen to be decreasing from 2015 to 2050. The decrease could be because of reclassification of commercial buildings into other sectors or change in water sources to recycled water. The decrease could also be because according to Metrowater, Chennai is already "built up" with limited space available for expansion. Of course, this reasoning will change with new Chennai Metropolitan Development Authority (CMDA) expansion and so will the water demand projection.

Assuming that the "new construction and industrial projects" category consumes 60 percent of the total water consumed by all categories of projects granted environmental clearance, for 2016, the water demand projection of Metrowater was approximately 2.72 MLD, while water requirement for new construction projects granted EIA clearance for 2016 was 2.95 MLD indicating that Metrowater's expansion plans seem to more or less account for new permissions granted. However, this statement is only valid based on two assumptions; a) the percentage (12.6 percent) of industrial and commercial water demand to the total water demand is constant for every year going forward and, b) the category "new construction and industrial projects" consumes approximately 60 percent of total water consumed by all categories of projects granted environmental clearance.

These assumptions need not be valid for the future. Water demand projections for the industrial and commercial sectors are seen to be decreasing from 2015 to 2050 (Table 3). The decrease could be because of reclassification of commercial buildings into other sectors or change in water sources to recycled water. The decrease could also be because according to Metrowater, Chennai is already "built up" with limited space available for expansion. Of course, this reasoning will change with new Chennai Metropolitan Development Authority (CMDA) expansion and so will the water demand projection.

The second assumption need not be valid because the new construction and industrial sector might have a lower water requirement than the assumed 60 percent, and other sectors such as non-coal mining, hydroelectric and thermal projects might have higher requirements. Taken together, this implies that unless there is a slowdown in the granting of permissions to new construction and industrial projects, demand for water might outstrip planned supply.

Even if these assumptions might be valid for the future, there are institutional disparities that have not been accounted for while making the water demand projection. The most evident is that neither the SEIAA nor the CMDA have stated that they will be granting fewer environmental clearances and planning or building permissions respectively in future. All new large construction projects in the CMA are required to first get a clearance, i.e., a “No Objection Certificate” from SEIAA and then planning and building permission from the CMDA. Being the primary development authority for the Chennai region, the CMDA’s functions encompass creating a master plan that shapes Chennai’s development trajectory and granting planning and building permissions based on guidelines already set out in its development regulations. These development regulations provide detailed guidelines for all development defined in the Town and Country Planning Act 1971 and only reject applications if any of the criteria mentioned in the regulations are not met. While the SEIAA rejects projects if proposals do not provide required information as per the Environment (Protection) Act, 1986. Both SEIAA and the CMDA are not mandated to reject projects for any other reason.

Further, the total water requirement of new construction and industrial projects computed for 2016 is a conservative estimate because it considers only Category B projects that must get approval from the SIEAA. There are other projects which are either too large (Category A), so they must get permission directly from the Ministry of Environment and Forests (MoEF) or so small that they need not get environmental clearance at all. These projects can be approved directly by the local body and not the CMDA – in this case the GCC within city limits, town and village panchayats in those areas falling under Tiruvallur and Kanchipuram districts in the CMA. All these projects have a significant water footprint and should be accounted for while projecting future water demand.

In conclusion, there does not seem to be any link between the number of environmental clearances granted for new projects and future water demand projection by Metrowater. The number of ECs granted for 2016 coincidentally matches the water demand for the same year based on certain assumptions, but it is very possible that this will not be the case in future. Metrowater’s future water projection for the industrial and commercial sectors shows a decrease in water requirement up to 2050. This decrease, perhaps due to change in water source or project reclassification, seems to underestimate future water demand. Further, unless the agencies (GCC/SEIAA/CMDA/MoEF) responsible for granting permissions either coordinate or cap the number of permissions granted each year, supply and demand mismatches are likely to continue. The recent increase in the CMA area from 1189 sq. kms to 8878 sq. kms implies that a larger area with subsequently higher overall water requirements will now have to be serviced by Metrowater. It is critical that they are equipped to supply the actual water requirement to be better prepared to handle extreme climate events such as droughts and floods which the service area is prone to.

Utility-based supply such as that of Metrowater is intrinsically vulnerable to climate change and its impacts (in this context drought and floods) because it is a large and complex system involving multiple actors. In the dry season, piped water systems face higher risk because supply may be more intermittent with increased risk of contamination through backflows, while in the wet season flooding is likely to cause contamination through cracks in pipelines. However, well-run utilities with adequate human capital in the form of trained and well-qualified staff, financial capital to upgrade and maintain existing infrastructure and active interaction with other relevant agencies, can potentially be highly resilient to the impacts of climate change and consequently so will utility users (WHO, 2009).

Water Balance or Water-Sector Sustainability in Chennai

Water supply in Chennai is based on water availability, with variations depending almost entirely on rainfall. A study of Metrowater's average supply over 35 years indicates that monthly amounts supplied between September and December (i.e., the months during which the north-east monsoon is received) are generally higher than averages for the entire year. Supply in October 1988, for example, was 183 MLD, while the monthly average for that year was 154 MLD (Munian, 2010). Insufficient rains mean water scarcity in Chennai, and they are inevitable some years. In addition, rainfall patterns are predicted to change, with rain likely to fall in shorter, large bursts – see Chapter 6 for more details on the likely impacts of climate change on rainfall. Moreover, Chennai's reservoirs have limited storage capacity. One analysis of historical data indicates that 15 months' storage cannot guarantee a minimum supply over a multi-year drought – as calculated using 2010 levels of demand (Srinivasan, V., July 2010). Additionally, Chennai's groundwater resources are being depleted as a result of over-extraction, as discussed above, and are also increasingly contaminated by pollutants . At the same time, demand for water in Chennai is increasing and is projected to continue to increase.

Estimates for total water requirements for Chennai city, as mentioned, vary according to source. According to Metrowater's website, they were 710 MLD in 2001, are 650 MLD today, and are predicted to be 942 MLD in 2021 (Chennai Metrowater, Water Supply System). This will increase still further if and when plans to expand the Chennai city boundary are materialized. Furthermore, current demand is actually restricted – by water shortages and the failure of piped water supply to regularly provide for significant portions of Chennai's population. Solving any or part of these issues– as is planned – (see next chapter) is likely to increase Chennai's demand for water still further (Munian, 2010).

It is clear that supply can be tenuous and that demand is increasing. However, because estimates for total supply and demand vary, it is hard to say whether the two equate. Metrowater officials we interviewed suggested that they essentially do, but predict an imbalance going forward – particularly in light of plans to expand city boundaries (Interview with Metrowater officials, 14 February 2018). Therefore, they argue, it is important to increase capacity and supply. Others point to the extreme measures that are sometimes required to meet water needs as a clear indication that there is no balance. They point, for example, to the occasional alternate-day rationing of drinking water required in Chennai. Others point to the extreme scarcity during droughts as an indication that balance is lacking – so drastic in 1993, for example, that 2300 cubic metres of water was transported to Chennai by train from Erode and Neyveli – 425 kms away (Biswas, Asit K. & Uitto, JuhaI., 1999).

Still others dismiss the idea that a lack of balance defines or will define Chennai supply and demand. Chennai receives adequate rainfall to supply its needs, they argue: more than the state and national averages, and more than many regions that fare far better in their water management systems. "If you ask me," one expert told us, "there is no real gap." The actual problem, these experts say, is with Chennai's water management system, and the means used to address supply shortages. They disagree with efforts to build on reservoir capacity, increase supply from faraway rivers or construct new desalination plants. Instead, they argue, Chennai should revive traditional water catchment systems to improve capacity and ensure water-sector sustainability. Chennai receives ample amounts of rainfall, they argue, and its 320 lakes, tanks and ponds are sufficient to capture and store it. Moreover, these existing waterbodies have many benefits: they supply drinking water, they recharge groundwater, they create a microclimate and they help maintain biodiversity. Furthermore, the money spent on large infrastructure projects would go further if spent on reviving these traditional systems and encouraging a return to decentralized water management (Narain, S., 2017; SaciWATERs, 2018, personal communication).

CHAPTER 4: DRAINAGE, SANITATION AND SOLID WASTE

CHAPTER 4 : DRAINAGE, SANITATION AND SOLID WASTE

This chapter presents Chennai's drainage and sanitation systems: the mechanisms by which excess water, waste water, excrement and solid waste are removed from the Chennai city area. Drainage is particularly important in view of Chennai's flat topography (discussed further on page66) which means that excess water doesn't always readily flow away from the city. This means that, unless it is channelled away, it can stagnate and – if in large amounts – inundate. Chennai drainage includes macro and micro drain instruments. Sanitation – which includes collection, treatment and disposal of sewage– also impacts the water sector; it is closely linked with water quality and water pollution. Finally, solid waste is a major contributing factor to disrupted drainage systems as well as to pollution of waterbodies and groundwater tables.

Macro Drains

Chennai's macro drainage system consists of the Cooum and Adyar rivers and a network of canals and drains. During monsoon seasons, or when rainfall is heavy, this network transports excess water away from the metropolitan area and eventually into the sea. The network covers a total length of 157.8 kms and is administered by the PWD. Major canals are the Buckingham Canal, Otteri Nullah and Virugambakkam-Arumbakkam drain.

The Buckingham Canal is perhaps the most widely known. It runs north to south and connects all three of the Chennai region's rivers, thereby intercepting all drainage that flows to the east. It was constructed in 1806, originally for navigation purposes and to transport goods, as well as to accommodate floodwater. Today it is used exclusively for its drainage function. It runs 40 kms through the CMA (Greater ChennaiCorporation Disaster Plan, 2017). Beyond drainage, the Buckingham Canal serves the added function of providing a barrier that arrests seawater intrusion (CMDA, 2010).

Another macro drainage system function is to discharge excess reservoir water: when major rainfall fills reservoirs to their full capacity, manned regulator controls release water from those reservoirs into one of Chennai's three rivers. The regulator control for Chembarambakkam reservoir, for example, is situated at Korattur anicut, and released water flows into the Cooum river. Excess water from Poondi reservoir, on the other hand, is released into the Kosathalaiyur river.

Micro Drains

In addition to macro drains, storm water drains also channel excess water into Chennai’s major drainage network. Storm water drains are administered by the GCC. Responsibility for their management lies with the CMDA, PWD and TNSCB. Chennai has 7360 storm drains, covering a length of 1894 kms (Greater Chennai Corporation Disaster Plan, 2017). These drains can be smaller or larger in size, depending on whether they collect run-off from smaller or larger streets.

Sanitation

Sanitation is defined as “conditions relating to public health, especially the provision of clean drinking water and adequate sewage disposal”. In this section, we address sewage and solid waste. Chennai’s system for sewage collection, treatment and disposal is presented, along with estimated amounts involved. Also presented is an overview of Chennai’s system for managing solid waste, including some of the data available onamounts produced. Solid waste is included here because of the tremendous impact it has on Chennai’s water sector, including its drainage system.

Sewage

Sewage is defined as “excrement or waste water (that which has been used in homes, institutions, businesses or as part of industrial processes) as conveyed by sewers”. Chennai’s sewage is collected at 445,260 connections in homes and other buildings and then transported through 4265 kms of sewer mains to 232 sewage pumping stations, where it is treated at 11 treatment plants (Figure 17). This system covers 99 percent of the core city and selected additional areas, serving an estimated 810,014 consumers. It is managed by Metrowater in five distinct zones, each with independent collection, conveyance, treatment and disposal facilities (Arappor Iyakkam, 2017).

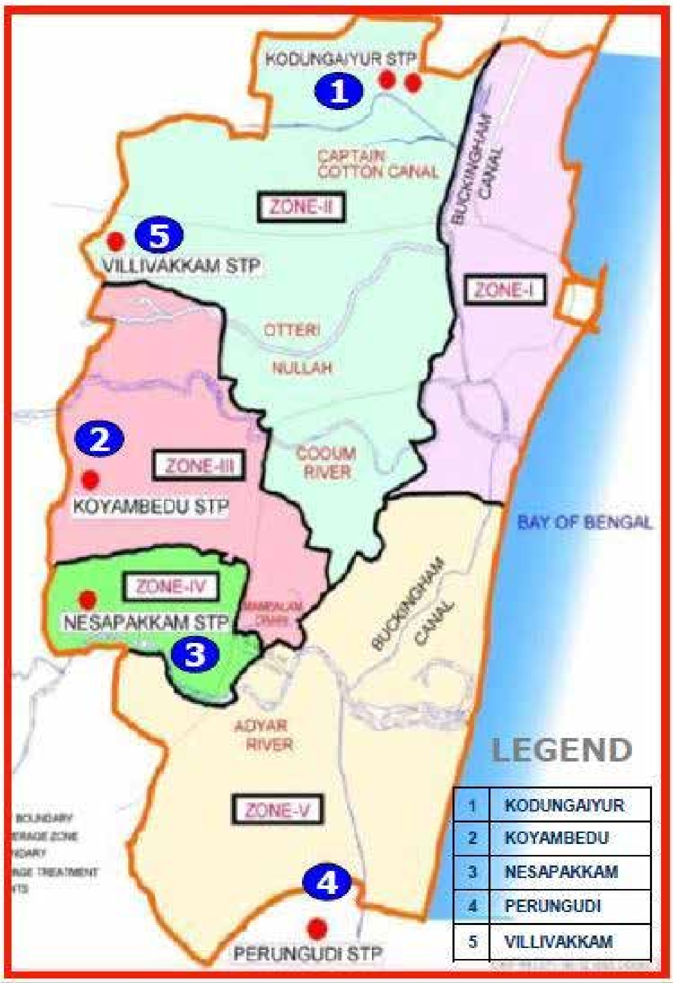

Figure 17: Chennai sewage system

Source: Metrowater, 2013

It is not clear how much sewage Chennai generates. Different sources provide different estimates. According to Metrowater's website, 550 MLD is generated. However, a senior Metrowater engineer clarified that this only accounts for sewage generated in the nine core areas of Chennai. It does not include sewage generated in other areas, where collection is not uniform (Metrowater, 2018, personal communication). Another Metrowater document indicates the total amount generated is 580 MLD (Metrowater, 2013). Arappor Iyakkam, a civic group in Chennai, calculated the total amount based on India's Central Pollution Control Board guidelines, which indicate that the amount of sewage generated is equal to total water supply multiplied by 80 percent. Accordingly, the Arappor Iyakkam estimate for total sewage generated in the CMA is 1952 MLD; it is based on a total water consumption estimate of 2441 MLD (2017).

Regardless of the amount generated, that which is collected is first processed by a pumping station and then piped to centralized treatment centres where it is treated. Sewage is treated according to three distinct processes: a primary, secondary and tertiary. The primary process removes solids and grit; the secondary process aerates sewage, recycles sludge and digests all organic matter; and the third involves reverse osmosis that further filters out unwanted elements. This third process is required if water is to be reused (Metrowater, 2018, personal communication). Currently, Metrowater treats sewage in five zones at 11 treatment plants with a total capacity of 727 MLD. These plants use a combination of primary and secondary processes. All plants have the added benefit of biogas to generate power to operate each plant, which reduces reliance on state-supplied electricity and reduces greenhouse gas emissions (State of Environment Report for Tamil Nadu, 2017; TUFIDCO, 2017, personal communication).

Once treated, a small portion of the treated sewage is sold to industries and the remainder is released into rivers. According to Metrowater, 550 MLD is currently treated. The discrepancy between this and the total treatment capacity is explained as the outcome of the city area's "poor sewage collection system", where problems include illegal sewage connections that link directly to waterbodies and an absence of underground sewage connections (TUFIDCO, 2017, personal communication; Arappor Iyakkam, 2017). Of this 550 MLD, 23 MLD is sold to industries, including Madras Refineries and Madras Fertilizers. Industries typically treat all purchased sewage using the tertiary treatment process before they use it.

Importantly, most Metrowater-treated sewage is dumped into city waterbodies, contributing significantly to their pollution. See Figure18 below for estimated amounts. According to official figures, a minimum of approximately 527 MLD is released into waterbodies. Of the treated 550 MLD, 23 MLD is sold to industries, and Metrowater uses a small amount of the remaining treated sewage for horticultural purposes around its campus and parks. The entire remaining amount is released into waterways (Metrowater, 2018, personal communication).

In addition, untreated sewage is also dumped in city drains and waterbodies; it is referred to officially as "the most visible manifestation [of] severe pollution of the six major waterways and drains". No official estimate exists for how much untreated sewage is dumped this way. However, the Arappor Iyakkam estimate referred to above suggests that the number may be as high as 1402 MLD. This dumping occurs by means of illegal sewage connections that link directly to waterbodies, by trucks discharging sewage into waterbodies, or by sewage being let out directly into storm drains.

Untreated sewage is reaching a critical point in many countries, with negative outcomes on many levels. At the local level, waterbodies and groundwater tables are polluted and drains are clogged, leading to flood risk. At a global level, there is also evidence that urban waste water may contribute to antimicrobial resistance, or the spread of superbugs that don't respond to antibiotic treatment. This means sewage pollution of Chennai's waterbodies could be contributing to increasing numbers of untreatable infections around the world (Qadir, M. et al., 2011).

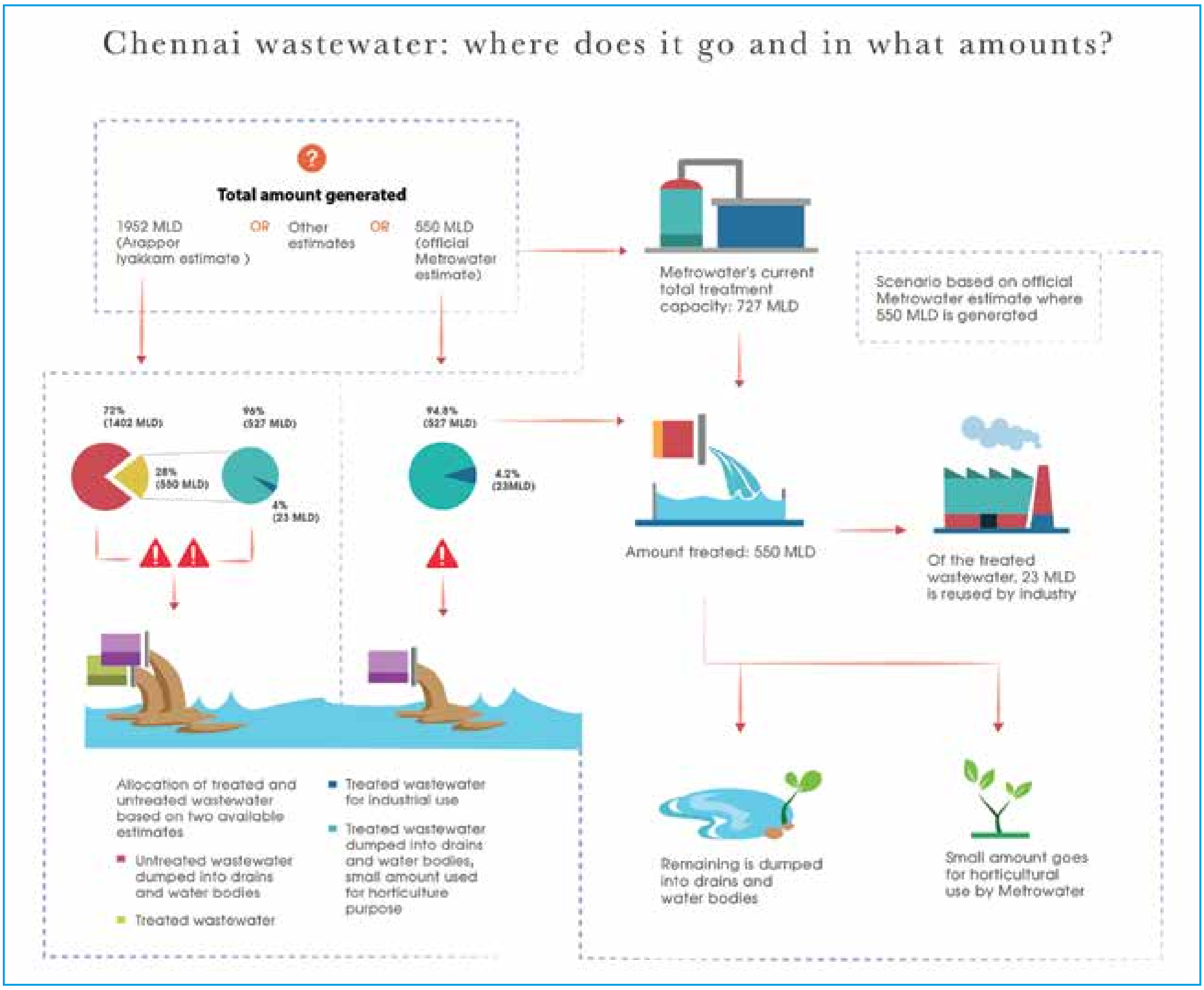

Figure 18: Chennai wastewater amounts and reuse

Solid Waste

Solid waste poses a significant and growing threat to Chennai's water sector. While some municipal waste is collected and processed, large amounts are dumped into waterbodies every day. This dumped waste comes primarily from residences and businesses, including hotels, restaurants and markets – so it contains a range of materials including plastics, organic waste, metal, glass and rubber. Chennai waste pollutes waterbodies and clogs drainage systems, contributing to pollution and flood risk. It also contributes to poor health outcomes by providing breeding grounds for disease-bearing organisms such as mosquitoes and rats. Formally collected and processed waste is hazardous to the water sector as well: much of it ends up in landfills where it seeps into the ground, contaminating water tables.

In terms of the waste dumped into waterbodies, data does not appear to exist on quantities. However, we do know that an estimated 5400 metric tons is generated in Chennai every day (Seddon, J. et al., 2016). Additionally, 700 metric tons of building debris is generated every day (GCC, Solid Waste Management Department, 2018). We also know that the amount of waste Chennai produces has been steadily increasing: 3000 metric tons per day in 1996, 4067 metric tons per day in 2001 and 5400 metric tons per day in 2016 (Second Master Plan for Chennai Metropolitan Area: 2026, 2008; Seddon, J. et al., 2016) (Figure 19). These figures represent a growing number of consumers and also increasing amounts of waste generated per capita: 585 grams in 1996, 620 grams in 2001 and an estimated 760.60 grams in 2016.

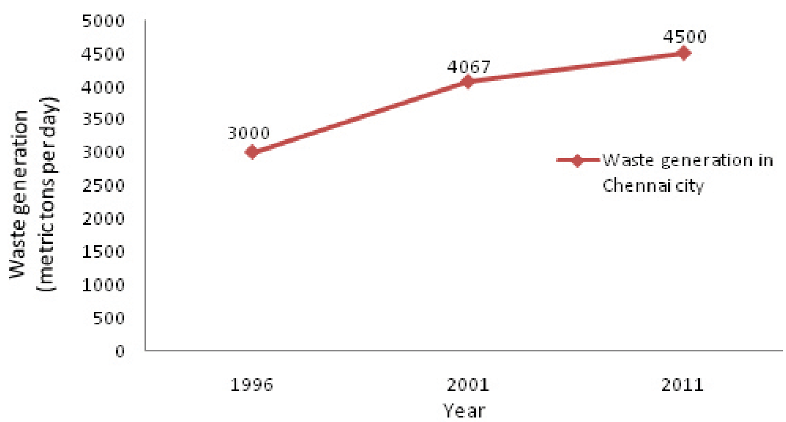

Figure 19: Waste generation in Chennai city
Source: GCC, Solid Waste Management

The GCC, the entity responsible for collecting and processing solid waste, estimates the following as the sources of Chennai's waste and the percentage generated by each source:

Source of Waste	Percent of Generation
Residential	68
Commercial	16
Halls, Schools, Institutions	14
Industrial	2
Hospitals and Clinics	Disposed separately at source (no data)

Table 4: Source of Chennai waste and its percentage

Source: GCC, Solid Waste Management

Another area of concern is biomedical waste. Experts are concerned about ongoing dumping of this waste, particularly in peri-urban areas, which results in water contamination by hazardous pollutants. They are also worried about processed biomedical waste not being treated correctly – with other negative outcomes. International standards require that biomedical waste be incinerated at temperatures higher than 850 degrees centigrade for sustained periods of time lasting longer than two seconds, and Indian standards are still more stringent: they require a two-chamber incinerator system, with the primary chamber holding a minimum temperature of 800 degrees centigrade and the secondary chamber a minimum temperature of500 degrees centigrade (WHO, Standards on dioxins and their effects on human health, 2016). Failure to comply with these regulations leads to significant air pollution impacts and negative health implications. The GCC does not appear to have data on amounts of biomedical waste produced (see Table 4 above), but some estimates suggest that 100-200 grams is produced per hospital bed, which amounts to a large quantity: an estimated 13,974 hospital beds in Chennai (Chennai District Statistical Handbook, 2015-2016). This is likely to increase, particularly considering Chennai's growing recognition as an Indian hub of medical tourism (Janakarajan, S., 2007; SaciWATERs, 2018, personal communication).

CHAPTER 5: INVESTMENTS IN THE WATER SECTOR

CHAPTER 5 : INVESTMENTS IN THE WATER SECTOR

Demand and supply for water in Chennai may or may not equate, and it is clear that drainage, sanitation and solid waste issue significantly impede the functioning of Chennai's water sector. Nonetheless, investments are being made to improve the sector and the extent to which demand and supply match. Numerous bodies, ranging from Metrowater, the GCC and the PWD, to civil society, are making ongoing efforts to improve on what exists. These investments are varied in nature – from large-scale, large-budget projects to group clean-up drives and smartphone applications. At one point, chemicals were apparently spread on Chennai lakes in an attempt to control evaporation, with an observed 25 percent saved (Biswas, Asit K. & Uitto, Juha I., 1999). This section describes other investments being carried out, grouped according to the entity making them. They include investments made by Metrowater, the GCC, the PWD, multi-government groups such as the CRRT and the Sustainable Water Security Mission (SWSM), citizens and public-private partnerships. Also mentioned are a number of ongoing schemes to conserve water at the district level.

Metrowater Investments

Chennai's water utility, Metrowater, is well aware of scarcity issues facing the metropolitan area, and is taking active steps both to conserve existing drinking water resources and to invest in mechanisms to improve supply (Figure 20). One major conservation effort is aimed at industries. In order to receive government sanction, industrial projects are mandated to make their own water supply arrangements– or use recycled water. These industries cannot legally utilize city drinking water supply. An early example of this was Madras Fertilizers Ltd who at first utilized 18 MLD of raw (untreated and therefore non-potable) water that was sourced from aquifers located close to the site and supplied by Metrowater. However, that was stopped entirely during the 1983 and 1987 droughts, forcing the company to shut down temporarily and to search for new solutions which ultimately involved the construction in 1993 of an STP using reverse osmosis technology to convert 15 MLD of effluent into 12 MLD of industrial-grade water (Biswas, AsitK. & Uitto, Juha I., 1999).

Additional Sewage Treatments Plants

Metrowater has proposed to improve sewage reuse efforts with plans to design, build and operate three additional tertiary treatment plants using reverse osmosis, with a total capacity of 90 MLD. This is an indirect response to Tamil Nadu's chief minister's announcement under Rule 110 in the State Assembly that Chennai must recycle and reuse more of its water.

Plans to construct the new plants are underway. The first is at Sholinganallur, with an anticipated capacity of 36 MLD and a total anticipated cost ofINR 27.31 crore. Also, construction of two plants in the north of Chennai is underway: one at Kodungaiyur with a 45-MLD capacity and a total anticipated cost of INR 223.91 crore, and one at Koyambedu which is projected to cost INR 394 crore. Both these plants will serve SIPCOT industries along the Manali to Ennore and the Manali to Minjur corridors. Construction on both is expected to be complete by the end of 2018.

All three new sewage recycling plants share similar attributes. They all follow a three-stage plan for treatment: pre-treatment, to control suspended impurities; secondary treatment, to limit silt density index; and tertiary treatment and reverse osmosis, to disinfect. The projects also all include transmission pipelines to carry treated water directly to industries. In terms of funding, the projects are all designed as public-private partnerships, with costs shared by state and Central governments and Metrowater, and loans and funding from entities such as the World Bank, Japan's Overseas Economic Cooperation Fund (OECF), the Japan International Cooperation Agency (JICA) andJ awaharlal Nehru National Urban Renewal Mission (JNNURM) (Source: Chennai Metrowater, Projects).

According to some officials, Chennai's sewage system has been subject to more improvements than the water supply system. Capacity has been added and modifications made. However, this work is also described as reactive; done in response to civic complaints rather than preventive.

New Desalination Capacity

In addition to efforts to recycle and reuse water, Metrowater plans to invest heavily to improve on Chennai's water supply, primarily with proposed plans to add 550 MLD to Chennai's supply capacity by means of two new desalination plants. The first is planned at Nemmeli with an anticipated capacity of 150 MLD. This will be phase 2 of the existing Nemmeli plant, which was constructed in 2013 and currently supplies an estimated 85 MLD. The project is anticipated to cost INR 1371.86 crore, 60 percent of which will be covered by a loan from KfW, Germany, with the remaining 40 percent to be contributed by the state government from its own resources including Central government schemes (Municipal Administration and Water Supply Department, 2016).

The second proposed desalination plant is to be located at Perur with an anticipated capacity of 400 MLD. The project was initially costed at INR 4070.67 crore and then revised to INR 5300 crore in 2017 (New Indian Express, 2017). The Tamil Nadu state government has approached the Central government for approval to implement this project with funding from JICA (Municipal Administration and Water Supply Department, 2016).

Additional Water Supply from Lakes and Other Waterbodies

Metrowater has also been investigating the feasibility of drawing additional water supply from lakes and other waterbodies in the CMA. A Metrowater study indicates that a total of 71 large waterbodies were inspected in July 2015, with 27 found to contain water, 30 to partially contain water and 14 not to contain any water at all. In terms of quality, 39 were found to contain sewage pollution. The study recommends using 29 of the inspected waterbodies as sites for constructing a total of 87 open wells and borewells. It also recommends that wells be dug in the vicinity of the waterbodies, with three wells recommended around each of the 29 waterbodies. Overall, it is estimated that these wells will provide 5 MLD towards city water needs – with the one caveat that supply would only be extendable to locations in close proximity to the dug wells (Metrowater, 2018, personal communication).

It is often argued that Chennai should look to its existing waterbody structures to increase metropolitan water supply. Experts, including those at India's Centre for Science and Environment and Saci WATERs, emphasize that over 300 irrigation tanks populate the Chennai region. They also point to the adequate amounts of rainfall received most years. They argue that Chennai need only revitalize irrigation tanks and use them to capture and store the rainfall; that doing so would solve most water supply woes. Metrowater's efforts to investigate the feasibility of drawing on these waterbodies for additional supply appear to be in line with such recommendations; however, conclusions to dig borewells around these existing waterbodies appear to be more in line with shorter-term goals of extracting water rather than the longer-term sustainable water management that irrigation tank revitalization would mean. Moreover, we do know that Metrowater views efforts such as increasing desalination plant capacity to be safer bets because they see rainfall patterns as unpredictable and unreliable.

Flow Meters

A Chennai smart city project recently approved the installation of 251 electromagnetic flow meters in Metrowater's distribution system and water treatment plants. These meters will allow for control of non-revenue water, regulation of uniform distribution and assessment of demand, generally helping to ensure that "each drop produced is properly accounted for", according to an official involved. The meters are estimated to cost INR 11.63 crore, and will be installed in both core city areas and extended limits, with the latter receiving more flow meters (Kumar, Pradeep, 2018).

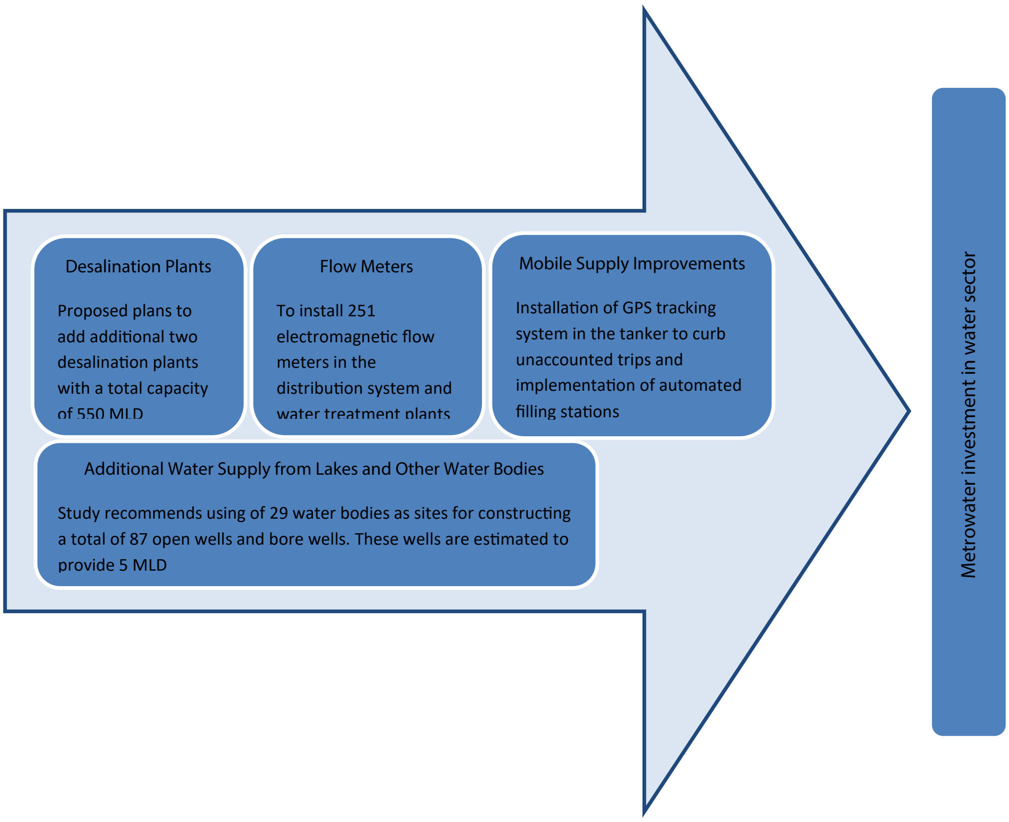

Figure 20: Metrowater investments

Mobile Supply Improvements

With Metrowater's increasing reliance on tankers to supply metropolitan area water, steps are being taken to improve this delivery system. In particular, Metrowater is seeking to curb unaccounted tanker trips by implementing a GPS tracking system. Tankers are commissioned to source water at filling stations or large peri-urban sumps, and then deliver it directly to predetermined destinations. However, many tanker drivers make unscheduled stops before their scheduled deliveries, selling off some of their supply to commercial establishments such as teashops and small restaurants, and pocketing the proceeds. The result is that supply is both delayed and diminished in quantity (Lakshmi, K., July 2017).

Another step towards improving mobile supply delivery is the planned implementation of automated filling stations. These will help Metrowater monitor the filling of tankers. Up until now, drivers operated valves to fill tankers themselves, leading to frequent tanker overflow and wastage. The new mechanisms will shut automatically after 6000 or 8000 litres have been dispensed, depending on tanker size, preventing leakage and waste (Kumar, Pradeep, 2018).

Greater Chennai Corporation Investments

The Greater Chennai Corporation, a civic body, is also investing in Chennai's water sector, primarily in the area of storm water drains.

Storm Water Drains

GCC's 2017-2018 budget estimate allocates INR 930 crore for storm water drains, with different entities having sanctioned different amounts, as detailed below. The GCC will spend these funds to upgrade and clean existing drains, as well as to construct new ones.

Description	Amount (INR in thousands)
JNNURM – Storm Water Drains	100,000
Storm Water Drains – GCC	200,000
Tamil Nadu Sustainable Urban Development Project - World Bank funding through TNUIFSL	7,000,000
Storm Water Drains	2,000,000
Total	**9,300,000**

Table 5: Storm water drains

Source: Greater Chennai Corporation Budget Estimate, 2017-2018

In addition, the GCC is also taking steps to mechanize the desilting of Chennai storm water drains. Desilting is a major component of storm water drain maintenance. Silt build-up in drains prevents water from running off and contributes to flooding in many Indian cities, from Mumbai to Chennai. Also, India's Supreme Court recently ruled to prohibit the employment of humans for this task, and in response, the GCC is procuring three robotic excavators and one amphibian vehicle to do the job. The amphibian vehicle will clean the waste in approximately 60 percent of Chennai's waterways, while the robotic vehicles, which clean smaller drains with a width less than 3.5 metres, will do the rest – with the North, South and Central regions of Chennai each covered by one robotic excavator (Times of India, 7 July 2015). It is not clear, however, whether such efforts are sufficient when compared with the numbers of storm water drains requiring maintenance. Nor have we seen information about the frequency with which these exercises will be carried out.

These investments in Chennai storm water drains are viewed alternately as extremely promising and as a “big racket”. On the one hand, government officials we spoke to were categorical about the effects these investments will have. Floods will no longer be a threat to Chennai once investments have been completed, they assured us (Greater Chennai Corporation and Chennai Smart City, 2018, personal communication). On the other hand, some experts dismissed these solutions. The government spends money on storm water drains, they told us, but doesn’t maintain them, allowing sewage and waste to be dumped into them, rendering them ineffective (SaciWATERs, 2018, personal communication).

Improving Civic Amenities and Boosting Flood Preparedness

The GCC is also identifying gaps in civic amenities and working to boost flood preparedness. A project to map these gaps is now underway using a drone-mapping tool. The project aims to plan and prioritize development work, including that related to water in and around the city (The Hindu, 22 November 2017). And the city will be more prepared for floods as a result of the flood sensors that GCC is installing in 16 locations across Chennai. These sensors will provide real-time alerts to civic officials, prompting them to bail out water from streets more quickly, with the aim of minimizing traffic congestion (The Hindu, 13 January2018).

Public Works Department Investments

Chennai’s Public Works Department is also investing in the city’s water sector, primarily with the creation of a new reservoir.

Chennai’s Fifth Reservoir

Plans are under way to investigate the possibility of creating Chennai’s fifth reservoir at Thervoy Kandigai-Kannankottai, 60 kms from Chennai. The project would involve linking two waterbodies, with projected capacity of 1 tmcft, which, it is estimated, will provide up to 30 days of drinking water supply to Chennai. Flow from here would be channelled to Poondi reservoir by means of a pipeline, which has already been laid by Metrowater. This new reservoir project was reportedly initiated in September 2013 under the Augmenting Chennai City Water Supply Scheme, and 70 percent has reportedly been completed. Currently, land acquisition processes are reportedly pending while farmer compensation packages are being worked out. The total project cost is INR 330 crore and will be carried out by PWD’s Water Resources Department (Lakshmi, K., September2017).

Other PWD Investments

Additional PWD investments are being carried out to create more storage capacity in various existing tanks, in constructing check dams and in desilting and rehabilitating three tanks in Ambattur, Korattur and Madhavaram (Water Resources Organization,2012).

Multi-Government Agency Efforts

Chennai Rivers Restoration Trust (CRRT)

The Chennai Rivers Restoration Trust is another government investment in the water sector; in this case in the form of a multi-department coalition or trust with the explicit aim of ensuring "pollution free and clean waterways and waterbodies" (CRRT website). The trust was initially created in 2006 under the name Adyar Poonga Trust. At that time its main thrust was the development of eco-parks – the first one being Adyar Poonga, situated on 58 acres around Adyar creek. In 2014 the trust was renamed CRRT with the added mandate of bringing together existing schemes aimed at cleaning and restoring Chennai's waterways and waterbodies. CRRT involves multiple agencies including Metrowater, GCC, PWD,TNSCB, the Commissioner, the Municipal Administration and the Department of Rural Development. Current projects include the continued implementation of the Adyar Poonga eco-park, an "Integrated Cooum River Eco Restoration Plan", a master plan for eco restoration of Adyar estuary and creek and plans to restore the Buckingham Canal and eventually map and restore all of Chennai's waterbodies.

Cooum River Restoration

CRRT's Integrated Cooum River Eco Restoration project – "probably the flagship of all restoration efforts ever undertaken", according to one newspaper (Pattabiraman, B., 22 Sept.2017) – assigns different sub-projects to different agencies, with a total of 69 sub-projects listed altogether. Each agency funds the work it is to carry out. For example, the PWD is responsible for implementing and paying for desilting, while the GCC is assigned – and will pay for – removal of solid waste. The overall project is estimated at INR 1934.88 crore, and is divided into short, medium and long-term sub-projects, with a specific budget for each (CRRT, 2014).

While doubts have been expressed about CRRT's method, it is clear that their goals are both celebrated by Chennai's public and an indication of government commitment to achieving those goals. Misgivings include CRRT's ability to execute projects: Can river encroachers actually be relocated, for example, and to where? Also, why are the very organizations that contribute to problems assigned the job of fixing them? Why, for example, is Metrowater assigned the role of building STPs and diverting sewage away from rivers when they are supposed to check illegal sewage discharge into rivers in the first place? Further doubts have also been voiced about CRRT's ability to actually bring various agencies together to collaborate, and similarly around their ability to enforce or implement schemes. Such questions have been raised at many levels, including by the National Green Tribunal. CRRT's goals, however, are "goals that almost every Chennai citizen wants to see achieved" (Pattabiraman, B., 22 Sept.2017).

Sustainable Water Security Mission

The Sustainable Water Security Mission was formed in September 2015 when the then Chief Minister of Tamil Nadu, Ms. Jayalalitha, launched it by means of a suo motu (Rule 110) announcement in the Legislative Assembly (New Indian Express, 29 September 2015). The mission was subsequently announced in Chennai city for an estimated cost of INR 5 crore which was accorded under funding from Chennai Mega City Development Mission (CMCDM) (GCC website, Storm Water Drain). Metrowater was appointed the nodal implementing agency; the team includes Metrowater's Executive Director, an executive engineer, a hydrogeologist, deputy hydrogeologist and two assistant engineers. Other SWSM members include GCC, Chennai Smart City Limited, CRRT, PWD and TNUIFSL. Funds are channelled through TNUIFSL who also appoint consultants to prepare detailed project reports. In addition, several NGOs are involved, chiefly to stimulate community participation, including the Environmentalist Foundation of India (EFI), Chennai Rain Centre, Bhumi and Our Clean Green Town (Government official from TNUIFSL, 2017). The mission will also be extended across Tamil Nadu (New Indian Express, 23 September 2017).

Chennai's SWSM aims to protect and restore Chennai waterbodies and to meet Chennai's growing drinking water needs by implementing various projects in the following areas:

- Restore and rejuvenate waterbodies in and around Chennai
- Expand and strengthen rainwater harvesting across the city
- Grey-water recycling and reuse
- Carry out related research, documentation and outreach

Campus Rainwater Harvesting

A total of 15 campuses have been selected across Chennai for the design and installation ofcampus rainwater harvesting (RWH) structures (SWSM website, Rainwater Harvesting).Campuses include the Chennai Trade Centre, the Rajiv Gandhi Government General Hospital, the Tondiarpet bus terminal and Chennai Corporation offices, in addition to college campuses such as Presidency College, Ezhilagam and Dr. Ambedkar Government Arts College. Of these, the GCC proposed to take up six locations in the year 2015-2016 and the work has been reported as completed at a cost of INR 19.40 lakh (GCC website, Storm Water Drain). The remaining nine locations were taken up by Metrowater and are reported to have beencompleted. The rainwater from rooftops and surface run-off will be collected in trenches/drains and diverted to recharge wells located within each campus with the aim of helping to recharge groundwater aquifers and increase groundwater tables. The quantity of water to be harvested every year is estimated at 65 million litres (SWSM website, Rainwater Harvesting).

Storm Water Harvesting

Another effort involves recharging temple tanks in the city with storm water. A total of 51 temple tanks have been identified, of which storm water harvesting and recharging efforts have been completed for 36 tanks. The estimated quantity of water to be conserved is 35 million litres per year.

Waterbody Restoration and Rejuvenation

Over 280 waterbodies were identified in Chennai and its surrounding region (New Indian Express, March 2017), of which 32 were proposed for restoration during the year 2016-2017. Of these, six have been completed, including Sholinganallur, Perungalathur, Sithalapakkam, Nanmangalam and Perumbakkam (SWSMwebsite, Restoration and Rejuvenation of Waterbodies). A pilot project has been initiated for 15 more waterbodies (New Indian Express,23 March 2017). Also, RWH facilities were proposed for 17 temple tanks during the same time frame (GCC website, Storm Water Drain).

Grey-Water Reuse and Recycling

Metrowater has identified Paruthipattu lake in Avadi as a pilot location for groundwater recharge using treated sewage (SWSM website, Grey Water Reuse and Recycling). In addition, 10 campuses are to be selected for designing and installing grey-water structures for grey-water recycling. One of these has already been completed at Victoria Men's Hostel, Presidency College (SWSMwebsite, Grey Water Reuse and Recycling).

Research, Documentation and Outreach

An online platform to collect data on lakes is being created to collate data and encourage volunteering efforts (Lakshmi, K., August2017). Also, a dedicated Metrowater team has been formed to monitor the progress of the various projects.

Citizen-Led Investments

Chennai's residents are investing to improve the city water sector as well. In one example, a people's movement successfully organized the clearing of religious structures from a lake and a canal. These encroachments were demolished by the PWD after

Chitlapakkam Rising, a public group with over 3128 members, created social media campaigns and met with officials to successfully protest the existence of the encroachments (Shekar, L., 2018). In another example, flood-related maps were created – one in the aftermath of Chennai's 2015 floods called Chennai Flood Map, which visualizes the impact of that flood, and another called RiskMap that crowdsources flood risk (The Hindu, 31 October2016; Chakrapani, Saranya, 8 November 2017).

In other cases, citizen-led efforts are organized by groups. For example, the EFI organizes effective lake, beach and waterbody clean-ups. Also, the Dhan Foundation has carried out extensive tank-restoration work.

Rainwater Harvesting (RWH)

A "rainwater harvesting movement" is described as having been born in Tamil Nadu in 2001 with the launch of a statewide RWH programme. Amendments were made to Section 215 (a) of the Tamil Nadu District Municipalities Act, 1920 and Building Rules 1972, making it mandatory to provide RWH structures in all buildings. In addition, the Madras Metropolitan Groundwater Act stipulates that no new site plans can be sanctioned without provision for rainwater harvesting.

While initiated and mandated by the government, this is essentially a citizen-led movement, in that citizens will drive its actual implementation. RWH involves the construction and maintenance of rooftop structures that harvest rainwater, and then direct it back into the ground through pipes. This improves aquifer recharge. RWH is not thought to impact piped supply other than by potentially minimizing demand for it (because consumers draw more from groundwater).

Chennai's Rain Centre recently conducted an audit of this movement. As we write this report, the audit is still being finalized and we are not able to access it. However, Rain Centre officials indicated that the audit concludes that only 40 percent of Chennai residents had RWH structures when the audit was conducted (Rain Centre, 2017, personal communication).

While this rainwater harvesting movement has been widely publicized, some experts view RWH through a broader lens. They see rooftop structures as good efforts to improve groundwater recharge, but argue that RWH should not be limited to these spaces but should be expanded to include the network of tanks and ponds around Chennai to harvest water (SaciWATERs, 2018, personal communication).

While this rainwater harvesting movement has been widely publicized, some experts view RWH through a broader lens. They see rooftop structures as good efforts to improve groundwater recharge, but argue that RWH should not be limited to these spaces but should be expanded to include the network of tanks and ponds around Chennai to harvest water

Efforts Facilitated by the Dhan Foundation

Community-centred conservation efforts, including development of small-scale water resources across India, are being implemented in parts of Chennai. Here, activities include work on isolated tanks and tank-based watersheds, and reviving chains of tanks in smaller river basins so as to multiply the impact of renovation and restoration efforts.

Public-Private Partnerships in Waterbody Revival

CRRT, PWD and other government bodies are planning to revive Chennai waterbodies. Citizens are volunteering to organize and help. For example, an NGO collaborated with the government and a private company to restore parts of Chennai's Pallikaranai marshland. The NGO – Care Earth Trust– worked with the PWD, the responsible agency for marshland administration, on a plan. A private multinational company, VA Tech WABAG, provided funding support. The project involved Narayanapuram lake, one of many in the marshland. The lake was cleared, de-weeded and replanted with appropriate vegetation. Bunds were constructed to protect its periphery, and sewage pipes leading into the lake will be plugged (Gopalakrishnan, S. ,March2017).

Efforts to rejuvenate waterbodies and rivers are common across India today. A prime example is Prime Minister Narendra Modi's National Mission for Clean Ganga River project, which was established in 2014. Others include Sadhguru's 2017 Rally for Rivers campaign. These efforts, as in the Pallikaranai marshland example above, are sometimes successful. Another instance can be seen in Kerala where 10 rivers and about 150 tanks are reported to have been successfully revived. In the Kerala case, volunteers were a driving force behind the collective effort (Manorama, 2017). The public-private partnership model applied above serves as another example of how to achieve successful waterbody rejuvenation.

However, a lack of coordination often appears to qualify Chennai waterbody rejuvenation efforts, many of which are simultaneously carried out by disparate agencies. Also, lake restoration is a particularly complex problem because of the involvement of multiple stakeholders, associated issues of encroachment, and the need for long-term maintenance and monitoring, preferably by a group of public and private stakeholders. The primary analysis section below gives some perspective.

Primary Analysis: *How well do efforts relating to the restoration of waterbodies integrate with the overall water ecosystem?*

Several attempts have been made over the past decade and more to revive waterbodies in the CMA, including lakes, rivers and canals. One such effort was to restore and rehabilitate the ecology of the Adyar creek (extending from Greenways Road to Chettinad Palace near the coast). This was carried out by the Adyar Poonga Trust in

2006. While the primary objective was to restore the creek and create an eco-park, it has since embraced a larger role of restoring waterbodies and preserving ecological balance through restoration.

Renamed "The Chennai Rivers Restoration Trust" (CRRT), the body is engaged with the task of restoring approximately 214 kms of waterways and 42 waterbodies in the CMA by "desilting, diverting sewage, scientific solid waste management, embankment protection, developing walkways for public use and so on" over a period of nine years beginning in 2014 (TNUIFSL and CRRT, 2016). These 42 waterbodies and 13 waterways were selected out of 1 waterbodies and include the Adyar, Cooum and Kosathalaiyur rivers and Buckingham Canal. Since CRRT had already begun restoration works for four lakes, 38 lakes and 13 waterways were finally chosen.

CRRT's master plan for this project provides information on which waterbodies were selected for restoration and describes in detail the physical characteristics of these waterbodies. All the lakes in the 1189-sq. km CMA were considered for renovation; those that had already been selected for restoration as part of the World Bank-assisted IAMWARM (Irrigated Agriculture Modernizationand Waterbodies Restoration and Management) project were excluded. The criteria used to select the waterbodies include "lakes within boundaries covered in CMDA's Second Master Plan and in core city boundaries, lakes with ecological significance, lakes with visibility, lakes in dense areas, lakes with water spread area of more than 10 hectares and depth or more than 3 metres and so on" (WAPCOS Ltd, 2015). The selection of the criteria was based on a set of parameters that, on paper, included: public demand; environmental consideration such as habitat for birds; fisheries development; potential as a drinking water source; potential for reviving from encroachment and for recreational activities; dependent ayacut lands; proposal for restoration from the government and restored/ ongoing projects under IAMWARM.

Based on the selection of lakes taken up for restoration, we find that the above-mentioned criteria were not strictly adhered to in the selection process. For instance, several lakes such as Vitchoor tank and Madhavaram Rettai Eri in Kosathalaiyur sub-basin, and Movarasampattu Eri, Thamarai Kulam and Sembakkam tank in Kovalam sub-basin do not meet the selection criteria.

The vision for the project is to restore the "ecological health" of waterbodies. It is unclear if these selection criteria have any ecological or hydrological significance in terms of enhancing water-retention capacity of the basin as a whole and consequently in terms of mitigating the impacts of flooding. It appears that many lakes selected for restoration are near roads and therefore restoring these would result in higher visibility. However, the selection leaves out lakes located farther inland that might have a more significant role to play in water retention.

Restoration efforts include several isolated lakes in a network, for which connection channels no longer exist, subsequently reducing the network's potential to minimize the impacts of flooding. Many of these lakes and those not selected for restoration were once part of an interconnected system of waterbodies including erys, canals, feeder canals and wells that were interlinked through channels that enabled run-off from one waterbody to the next, until it reached the sea. There is substantial scientific evidence to show that, historically, the ery system served the purpose of efficient flood management (Arabindoo, 2016; Jameson & Baud, 2016; Sakthivadivel et al., 2004). Therefore, selection of all the lakes in a single basin or network whose connection channels can be revived could have a larger positive impact on flood mitigation efforts.

Our analysis also reveals that several lakes, including Kadaperi lake, Tambaram Pudu Thangal, Thiruneermalai lake, Irumbuliyur lake, Madhavaram lake and Pallikaranai big tank, that were selected for restoration by CRRT are already under the IAMWARM project, indicating a duplication of efforts and financial resources.

This analysis was not intended to critique the selection of waterbodies, but rather to investigate if the selection of these waterbodies – a key ecological resource in the water system – fits within a systemic approach to Chennai's drainage and water retention infrastructure. Restoration of waterbodies is an endeavour well worth investing in, and the efforts made by the agencies involved in this project are certainly worth recognizing. The analysis indicates that some aspects of the choices made are logical and can enhance the performance of the water system as a whole – for instance, most waterbodies selected are of a certain minimum size; the areas selected have by and large not been addressed by existing CRRT, PWD and IAMWARM efforts; these areas are also conducive to lake restoration as the infiltration quality of the soil is poor, potentially leading to a flood hazard. On the other hand, the criteria by which the waterbodies were selected is opaque, and there seems to be no clear connection between the use of these restored bodies to augment drinking water supply or to enable the drainage network. Crucially, a network-based approach to restoring lakes that ensures that a network of lakes linked together are restored, thereby creating force-multiplier effects in the capability of a region to store and drain water, may have been a useful strategy. Minor overlaps in the restoration of lakes with other schemes also exist. Overall, the effort outlined here is likely to be of great use, but it underlines a lack of system-wide thinking and integration between practices of various agencies.

CHAPTER 6:
WATER SECTOR VULNERABILITIES, RISKS AND THREATS

CHAPTER 6 : WATER-SECTOR VULNERABILITIES, RISKS AND THREATS

While the previous chapter outlined the many investments being made to improve Chennai's water sector, this chapter highlights the vulnerabilities, risks and threats it faces. They include situational vulnerability, climate risks and urban risks. Each risk is at once separate from and closely interlinked with the others: each one compounds and detracts from the others in multiple complex ways.

The mapping here of these many risks and threats begs the questions: To what extent does the design and implementation of water-sector investments scientifically consider them? Is it possible that investments are based more on past trends or heuristics than they are on risks and threats – many of which manifest more in the future and are therefore essentially unpredictable? These are some of the key questions around the sustainability of Chennai's water sector.

Situational Vulnerability Analysis

Chennai's state of water is inherently linked to its location; any review of its water sector must include an analysis of where the city is situated. Primarily, Chennai is positioned in the shadow of the Western Ghat mountain range. This influences where and when it receives rainfall, most of which occurs during the north-east monsoon. Chennai is dependent on this monsoon because it has no perennial water source. Also, Chennai is a coastal city at a low elevation. It lies on the Bay of Bengal shoreline, and is, on average, 6.7 metres from mean sea level (Lavanya, Ar. K., 2012). This makes the area inherently vulnerable to water-related hazards. "Chennai is at sea level, with some areas below sea level and some slightly above," says Jayshree Vencatesan of Care Earth Trust, a conservation and biodiversity organization in Chennai. "This means it is at risk to floods, droughts and sea-originating shocks such as storms, cyclones and tsunamis" (Jayshree Vencatesan, 2016, personal communication). In addition, coastal proximity means Chennai is at increased risk from meteorological events such as El Nino, which may have impacted the severity of rainfall in December 2015, and to Bay of Bengal warming, which may increase depressions during certain seasons (Murthy, B.S. et al., 2016). Also, sea-level rise and saline intrusion are considerable threats. Finally, Chennai is differentiated from the sea by mechanisms such as beaches, sand dunes and brackish-water lakes. These natural boundaries protect the city and the region from coastal events. Any intervention – human or otherwise – will influence Chennai's situational vulnerability.

Water-Sector Risks and Threats: Climate Related

Climate change is affecting – and is predicted to continue to affect – Chennai's state of water. This is occurring in myriad interconnected ways. Rainfall and groundwater levels are likely to be impacted, sea level is predicted to rise, and the severity and frequency of storms is likely to change. All of this is likely to affect city water availability and detract from efforts made to improve on it. It also begs the question as to whether such risks are sufficiently considered in the design and implementation of investments to improve the sector.

Rainfall

Research indicates that rainfall in Tamil Nadu will change with the climate.The Tamil Nadu Department of Environment's State Action Plan on Climate Change predicts that rainfall will increase considerably towards the end of the century (around 2081-2100). Such increases may already be evident in some parts of the state: an ongoing study of 100 years of Tamil Nadu rainfall data found it is already higher in certain districts (Saci WATERs, 2018, personal communication). A study of data from the Cauvery Delta, which is adjacent to Chennai, predicts that mean annual rainfall will increase moderately in the period leading up to 2050. Research also indicates that rain will fall in shorter spurts, with the number of rainy days forecasted decreasing by half in the end of the century, and that there will be a 19 percent increase in storm rainfall (ADB, 2014).

The intensity of rainfall is also forecasted to change. Annual rainfall is predicted to intensify to 7-12 mm/day, with an additional increase of 8-14 mm forecasted by the end of the century. The intensity of rainfall during the southwest monsoon is likely to remain at its present 3-6 mm/day in the coastal areas but increase to 9-16 mm/day in the rest of state. During the northeast monsoon, however, rainfall intensity is likely to increase to 9-22 mm/day by the end of the century across the state, with heavier precipitation near the coast. This means that Chennai is likely to experience little change in the intensity of the south-west monsoon, but increased intensity during the north-east monsoon over the course of the century (Tamil Nadu State Action Plan for Climate Change [TNSAPCC], 2015). This is contradicted by results of another study, which predicts a 16-23 percent reduction in rainfall during the southwest monsoon and a 4 percent rainfall increase during the northeast monsoon (ADB, 2014 &Srinivasan, 2013).

Rainfall is further predicted to be influenced by the El Nino and La Nina effects. These result from climate factors due to greenhouse gas emissions that are released into the air, causing air temperatures to increase, leading to increased moisture evaporation from land and lakes, rivers and other waterbodies. According to a Skymet Meteorologist, El Nino will meandeficit rainfall during the south-west monsoon and excess rainfall during the north-east monsoon in El Nino years. The El Nino effect was a contributing factor to heavy rainfall and resulting flooding in Chennai in 2015 and to a drought summer season in 2016 (Raghu Krishnan, 2015).

Groundwater Levels

Studies predict that groundwater resources will suffer – directly and indirectly – as a result of climate change. As mentioned on page 24, groundwater resources are already overexploited across Tamil Nadu, with an estimated 80 percent being used, and the number of overexploited blocks has risen from 21 percent in 1980 to 48 percent today. Climate change is expected to aggravate this situation. Flood and drought occurrence, for example, is predicted to increase, which in turn will affect groundwater recharge. Also, hydro-meteorological parameters such as evaporation, evapotranspiration, wind direction and wind speed are likely to change, and these are predicted to either directly or indirectly impact groundwater resources. A study of data from Tamil Nadu's Cauvery Delta predicts an increase in evapotranspiration in the long term (i.e., between 2071 and 2098) as a direct result of increasing temperatures and precipitation (Gosain, A.K. et al., 2011). At the same time, state dependence on groundwater is likely to increase as a result of predicted losses from reservoirs due to evaporation (TNSAPCC, 2015).

Sea-Level Rise

Increasing global temperatures are forecasted to cause a rise in sea level, with shorelines shifting inland. Sea-level rise is estimated to be occurring along India's eastern coast at an average rate of 1.3 mm per year (Indian Network for Climate Change Assessment, 2016). Another report indicates that sea-level rise is occurring along Chennai's coast at a rate of 0.29 +/- 0.56 mm per year. The same report predicts that, by 2100, the highest and lowest values for sea-level rise in the entire Cauvery basin will be 0.87 mm and -.03 mm respectively – relative to shoreline levels in 1990 (Ali Dastgheib & Roshanka Ranasinghe, 2014). Other estimates for Chennai predict that sea levels will rise 0.7 mm per year (Climate Service Centre Germany [GERICS] & KfW Development Bank, 2015).

Sea-level rise affects the saltwater-freshwater interface, which is likely to cause seawater to intrude into freshwater resources in 13 coastal districts in Tamil Nadu, including the Chennai area (TNSAPCC). It also contributes to coastal erosion – which is rampant on coastlines around India. An inspection of the Tamil Nadu coast by a team of geologists associated with the Geological Survey of India determined that the shoreline along at least 12 beaches has eroded over the past four decades, with the extent of erosion ranging from 50 to 500 metres (Kotteswaran, C.S., 2018). While coastal erosion is primarily attributable to man-made construction, sea-level rise plays a role as well.

Storm Frequency and Severity

Climate change is also likely to impact storm frequency and severity in and around Chennai, as at the global level. Cyclones in and around Chennai are predicted to become more intense, giving rise to stronger storm surges. The average intensity of tropical storms across the globe is predicted to be between 2 and 10 percent stronger. At the same time, the frequency of storms is likely to decrease. This is a shift from the current trend in Chennai, which has seen a sharp increase in the number of storms in recent years. Tamil Nadu was hit by approximately 32 cyclonic storms between 1891 and 2006, of which 30 were severe. The region then saw a 37.5 percent increase in the number of storms between 2006 and 2011, with 12 storms occurring during that period (TNSAPCC, 2015). In spite of this recent trend, future projections predict a reduction in frequency of storms, both at the Chennai and global levels (Nayantara Narayanan, 2016).

Changes are also predicted in terms of cyclonic disturbance in the Bay of Bengal. This has direct implications for Chennai. The timing of these disturbances is likely to change. It is predicted that more will occur during post-monsoon months (October to February), and fewer during the pre-monsoon months of March to May (TNSAPCC, 2015). These conclusions were reiterated in a 2014 study from the University of Allahabad that analysed cyclonic data from the North Indian Ocean over a 122-year period, between 1891 and 2013. Findings here point to a larger number of cyclonic disturbances intensifying into tropical cyclones in the post-monsoon period, especially in November (Nayantara Narayanan, 2016).

Another finding relevant to Chennai is in terms of Bay of Bengal cyclonic paths. A researcher at Allahabad University finds that this path appears to be shifting. Right now the tracks are shifting southwards towards Tamil Nadu (Nayantara Narayanan, 2016).

Water-Sector Risks and Threats: Urban Related

While it is predicted that climate change will impact Chennai's state of water, urban factors will contribute significantly as well; in fact, they already are. Land-use changes, encroachment on waterbodies, water supply infrastructure and pollution are all issues that influence and will continue to influence the future sustainability of

Chennai's water sector. Additional risks and threats include Chennai's drainage, sanitation and solid waste system, which are discussed in Chapter 4.

Land-Use Changes

Increasing urbanization has meant a dramatic shift in land use in and around Chennai, with more and more agricultural land being urbanized. The following four maps of Chennai in 1980, 1991, 2000 and 2010 show the extent to which this has occurred, with significant increases in built-up space and a simultaneous reduction in floodplains, waterbodies and urban green space.

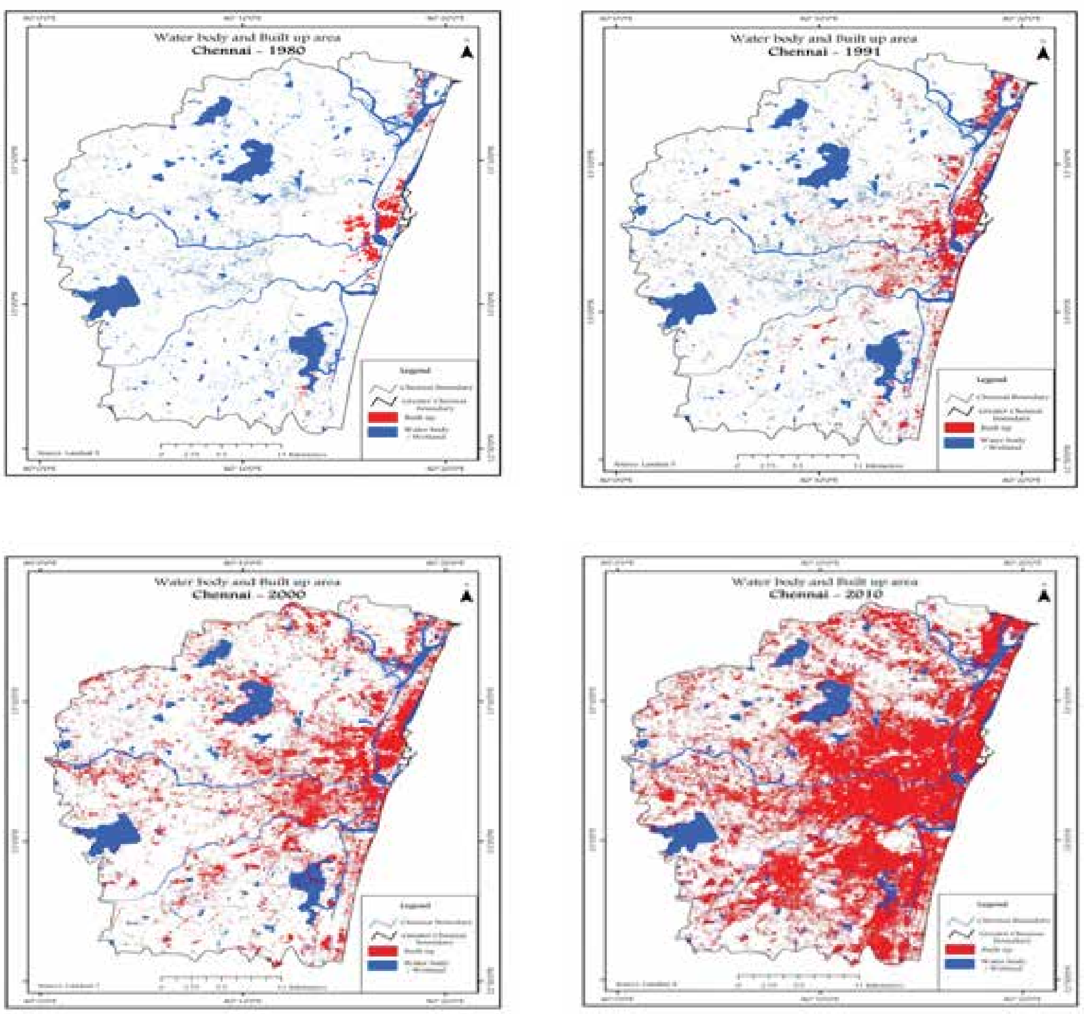

Figure 21: Land-use and land-cover change, 1980-2010

Source: Ongoing research programme on urban ecology, initiated in 2015, Care Earth Trust, Chennai

These changes have several implications for the water sector. They mean an increase in housing density, signifying increased water demand. They also mean changes to surface permeability, and, as a result, to the ratio of rainwater run-off to that which percolates back into the ground and recharges groundwater tables.The modelling analysis we conducted of the Adyar basin (see page 70 below) shows the extent to which this is occurring in that area of the city. Also, a report about Chennai's 2015 flooding event indicates that run-off percentages vary widely in different environments: 10 percent in natural landscapes, 30 percent in dense residential landscapes and 55 percent in urban landscapes (Esther and Devadas, 2016). Another study where a hydrologic-engineering-economic model is developed to address the complexity of urban water supply in Chennai city indicates that without rainwater harvesting, just 9 percent of rainwater makes its way back into the aquifer, with the remaining 91 percent running off into the sea. The study compared this to an estimated 18 percent aquifer recharge as a result of rainfall in rural areas (Srinivasan, V., July 2010).These results translate into significant threats to the sustainability of Chennai's water sector.

Encroachment on Waterbodies

Waterbody encroachment is another significant threat to Chennai's state of water. It was voted a top water-related concern by engineer-level government officials from water-sector departments who attended a workshop related to this report in January 2018. According to one account, 1130 hectares of lake area in the 1980s had shrunk to 645 hectares in the early 2000s as a result of encroachment. In many cases, this encroachment is in the form of illegal and/or informal structures that are constructed along waterbody shorelines (see photo below); in others, the structures are legal – the result of relaxed anti-encroachment rules meaning clearances to construct on top of or at the edges of waterbodies are given too readily. Parts of Chennai's OMR IT corridor, for example – Chennai's shiny example of economic modernization – are built on marshland (Nirmal, Rajalakshmi & BL Research Bureau, 2015).

Waterbody encroachment increases the chances of flooding by obstructing water run-off and overflow. It also contributes to water pollution: encroachers tend to discard waste into the encroached-upon waterbody. It is also a complex problem to solve. For one, evictions are legally complicated, particularly in cases where encroachers have occupied the space for years, in some cases 20-25 years. Also, clear alternatives often don't exist; Chennai faces housing shortages, particularly for lower socio-economic classes. How can encroachers be evicted when they have nowhere else to go? Also, resettlement is problematic, in many cases because new settlements tend to be far away from residents' place of work or schools for their children. Finally, solving encroachment requires

Figure 22: Encroachment on waterbodies
Source: News18, 2016

coordination among the many government entities directly responsible, including the Tamil Nadu Pollution Control Board, the PWD, the Revenue Department and local panchayat bodies.

Flooding and Drought

Flooding and drought occur with increasing frequency in Chennai, as predicted by climate change models. Sometimes, both occur within a 12-month timeframe, as in 2015-2016 when Chennai experienced unusually heavy rains in December 2015 and a period of drought the following summer. “Nowadays, we move from one calamity to another,” lamented Mr. Arun Krishnamurthy of the EFI (Urban Thinkers Campus Convention, 2017). A complex and interconnected range of factors cause this phenomenon.

Floods are likely in Chennai as a result of its coastal positioning.

Chennai’s flat topography also increases their likeliness:a slope of less than 0.7 m per km typifies most of Chennai’s terrain, meaning that water does not naturally run off but tends to stagnate.

Floods are likely in Chennai as a result of its coastal positioning (see section on situational vulnerability above). Chennai's flat topography also increases their likeliness: a slope of less than 0.7 m per km typifies most of Chennai's terrain, meaning that water does not naturally run off but tends to stagnate. At the urban level, storm water drain network issues also contribute to flooding. Currently, these drains do not cover the length of all Chennai roads and in many cases,they are also clogged with waste, sewage or silt. Also, the network in many areas of the city is ancient and collapsing: 22 drains were found to have buckled in December 2017 (Lopez, A.X., December 2017). Beyond storm water drains, waterways – which serve as major drains – are also often obstructed as a result of solid waste dumping and encroachments. In addition, the effects of flooding on some populations, including slum area populations, are magnified by high population densities, insufficient drinking water supply and sanitation, as well as inadequate road space.

Drought is assessed by the IMD on the basis of percentage of deviation of rainfall from long-term annual mean rainfall. Essentially, it is caused by monsoon failure. Also, as mentioned on page 61 above, it can be complicated by climate factors such as El Nino and La Nina. In addition to climate factors, urban factors contribute to drought risk as well. Supply inefficiencies and infrastructure leakages are two key factors, with groundwater over-extraction also contributing to supply inefficiencies. There are five categories of drought severity, ranging from no drought to severe drought (Chennai River Basin Report, Chapter 3). Water expert Rajendra Singh, also known as the "water man of India", describes Tamil Nadu drought incidences as largely caused by "improper maintenance of state water resources" (Venkat, Vidya, 2017).

Overall, flooding and drought may negatively impact the likelihood that investments in the water sector will be adequate. In spite of their increasing frequency, these come as shocks to the Chennai system, mitigating any gains that improvements may have brought.

Water Supply Infrastructure

Problems with water supply infrastructure are additional risks to Chennai's water sector. These problems mainly manifest in water and sewerage pipes, as well as in reservoirs and treatment plants. Much of Chennai's infrastructure hasn't been replaced in years. "Some of our infrastructure is 103 years old," remarked one Metrowater representative, "the technology is obsolete" (Government official from Metrowater, 2017). Also, pipeline leakages will diminish any increases made to supply. As discussed on page 34, pipeline leakages are common in developing countries, with losses as high as 50 percent in some areas – compared with lows of 5 percent in developed countries. One expert indicates that, between 2002 and 2006, pipeline leakages in Chennai accounted for approximately 15-35 percent of lost water, depending on the zone. These infrastructure issues need to be solved in order for investments in the sector to be maximized. One significant step towards solutions came in 1998-1999 when Metrowater shifted from breakdown maintenance to preventive maintenance in their O&M approach. Funds required for supporting systems were earmarked (Munian, 2010, p. 105).

Saline Intrusion

Saline intrusion – or saltwater intrusion – is defined as “the movement of saltwater into underground sources (aquifers) of freshwater”. It mainly occurs in coastal areas but can occur inland as well. Saline intrusion is likely to occur as a result of sea-level rise, as mentioned above, and it can also result from urban causes such as groundwater over-extraction. Across Tamil Nadu, groundwater resources are being depleted, as discussed on page 62 in the section on groundwater levels. The number of overexploited blocks in Tamil Nadu has increased from 21 percent in 1980 to 48 percent today (TNSAPCC). As these levels diminish, seawater filters in to fill them, particularly along coastal areas. Chennai’s Thiruvanmiyur aquifer, for example, is already saline as a result of over-exploitation, and ultimately being depleted (Interview with TUFIDCO official, Oct. 2017). Saltwater intrusion is also occurring to the north of Chennai, along the Minjur-Panchetti belt. A study conducted by the Department of Geology at Anna University found that saline intrusion was occurring up to 14.7 kms inland from the coast. Groundwater levels here were found to have dipped 15 metres below sea level, which paved the way for a mixing of sea and fresh waters (Lakshmi, K., 2015). One intervention mechanism is to construct and rehabilitate tail-end regulators to prevent saline water from intruding into channels (TNSAPCC, 2015).

Increasingly saline groundwater tables will impact groundwater availability, which in turn will certainly upset the balance between supply of and demand for water in Chennai – it will also detract from any outcomes that may result from steps taken to improve the sector.

Water Pollution

Chennai’s water is increasingly polluted. This is caused in large part by solid waste and sewage, including industrial waste and sewage water, which is dumped into waterbodies, rivers and streams, polluting them and seeping into groundwater tables. Additional pollutants come from landfill leachate, which contaminates groundwater tables, and from human activity such as clothes, vehicle and other household and commercial goods washing and fishing. All are further compounded by increasing population numbers and economic activity: while dumping into and washing in waterbodies has been done across India for decades, the sheer numbers and amounts involved today make outcomes more serious and less sustainable.

A significant amount of data exists around Chennai's water quality. Some is broad and some more specific to certain water sources, geographic locations or contaminants. PWD results are fairly broad: they test water samples from four locations in Tamil Nadu including Chennai, studying quality and suitability for domestic, industrial and agricultural use. Four thousand three hundred water samples are collected from surface and groundwater sources, during pre- and post-monsoon periods. PWD results from Chennai in 2015 indicate mostly safe levels of contaminants such as fluoride, but moderate to high levels of total dissolved solids (Water Resources Department website, Groundwater Investigation, accessed 15 March 2018). Large quantities of fluoride in water can be detrimental to human health, while dissolved solids are a general indicator of water quality, with a lower number being preferable. Another, more narrowly focused study of water samples from 10 Chennai lakes collected over two months finds the overall quality of Chennai water to be deteriorating. While the quality in Pallikaranai and Narayanpuram was deemed permissible for drinking, it was not so for other lakes. Perumbakkam lake, for example, was found to have 3998 mg/litre of dissolved solids. Indian standards dictate that levels higher than 500 mg/litre make water unsuitable for drinking (The Hindu, 21 April 2017).

Drinking water permissibility was also assessed in a 2016 analysis of Tamil Nadu Pollution Control Board data collected over a six-year period. Results indicate increasing levels of fecal coliforms and total coliforms in Chennai's Veeranam lake, but a reduction in levels of those same contaminants in Porur lake during the 2014-2015 period (Rajamanickam, R. & Nagan, S., 2016). Fecal coliforms and total coliforms are indications of contamination by human or animal waste, and they render water unsafe for drinking. In spite of reductions at Porur lake, its water was also deemed unsuitable for drinking purposes without disinfection by another 2016 study (Sunantha, G. & Vasudevan, N., 2016).

Some reports specifically examine Chennai's groundwater, while others study marine life to gauge accumulation of pollutants. For example, a 2011 study collected samples from groundwater in two Chennai zones – one northern and one southern. It found water quality to be within Indian standards, but requiring treatment before use for consumption (Loganathan, D. et al., 2011). Groundwater quality is of increasing concern in Chennai, as across India, particularly in cities. Polluting factors include poor sanitation and industry, as well as naturally occurring contaminants such as arsenic, fluoride and iron, which can be affected by natural factors such as lithology. Here, the groundwater percolation process that renders water potable can also sometimes be countered by factors such as lithology, climate, topography or rainfall (World Bank report, 2017). Saline intrusion, mentioned above, is also an increasing threat to Chennai groundwater quality.

Also, at least two studies examine levels of trace metals in sea animals to understand the multiplied effects of industrial waste dumping. Metal accumulation in marine life is significant as a bioindicator for the species itself as well as for its ecosystem, and can also be transferred to consumers including humans in the food web structure. One study found accumulated levels of lead and other toxic metals in crabs and shrimp in Pulicat lake, in the northern coastal region of Chennai. While these were deemed within permissible levels for human consumption, they clearly indicate bio-magnification in Pulicat lake, findings that are significant for ecosystem management (Batvari, B.P.D. et al., 2016). The second study found evidence of metal accumulation, including potentially toxic levels of lead and chromium, in six species of fish in Ennore creek, also in northern Chennai (Jayaprakash, M. et al., 2015).

Toxic substances, including particularly dangerous ones, are found in water supply throughout India. For example, India's water resources ministry provided information in December 2017 indicating that 239 million Indians, or 18.8 percent of the country's population, consume water contaminated by arsenic. This includes 3.7 million people in Tamil Nadu. Arsenic is a known poison, with long-term intake linked to arsenic poisoning as well as cancer and other diseases, according to the World Health Organization (Jadhav, R., 2017).

Primary Analysis: *Does the EIA process safeguard waterbodies against development?*

Environmental impact assessments (EIAs) were legalized in India in 1994 when the EIA Notification came into existence. The notification urges for more sustainable industrialization processes in the country by ensuring that potential environmental and social impacts of projects are identified before commencement of these projects. This notification mandates that all projects or activities (including expansion and modernization of existing projects and change in product mix) above a certain threshold (of size of operation/capacity) should procure an Environmental Clearance

(EC) prior to commencement of the project in question. The projects and activities are classified as Category A or Category B based on their potential impact on human health, natural and man-made resources. The latest amendment to the notification in 2006 pushes for more power to the states, with several of these projects going to the state for clearance depending on their size/capacity/area through an SEIAA in consultation with a State Environment Appraisal Committee.

In the Tamil Nadu context, the SEIAA grants environmental clearances through a process of screening, scoping, public consultation and appraisal. Between 2014 and 2018, 86 new construction projects have been granted clearance by the state government (SEIAA website). These projects include different types of housing projects from low income to luxury, industrial estates, beach resorts, hospitals, STPs, IT parks, etc. Clearance is granted based on potential environmental and social impact; for example, changes in soil, water and air quality, impact on wildlife habitats, settlement patterns, water consumption levels, aesthetic values – views, sociocultural systems and so on.

The EIA process measures the potential impact of a project within a 15-km radius of the proposed boundaries of areas which are sensitive for ecological reasons including wetlands, watercourses or other waterbodies, coastal zone, biospheres, mountains and forests. With respect to waterbodies, applicants are required to furnish details regarding potential impacts on surface water or groundwater levels and quality by identifying water sources, estimating water intake requirements, describing water extraction, transportation and rainwater harvesting methods, and providing a groundwater budget. However, the threshold for granting or denying clearance based on these parameters is unclear. For instance, what could be considered a large enough impact to not provide clearance? Or, can projects with limited potential impact and situated on the floodplain of waterbodies obtain environmental clearance? A manual on norms and standards for environmental clearance for large construction projects, published by the MoEF, states some of the metrics that proposals should have but does not categorically define a threshold for denying clearance.

Despite the set criteria for granting permissions, several projects in the state are in potentially ecologically sensitive zones, for example, floodplains of rivers, as seen in Table 6. Ten projects are less than 1km from the nearest waterbody, suggesting that they are especially prone to flooding and could have a negative impact on the neighbouring waterbody. The 2015 rains caused severe flooding and damage to several such buildings (critical for the smooth functioning of cities) located near/on the floodplains of the Cooum and Adyar rivers such as hospitals, educational institutions, IT parks, industrial estates, residential and commercial establishments and indeed associated human lives and livelihoods.

While it is interesting to note that according to the MoEF, EIAs can only be granted to industries if they are 1-2kms from floodplains or river systems, there is no denying that all developments close to rivers are at risk from flooding.

Name of the project	**District**	**Latitude and longitude**	**Closest waterbody**	**Distance (m)**
Mr. K.R. Anerudan(2)	Kanchipuram	12°55'55.77"N 80°5'8.28"E	Adyar River	90
Lancor Holdings (8)	Kanchipuram	12°53'39.38"N 80°13'17.74"E	Subramanya Lake	120
Prestige Estates Projects (7)	Chennai	13°03'36"N 80°15'31"E	Cooum River	150
Vasathi Homes(14)	Tiruvallur	13°04'53.5"N 80°09'30.2"E	Effluent Pond	215
SPR Construction Pvt. Ltd (10)	Chennai	13°6'8.67"N 80°15'14.89"E	Otteri Nallah	250
Mr. Raju Gupta(3)	Kanchipuram	12°57'10.56"N 80°09'46.86"E	Nemilichery Lake	500

Shivashankar(27)	Kanchipuram	12°54.075'N 80°13.631'E	Pallikaranai Marsh	680
Casa Grande(23)	Kanchipuram	13°0'42.03"N 80°10'16.42"E	Adyar River	800
Pallava Estate LLP(22)	Kanchipuram	12°44'43.20"N 79°59'22.57"E	Chettipunyam River	900
Lakshmi Royal(11)	Tiruvallur	13°3'0.63"N 80°9'10.89"E	Metrowater Lake	1000
Radiance Realty (21)	Tiruvallur	13°3'0.63"N 80°9'10.89"E	Cooum River	1230
Thanjavur Medical College(16)		10°45'33.39"N 79°06'22.30"E	Grand Anicut Canal	1980
WS Electric Limited(15)	Tiruvallur	13°1'56.66"N 80°10'9.33"E	Adyar River	2000
PNB Realty Limited(19)	Kanchipuram	12°51'34.31" N80°9'19.56"E	Bay of Bengal	10,000

Table 6: Sample of projects granted clearance in 2016
Source: SEIAA, Tamil Nadu

To conclude, the Environmental Impact Assessment Notification 1994 was legalized with the objective of making industrial development more environmentally and socially sustainable. However, we find that especially in the past few years, permissions have been granted for new construction and infrastructure projects through processes that do not seem to consider ecological sensitivities including proximity to waterbodies rigorously, defeating the primary purpose of the notification.

Modelling Exercise: *Does an increase in built-up area result in an increase in surface flows in the Adyar basin?*

This modelling exercise seeks to complement our secondary analysis through an investigation of the impacts of urbanization on surface flow patterns in the Adyar basin for a period between 2006 and 2040. The Adyar basin comprises a network of interconnected natural and man-made reservoirs such as Chembarambakkam tank (one of the largest reservoirs) that supply water to Chennai city. As the city grows, surrounding areas have witnessed increased rates of urbanization, especially over the past few years. This has increased the built-up area and consequently the area of impervious surfaces. An expansion in impervious surfaces prevents water from percolating into the ground to deeper aquifers, thereby increasing surface run-off and changing flow patterns in the event of rain. Such increased run-off could make a region flood-prone. Our goal is to understand whether and the extents to which surface water flow or surface run-off are likely to increase in the Adyar basin in the future.

Methodology: A combination of publicly available data on land-use and land-cover change, inflow and outflow of tanks, and other relevant parameters were used for the analysis. These were sourced from CMDA's Second Master Plan, Centre National de Recherches Météorologiques (CNRM) and Metrowater.

The hydrological modelling system –"HEC-HMS" was used to model the results. The "HEC-HMS" model simulates hydrological processes in a watershed and was designed by the Hydrologic Engineering Center of the US Army Corps of Engineers (USACE, 2010). Parameters that went into the model include precipitation and value of imperviousness. Precipitation data was estimated from CNRM, which was used to predict the likely daily rainfall from 2006 to 2040. We estimated imperviousness values based on current levels of built-up area by drawing polygons over buildings in the Adyar basin using Google Earth. We also used data on the amount of built-up area in the CMA provided by CMDA in their Second Master Plan from 1973 to 2026. A ratio of the two was taken and interpolated to estimate the final imperviousness values for six randomly selected years (2007, 2010, 2015, 2018, 2020 and 2026).

We ran monthly simulations from 2006 to 2040, for each selected year and consequently six different imperviousness values to estimate surface water inflow into three points in the Adyar sub-basin. This was done to test whether surface flows increase with increase in imperviousness in future years. The three points were (Figure 23)

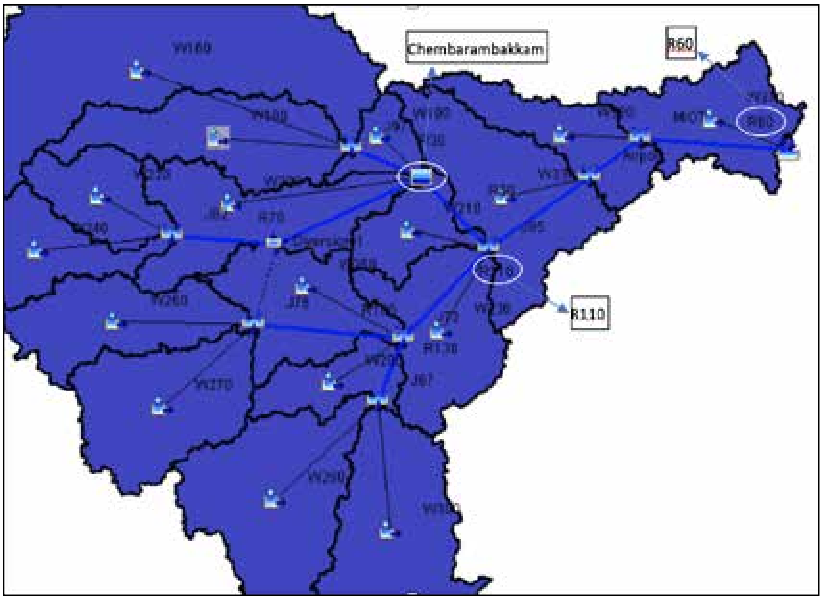

Figure 23: Study area for the model showing the three observation points

Chembarambakkam reservoir

R110 – a point south-east of Chembarambakkam

R 60 – a point to the east of Chembarambakkam and near MIOT hospital (Manapakkam) and the Chennai airport.

Chembarambakkam was chosen because it is the largest reservoir that supplies water to Chennai city, whose excess water is let off into the Adyar river through the points R110 and R60. The former (R110) is a reach (a section of river or stream between an upstream and downstream location) in the Adyar river that is connected to multiple channels and streams in the basin including the channel that carries out excess water from Chembarambakkam reservoir, while the latter (R60) is a reach on the river farther downstream, strategically located near MIOT hospital (Manapakkam) and the airport on the bank of the Adyar river.

Assumptions made in modelling were: a) increased surface flow into each observation point (Chembarambakkam, R110 and R60) would result in increased outflow in the connected water channels that feed into the Adyar; b) polygons measure areas that are completely builtup without any green spaces in between and; c) CMA's built-up area is proportional to built-up area in the Adyar basin.

Results: Model results from the basin-wide analysis included a combination of surface flows, surface outflows and storage levels for each of the observation points: Chembarambakkam, R110 and R60 for six simulation years from 2006 to 2040. We present the most relevant data: surface inflows compared to imperviousness values for six years for the monsoon months of September to December through box plots (Figure 24-Figure 25). Each box plot represents one month and demonstrates the likely monthly values of surface inflows or run-off in the three observation points over time as the built-up area increases as per CMDA's development plans.

Chembarambakkam was chosen because it is the largest reservoir that supplies water to Chennai city, whose excess water is let off into the Adyar river through the points R110 and R60.

For Chembarambakkam, there is more surface flow in October and November compared to the other months, corresponding with peak precipitation months of the northeast monsoon (Figure 24–Figure 27). However, in each month, there appears to be a gradual increase in the median value (represented by the thick black line at the centre of the box) suggesting that the amount of surface inflows (measured in m3/sec) is increasing with increase in imperviousness in each plotted year. The plots are also skewed to the right and show that with increase in imperviousness in each year, there seems to be larger variability in the surface flows as indicated by the size of the box and the whiskers. This could mean higher likelihood of flooding events around Chembarambakkam.

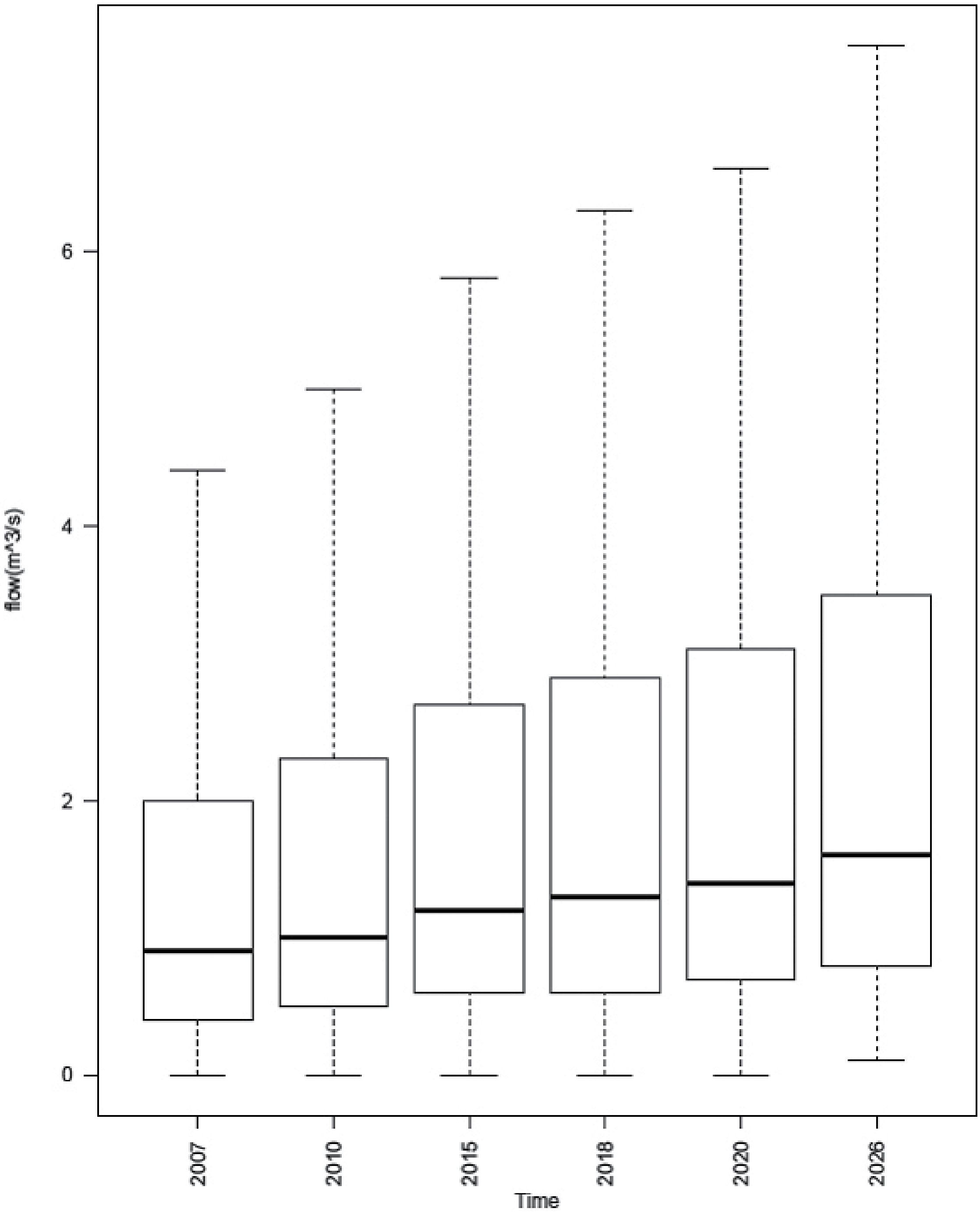

Figure 24: Surface inflow into Chembarambakkam in September

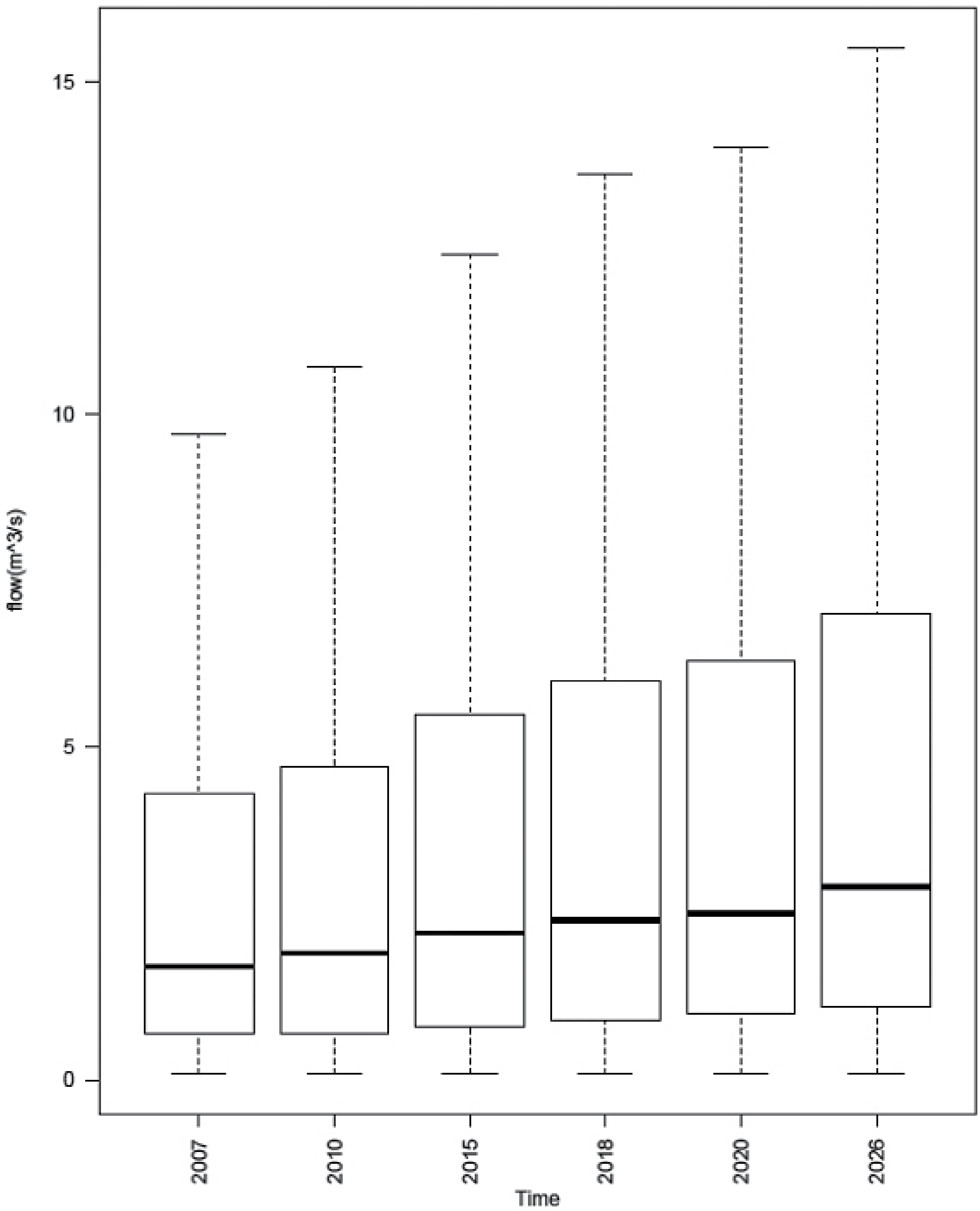

Figure 25: Surface inflow into Chembarambakkam in October

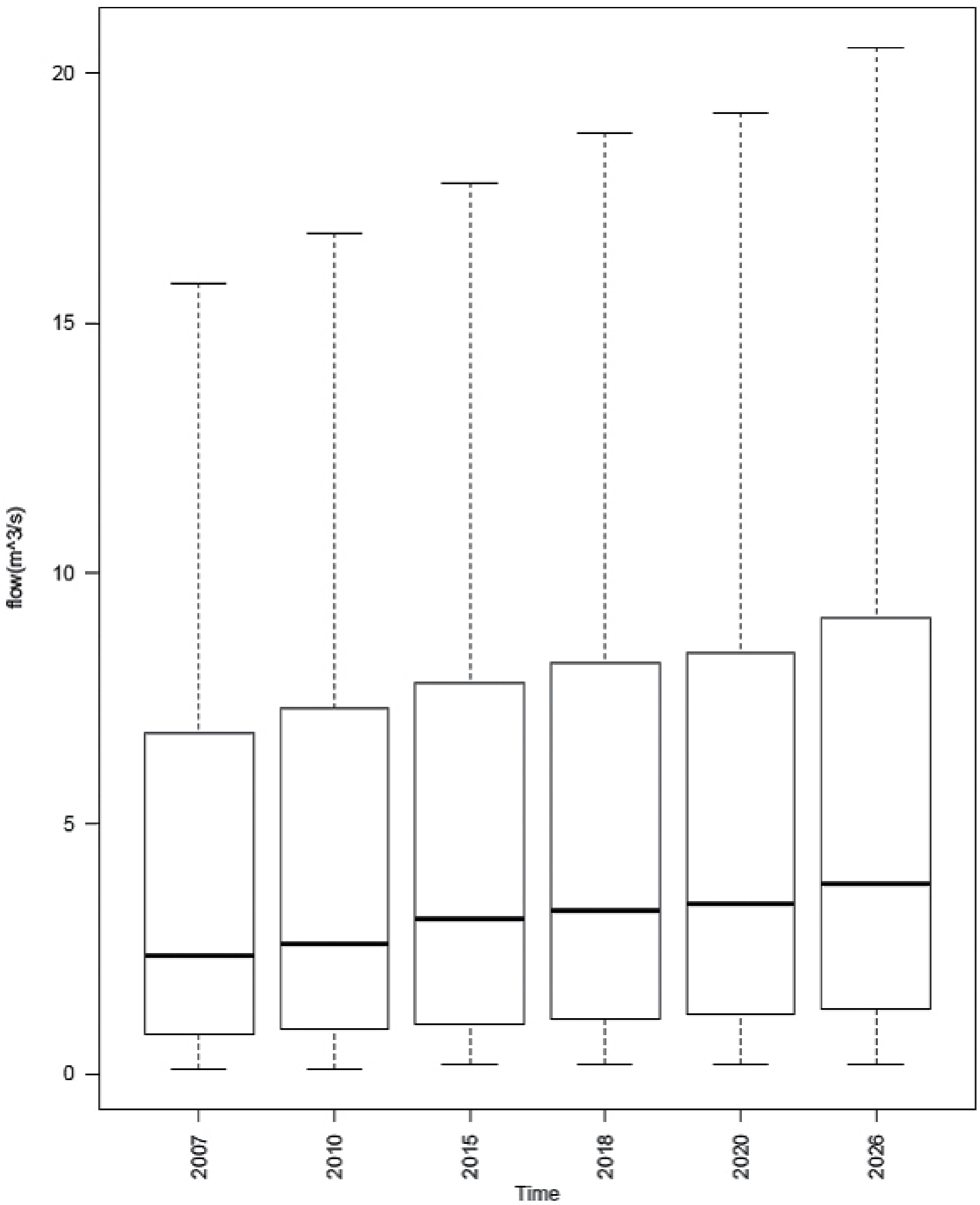

Figure 26: Surface inflow into Chembarambakkam in November

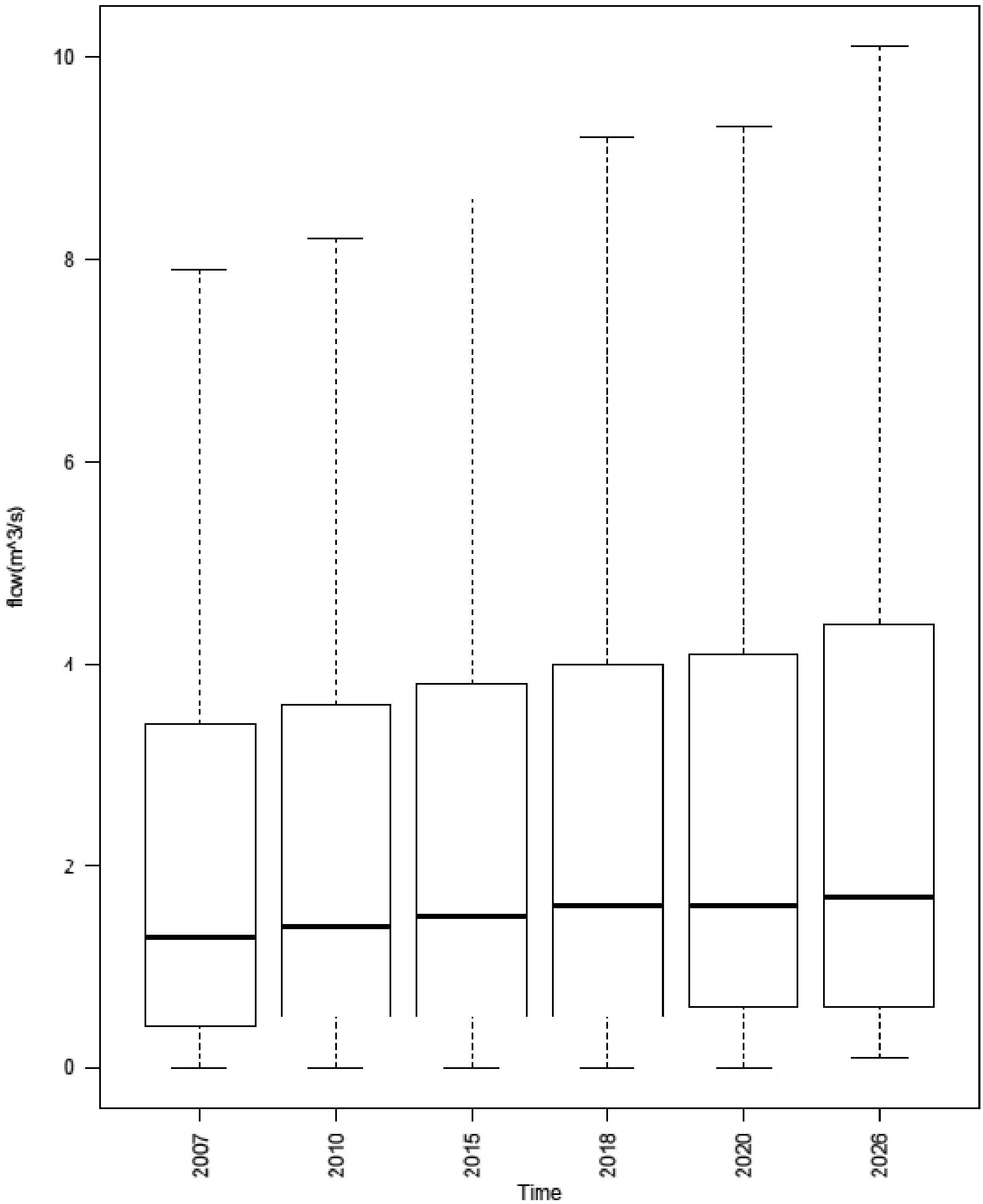

Figure 27: Surface inflow into Chembarambakkam in December

R110: Model results for this observation point are similar to Chembarambakkam. There is relatively more surface flow in October and November compared to the other months. However, in each month, there appears to be a gradual increase in the median value over time, suggesting that the amount of surface inflows (measured in m3/sec) is increasing with increase in imperviousness in each plotted year. The median surface inflow values for all months (between 1 m3/sec and 4 m3/sec) are similar to Chembarambakkam. The plots are also skewed to the right and show that with increase in imperviousness in each year, there seems to be larger variability in the surface flows as indicated by the size of the box and the whiskers. This could mean higher likelihood of flooding events around the point R110.

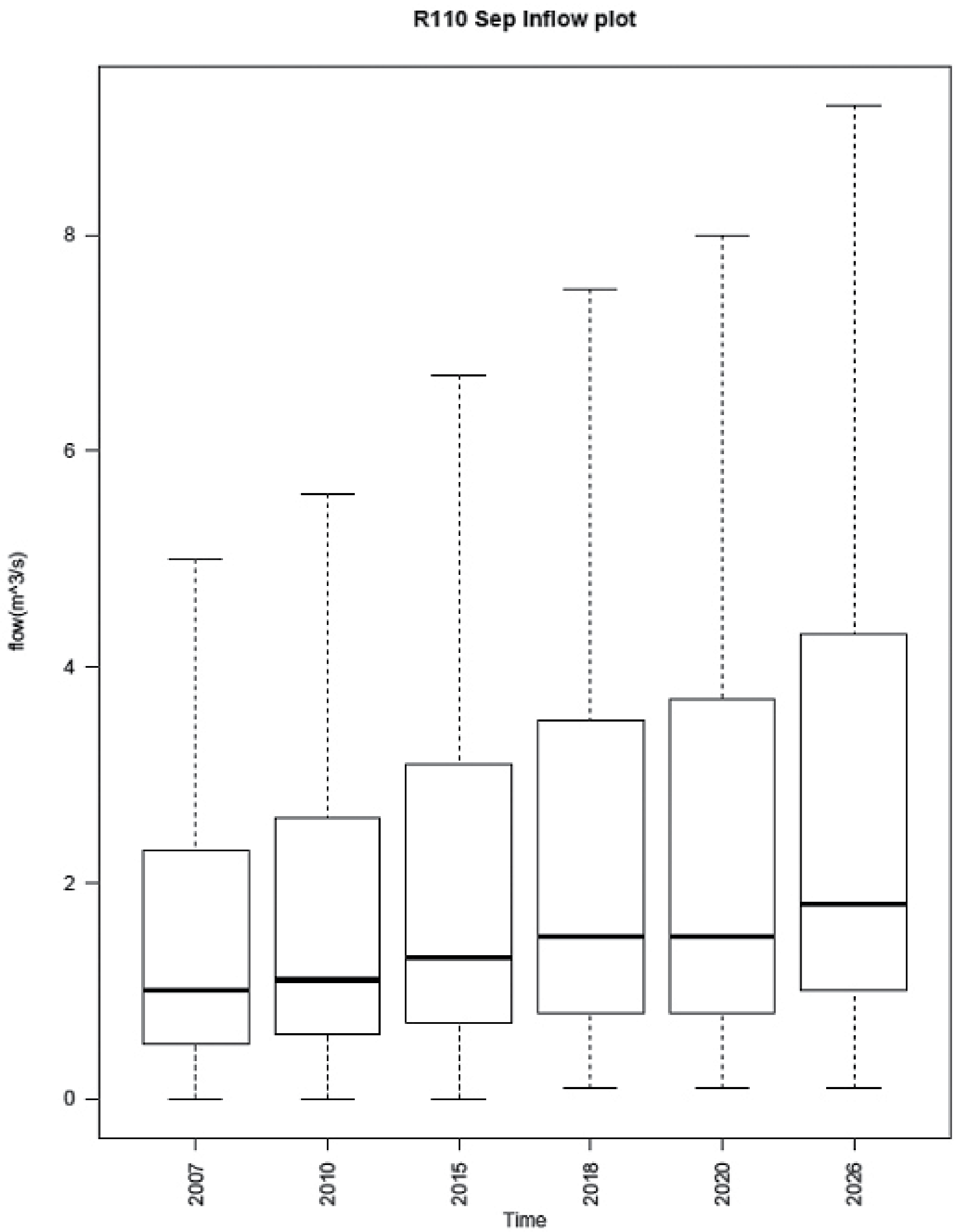

Figure 28: Surface inflow into R110 in September

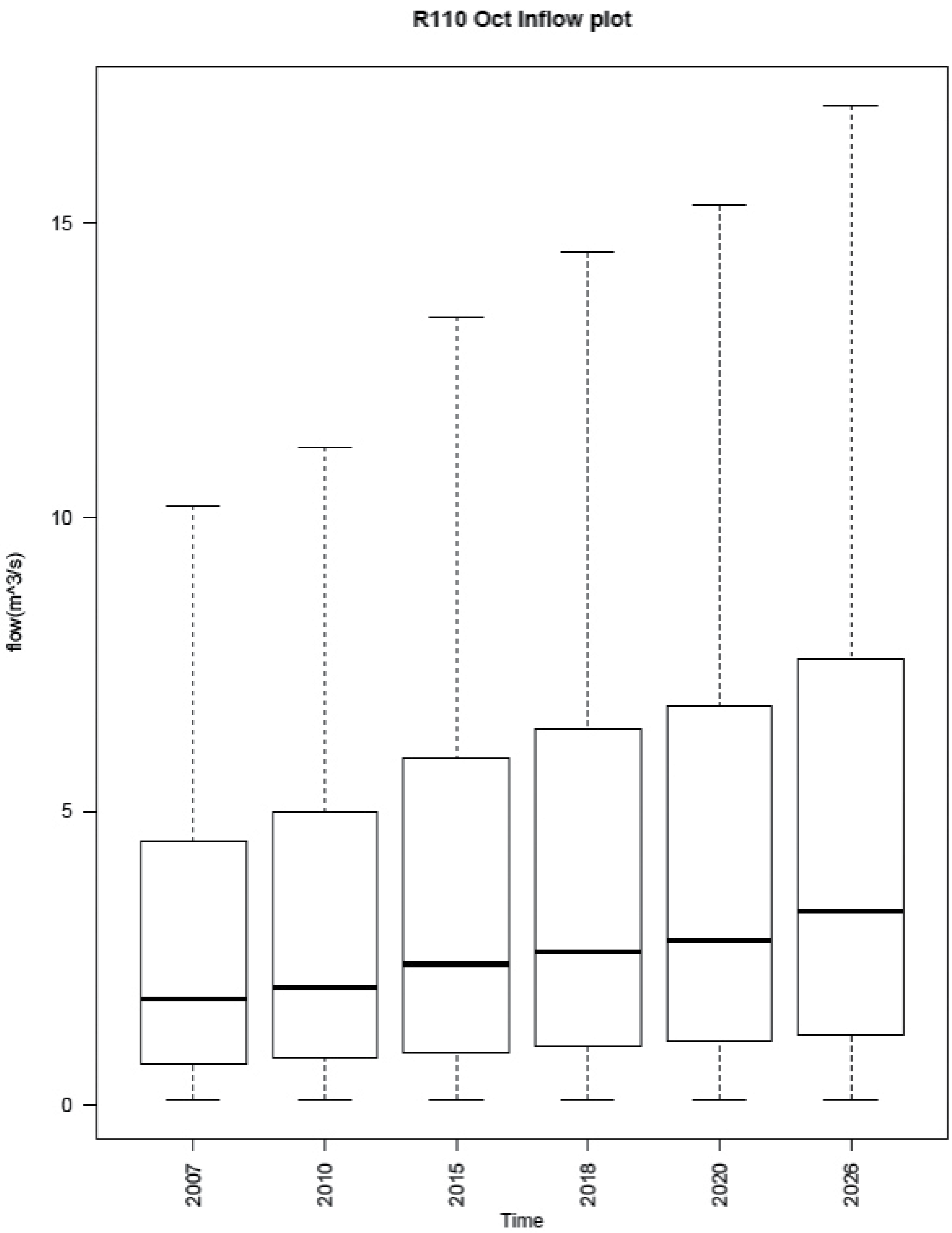

Figure 29: Surface inflow into R110 in October

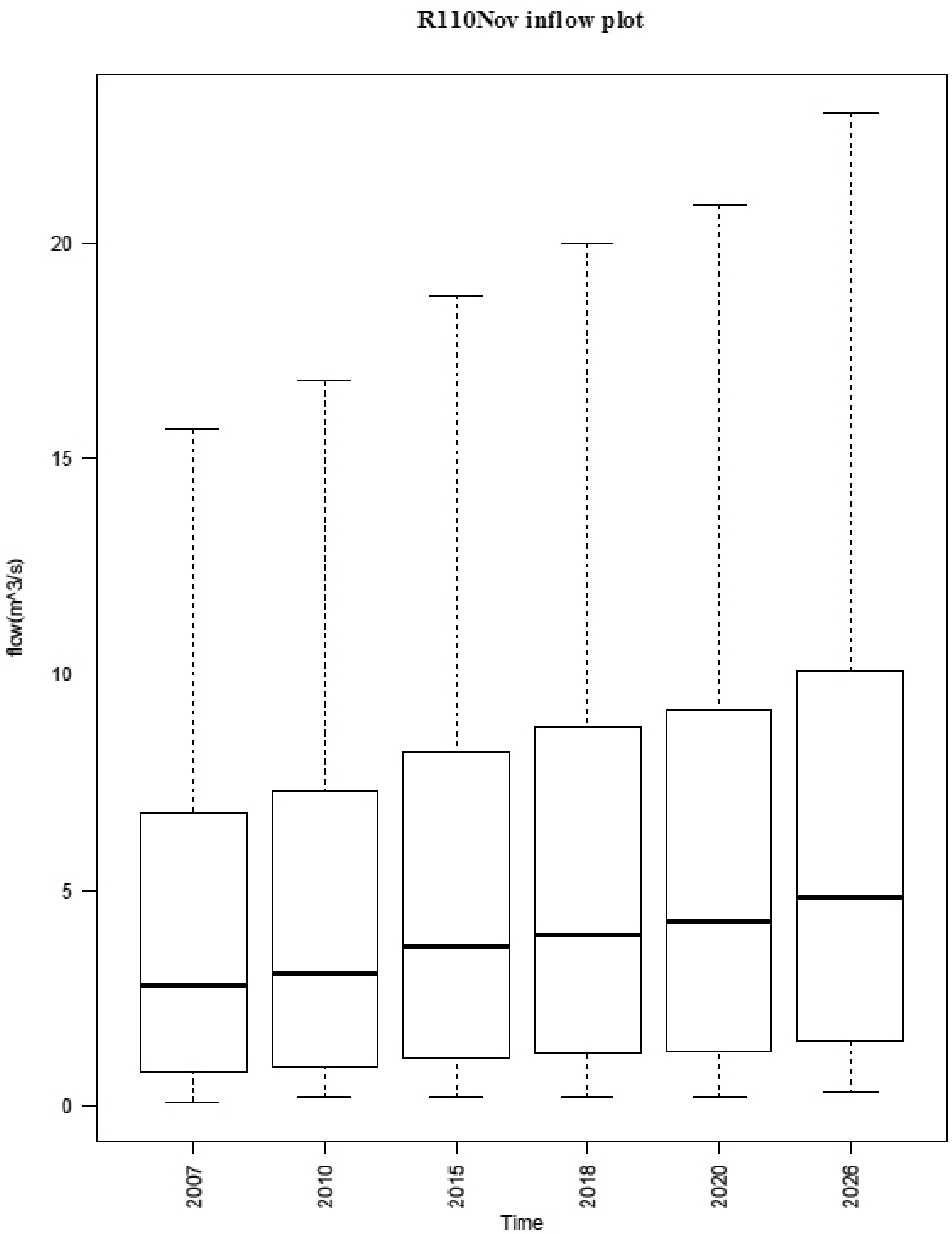

Figure 30:Surface inflow into R110 in November

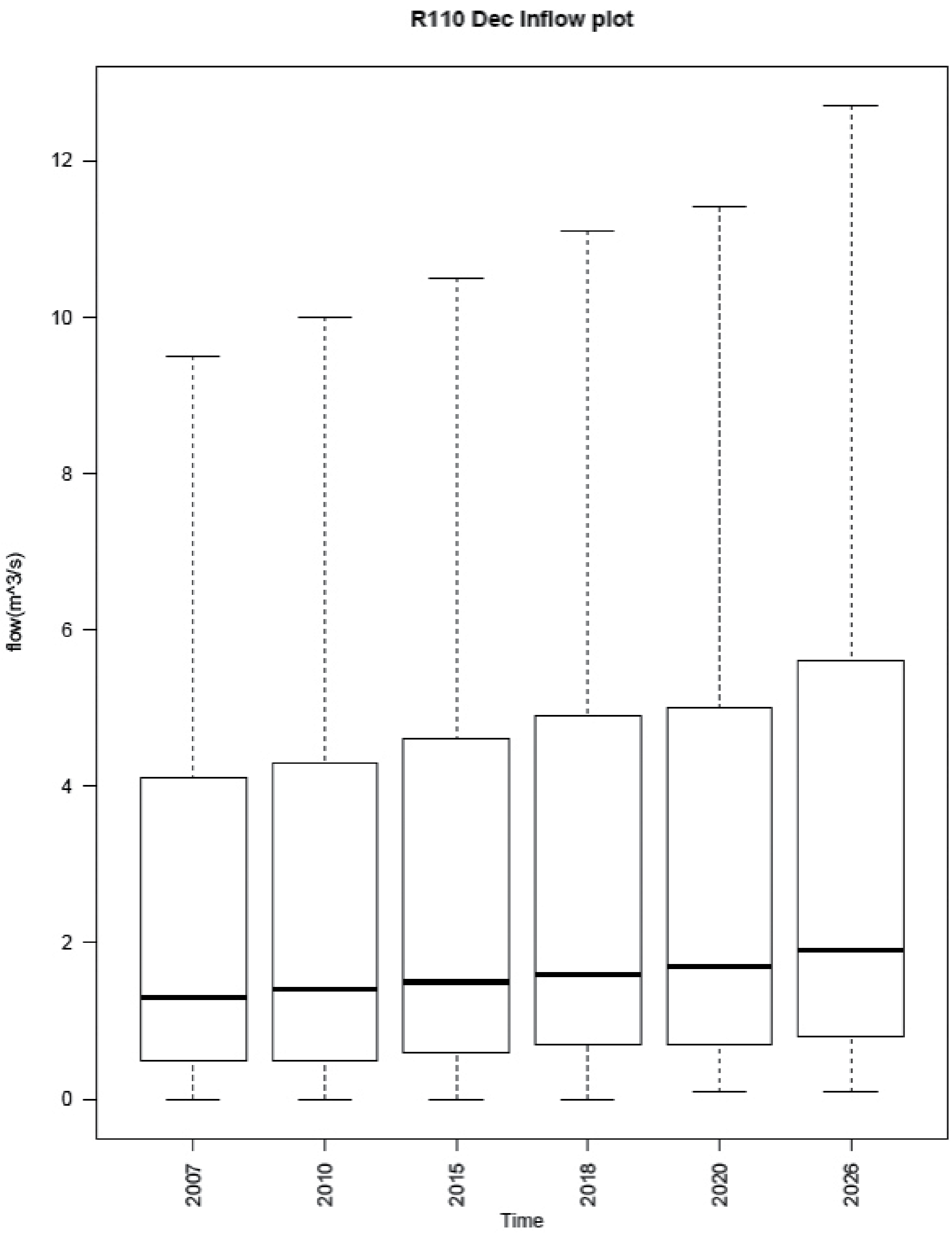

Figure 31: Surface inflow into R110 in December

R60: Similar results are seen for the observation point R60 – located near MIOT hospital and the airport (Figure 31- Figure 34). In each month, there appears to be a gradual increase in the median value suggesting that the amount of surface inflows (measured in m3/sec) is increasing with increase in imperviousness in each plotted year. The plots are also skewed to the right and show that with increase in imperviousness in each year, there seems to be larger variability in the surface flows as indicated by the size of the box and the whiskers. This could mean higher likelihood of flooding events around this point.

Yet, R60 differs from Chembarambakkam and R110 in that there are higher surface flows in October and November, with the latter showing a minimum median value of 10 m3/sec in 2007 that could increase to approximately 14 m3/sec by 2026(). This surface flow is greater than at Chembarambakkam, which could have a maximum inflow of approximately 2.5 m3/sec by 2026 and R110 with a maximum probable inflow of approximately 3-4 m3/sec. This is not surprising considering that R60 is farther downstream and hence would carry flow from multiple channels and streams including Chembarambakkam and R110. However, the results reiterate that this stretch of the Adyar river would be at higher risk from flooding due to extreme precipitation events in future as compared to Chembarambakkam and R110, consequently impacting life and property as evident from the damage witnessed in December 2015.

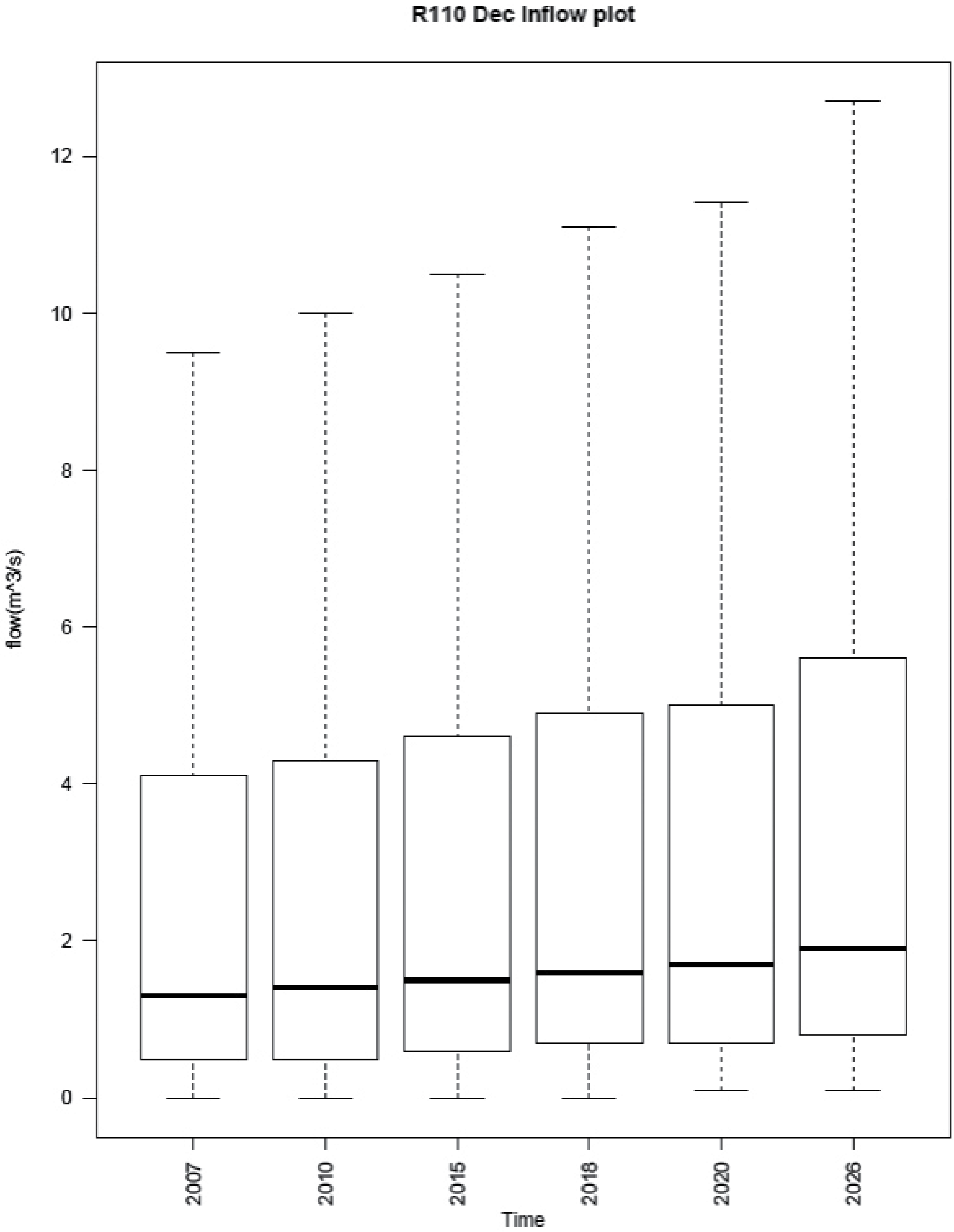

Figure 32: Surface inflow into R60 in September

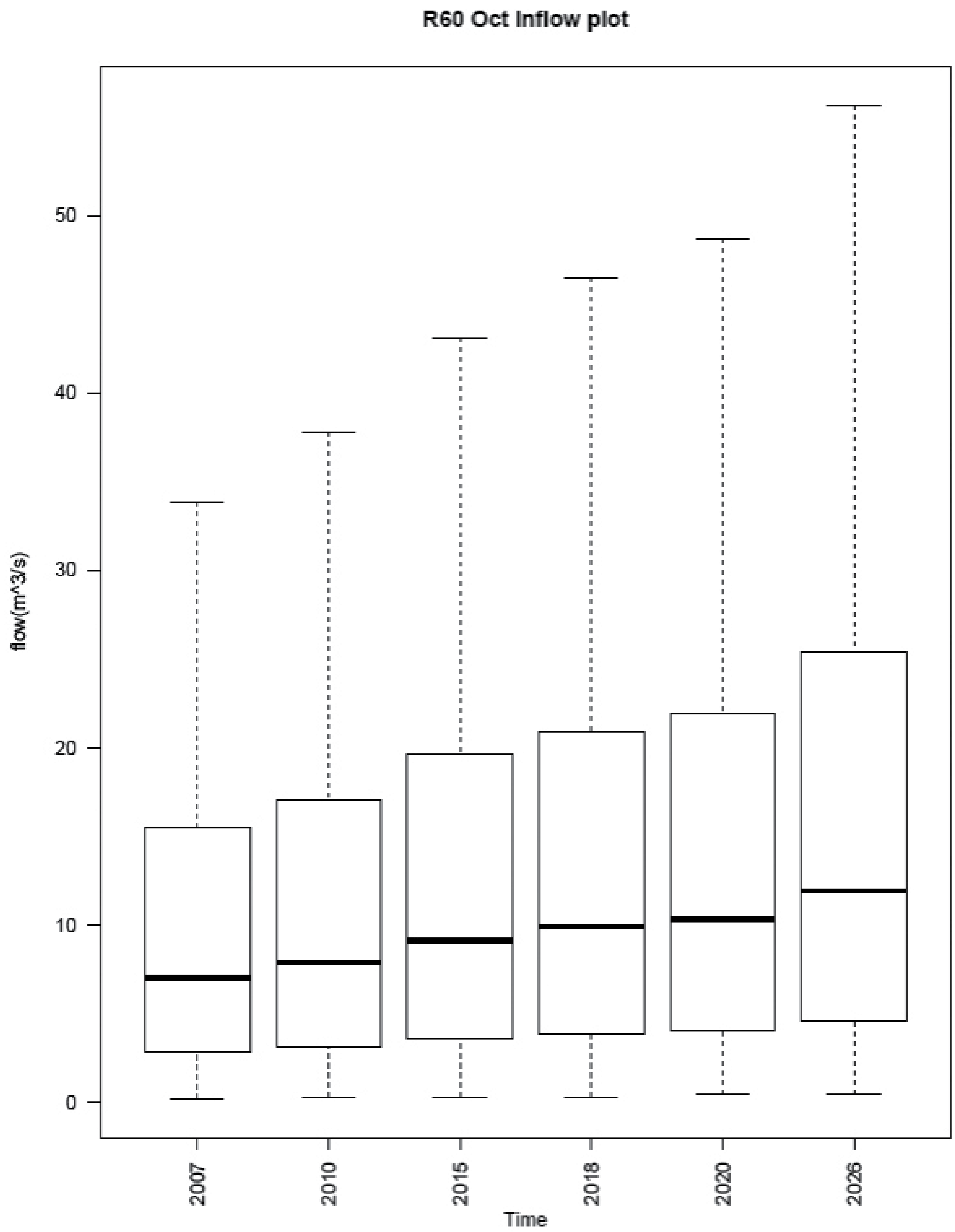

Figure 33: Surface inflow into R60 in October

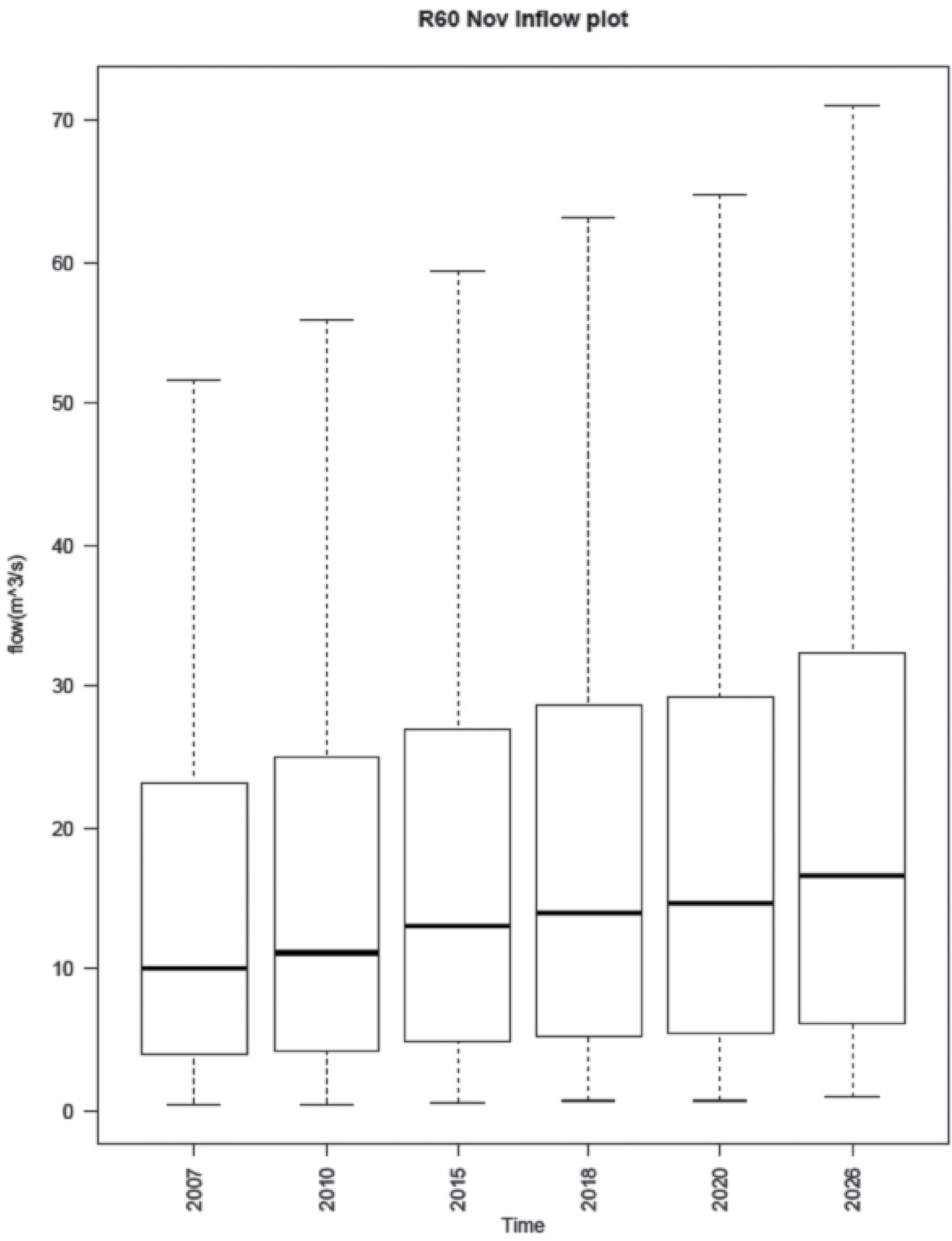

Figure 34: Surface inflow into R60 in November

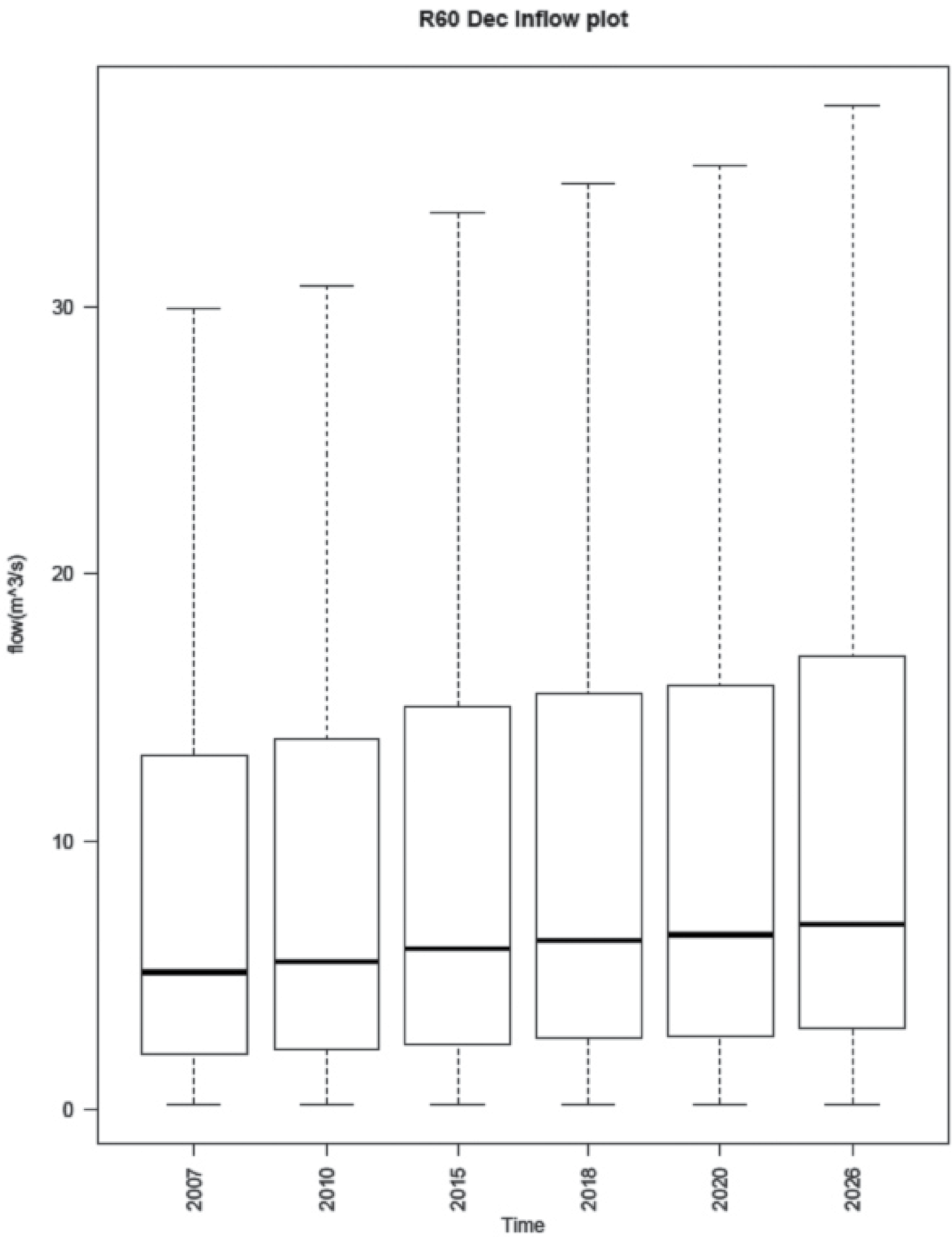

Figure 35: Surface inflow into R60 in December

Conclusions: The goal of our modelling exercise was to understand if an increase in built-up area results in an increase in surface flow or run-off in the Adyar basin for the period 2006-2040. We modelled surface water inflows into three strategic points in the Adyar basin: Chembarambakkam reservoir, R110 – a point in the basin, south-east of Chembarambakkam and R60 – a stretch of the Adyar river, east of Chembarambakkam, near MIOT hospital and the airport. At all three points, there is conclusive evidence to show that an increase in built-up area (measured by imperviousness values) results in an increase in the surface inflows or surface run-off, thereby increasing the vulnerability of the areas to flooding events in future. Among the three points, R60 demonstrates higher surface run-off, possibly because it is farther downstream and carries run-off from more channels and streams. However, the location of this point is critical as the area around it is highly built up and it is near a specialized healthcare centre and major transport hub. This makes it a vulnerability hotspot that requires sensitive, smart governance and planning mechanisms that aim to increase its adaptive capacity and consequently its resilience to climate change events. While questions have already been raised as to why these structures were built in the first place, it is critical that in future such instances are not repeated and those agencies involved in granting planning permissions take informed decisions based on existing environmental threats and vulnerabilities.

In addition to an absolute increase in run-off values, the variance in potential run-off is also shown to be increasing over time. While a definitive statement on how these dynamics impact flooding is out of the scope of this analysis and is heavily dependent on an estimation of drainage channels and patterns, this variance coupled with the experience of flooding in 2015 indicates that the probability of rainfall-led natural disasters will increase over the next few years as the built environment continues to infringe on the natural environment. It is therefore imperative that decisions on drainage, the built environment and the natural environment be made in a coherent manner in order to avoid catastrophes in the future.

CHAPTER 7: WAY FORWARD

CHAPTER 7 : WAY FORWARD

This report aggregates and analyses information about Chennai's current state of water, including future projections and risks. We do this using a city water assessment framework that examines water source and availability, water supply, demand and balance, drains and sanitation, water-sector investments or solutions, and vulnerabilities, risks and threats. The report also presents results from primary analysis exercises that we carried out, asking the following five questions. We assessed the first four using various methodologies as described in each relevant section, and the fifth using modelling:

- How stable have groundwater recharge rates been over time?
- Does new water demand match Metrowater supply projections?
- Do waterbody restoration efforts integrate with the water ecosystem?
- Do environmental impact assessment processes safeguard waterbodies against development?
- What are the impacts of urbanization on Adyar basin flow patterns?

In conclusion, our results show that an estimated 1000 million litres are currently available to Chennai every day; consumed by residences, businesses, institutions and industry. This water is sourced essentially from rainfall, which varies in intensity over the course of each year, and across years. The extent to which this rainfall varies can be extreme. Rainfall replenishes river flow and other surface sources, as well as groundwater tables. Water is also sourced from desalination plants, which treat brackish water and – to an almost negligible extent – from treated waste water.

Exact amounts for Chennai water supply and demand are not known: supply is by and large not metered but instead measured in terms of amounts of water released. As a result, officials rely on estimates, which for supply are equivalent to availability (approximately 1000 MLD today) and for demand range at present from 1050 to 2248 MLD. Because these numbers are not definitively known, it is unclear whether (and the extent to which) Chennai water supply and demand equate. What is clear, however, is that demand is projected to increase, given a burgeoning population with changing needs, a growing economy and plans to expand the CMA. Also, supply is likely to be impacted by the range of vulnerabilities, risks and threats that the sector faces.

It is also clear that Chennai is investing heavily in its water sector. There is widespread awareness that city area water balance, if it exists at all, is precarious, and steps and measures to improve and protect this balance are being planned and implemented by a range of entities including Metrowater, Chennai's water utility, other water-related government departments, the non-profit sector, civic associations, the private sector and, in some cases, partnerships between these different groups. Investments range from large-scale, large-budget projects, including new desalination plants and STPs, to tiny-scale efforts, including smartphone applications and socialmedia flood-mapping tools.

What is not clear is whether these efforts will be sufficient to ensure future water-sector sustainability. First, experts disagree about how sustainability is to be achieved. Some argue that an increase in desalination capacity, for example, will solve most problems, while others insist this is an overly expensive and environmentally detrimental option, positing instead that Chennai should return to traditional water-capturing systems that are managed at a decentralized level. At the same time, government officials assure us that ongoing storm water drain repairs will reduce flood risk to almost zero, while others we spoke to dismiss these repairs as almost inconsequential. Many, including officials we spoke with at Metrowater, opine that wastewater reuse should contribute far more significantly to Chennai water supply – that existing plans to improve on this are inadequate, at least in the near term. Others are certain that Chennai-ites have a "mental block" against wastewater reuse.

Second, our research indicates that current investments in the water sector do not seem to appropriately consider the many, very complex, interlinked and often intensifying vulnerabilities, risks and threats facing the water sector. For example, waterbody restoration efforts don't sufficiently account for sewage and solid waste dumping in channels; they typically don't include plans to clean these channels– which could mean a quick reversal of the entire effort. Another earlier example involves Metrowater's 1980s plan to implement a radial system that failed to foresee an increase in apartment complexes and resulting pressure on supply systems. This was later adjusted in the second master plan in the early 1990s which changed the configuration to a zone-based distribution system – but it indicates the narrow focus that seems to predominate water-sector improvement planning, and a lack of consideration of the general vulnerabilities and risks that can complicate plan outcomes (Interview with TUFIDCO official, 2017).

Also, many investments appear insufficiently coordinated across multiple plans and organizations. For instance, several related master plans define water-sector improvement efforts. However, a close reading of these master plans indicates they are often entirely uncoordinated: most do not consider any aspect of other plans. Lack of coordination is also a key problem generally defining water-sector governance, as indicated by several officials we met. One official lamented, "CRRT does one thing, Metrowater another, and CMA something entirely different" (Government official, 2017).

At a general level, our primary research leads us to conclude that a continuation of business as usual in the water sector will mean groundwater levels may plummet and run-off could increase, which in turn will translate into numerous social, economic and environmental problems for Chennai.

At a general level, our primary research leads us to conclude that a continuation of business as usual in the water sector will mean groundwater levels may plummet and run-off could increase, which in turn will translate into numerous social, economic and environmental problems for Chennai.

Going forward, we make the following broad and specific recommendations. They are based on our findings and analysis in this report, and also reflect a set of potential and future scenarios that we are working towards with the aim of facilitating better collaboration, greater convergence between planning and action, and concurrence between multiple stakeholder visions for the future development of the city along a more socio-environmentally and economically sustainable path. In the next phase of our work, we will incorporate these recommendations into potential future scenarios, which will then be validated with various stakeholder groups to define desirable and feasible scenarios that we will then work towards, with the ultimate goal of a more sustainable Chennai.

1. **Wastewater reuse:** we recommend this be made a more primary focus of water supply improvement efforts. While current Metrowater plans include investments in new treatment plants, and while related pilot programmes appear to be ongoing, such plans also seem to have been ongoing for years; they never seem to advance to the level we feel is required for Chennai. As mentioned on page 28, one expert defined these efforts as "stalled" in 2010. A Metrowater official we interviewed this year defined them as "moving slowly", emphasizing that they are key to solving Chennai water woes but estimating it will take another 10-15 years before they actually become reality. We recommend that this process be expedited so it is achieved sooner.

2. **Desalination versus wastewater reuse:** one step towards achieving the recommendation above could be to conduct an in-depth analysis comparing desalination with wastewater reuse as mechanisms for improving Chennai water supply. This would involve careful consideration of each approach, including the substantial infrastructure investments required,the significant environmental implications, vagaries in rainfall conditions and potential income streams. We recommend a "Monte Carlo" or similarly probabilistic approach for this analysis (rather than a traditional, deterministic approach).

3. **Groundwater protection legislation:** refinement and better enforcement are required here. Groundwater resources in Chennai, as across India, face a considerable threat, both in terms of over-exploitation and pollution. In Chennai, situated as it is on the coast, this threat is compounded by saline intrusion, which is both a result of over-exploitation and a factor contributing to pollution. Legislation exists to protect groundwater; however, it lacks clarity in some aspects and stories abound about a lack of enforcement – at every level. Both these issues need to urgently be addressed.

4. **O&M of existing water supply mechanisms needs to be improved:** this involves changes at the budgetary and the systems levels. At the budget level, just 20-50 percent of current budgets, depending on the agency, are allotted for O&M. As described by one official, "The government gives money for marriage but not for raising the family" (Government official from Metrowater, 2017). At the systems level, existing infrastructure and systems are often antiquated. Metrowater officials explained that water supply pipes are often very old, that a lack of instruments such as GIS or GPS considerably inhibits their ability to do their work and that monitoring systems, for example, to detect pollution levels, are adhoc. "There is no systematic manner by which we adopt technology," the official told us. "This is partially due to a shortage of funds, but that is not the only issue. It is also a system problem" (Metrowater official, 2017).

5. **Take active steps to curb demand:** improving Chennai's water sector appears to mainly focus on improving water supply. Very little seems to be done in terms of demand-side factors, and demand appears to be constrained almost exclusively by supply. We recommend that Chennai expand this focus to develop a strategy to generate awareness about water use and the tools that facilitate it, such as water-efficient showers, toilets and other appliances, including at the commercial and industrial level, and grey-water and wastewater reuse.

BIBLIOGRAPHY

ADB. India: Climate Adaptation through Sub-Basin Development Programme, preparedby Mott MacDonald Delhi, India. Manila:ADB, 2014.

Akshatha, M. Rs 700 crore spent annually as OMR residents wait in vain for piped water. Citizen Matters, 4 August 2017. Retrieved from, http://chennai.citizenmatters.in/omr-it-corridor-piped-water-supply-and-sewerage-network-problem-2433.

Anand, P.B. Some issues in managing water supply in Asian metropolitan cities. The Challenge of Urban Environmental Management. London: Ashgate, 1999b.

Anand, P.B. & World Institute for Development Economics Research. Water "scarcity" in Chennai, India: Institutions, entitlements and aspects of inequality in access. Helsinki, Finland: United Nations University, World Institute for Development Economics Research, 2001.

Annapoorani, A. et al. Assessing the water quality in coastal aquifer of Chennai, India - a case study. International Journal of Water,vol.11, No. 2 (2017).

Anushiya, J. & A. Ramachandran. Assessment of water availability in Chennai basin under present and future climate scenarios. Environmental Management of River Basin Ecosystems. New York: Springer, 2015: 397-415.

Arabindoo. Unprecedented nature? An anatomy of the Chennai floods. City, vol. 20, No. 6 (2016): 800-821.

Arappor Iyakkam. Why Chennai stinks? Citizens' effort to understand and solve sewage problem, 2017. Retrieved from, http://arappor.org/public/Document/activites/waterbodies/Arappor-Citizens-Report-Sewage.pdf.

Arasu, Sibi. Water mafia tightens hold on parched Chennai. India Climate Dialogue, 26 October 2017. Retrieved from, http://indiaclimatedialogue.net/2017/10/26/water-mafia-tightening-hold-parched-chennai/.

Arunprakash, M. et al. Impact of urbanization in groundwater of south Chennai city, Tamil Nadu, India. Environmental Earth Sciences,vol.71, No. 2 (2014): 947-957.

Ayyar, R.Tamil Nadu water crisis sends industries scouting for diverse solutions. Times of India, 7 July 2017. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/tn-water-crisis-sends-industries-scouting-for-diverse-solutions/articleshow/59479968.cms.

Batvari, B.P.D. et al. Heavy metals accumulation in crab and shrimps from Pulicat lake, north Chennai coastal region, southeast coast of India. Toxicology and Industrial Health, vol.32, No. 1 (2016): 1-6.

Biswas, Asit K. & I. Juha Uitto. Water for Urban Areas: Challenges and Perspectives. Tokyo:United Nations University Press, 1999. Retrieved from, http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0fnl2%2E2--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&cl=CL1.5&d=HASH7ecfef951c65b8a6f0da56.7.9&gt=1.

Boggaram, Vittal & Raj Bagath.Mapping, measuring and mitigating urban water challenges. WRI Ross Centre for Sustainable Cities, 2017.

Braun, B. & N. Castree. Remaking Reality: Nature at the Millennium. London and New York: Routledge, 1998.

Braun, B. The Intemperate Rainforest: Nature, Culture, and Power on Canada's West Coast. Minneapolis and London: University of Minnesota Press, 2002.

Chakrapani, Saranya. Risk Map app launched in Chennai to share info on flooding. Times of India, 8 November 2017. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/riskmap-app-launched-to-share-info-on-flooding/articleshow/61563363.cms.

Chennai Metropolitan Development Authority, Government of Tamil Nadu. Second MasterPlan for Chennai Metropolitan Area, 2026, Volume3, Chapter7, Infrastructure, 2008. Retrieved from, http://www.cmdachennai.gov.in/smp_main.html.

Chennai Metropolitan Development Authority, Government of Tamil Nadu. Second Master Plan for Chennai Metropolitan Area, 2026, Volume3, Chapter9, Solid waste management, 2008. Retrieved from, http://www.cmdachennai.gov.in/smp_main.html.

Chennai Metropolitan Development Authority, Government of Tamil Nadu. Seminar on waterways in Chennai, Session 3–River and drainage system in CMA, 2010. Retrieved from, http://www.cmdachennai.gov.in/SeminarOnWaterways.html.

Chennai Metropolitan Water Supply and Sewerage Board, Government of Tamil Nadu. Chennai Metrowater Projects. Retrieved from, http://www.chennaimetrowater.tn.nic.in/projects.html. Accessed 2 June 2018.

Chennai Metropolitan Water Supply and Sewerage Board, Government of Tamil Nadu. Desalination Plant at Minjur. Retrieved from, http://www.chennaimetrowater.tn.nic.in/desalination.html. Accessed 2 June 2018.

Chennai Metropolitan Water Supply and Sewerage Board, Government of Tamil Nadu. Water supply system. Retrieved from, http://www.chennaimetrowater.tn.nic.in/watersupplysystem.html. Accessed 2 June 2018.

Chennai Metropolitan Water Supply and Sewerage Board, Government of Tamil Nadu. Storage as on 30.03.2018 with reference to mean sea level. Retrieved from, http://www.chennaimetrowater.tn.nic.in/public/lake.htm. Accessed 30 March 2018.

Chennai Rivers Restoration Trust (CRRT), Government of Tamil Nadu. Cooum river eco-restoration project. Retrieved from, http://www.chennairivers.gov.in/downloads.html. Accessed 2 June 2018.

Chennai Rivers Restoration Trust (CRRT). AdyarPoongaPhaseI. Retrieved from, http://www.chennairivers.gov.in/Adyar-Poonga-PhaseI/adyar_poonga_Phase-1.html. Accessed 2 June 2018.

Climate Service Centre Germany (GERICS) &KfW Development Bank. Climate focus paper: Regional sea-levelrise in South Asia. Hamburg and Frankfurt am Main, 2015.

Climatemaps.com. Rainfall/Precipitation in Chennai, Tamil Nadu, India, 2017. Retrieved from, http://www.chennai.climatemps.com/precipitation.php.

Cronon, W. Nature’s Metropolis- Chicago and the Great West. New York, London: W.W. Norton & Company, 1991.

Dastgheib, A.& Roshanka Ranasinghe. Relative Sea-Level Rise Scenarios: Cauvery Delta Zone, Tamil Nadu, India. UNESCO-IHE, Institute for Water Education. Manila: ADB, 2014.

Department of Environment, Government of Tamil Nadu. State of Environment Report, Tamil Nadu, 2005.

Department of Environment, Government of Tamil Nadu. Tamil Nadu State Action Plan on Climate Change (TNSAPCC) final draft report. Chennai, 2015.

Department of Environment, Government of Tamil Nadu. Tamil Nadu State Action Plan on Climate Change (TNSAPCC) final draft report, Chapter 6, Water Resources, 2015. Retrieved from, http://www.environment.tn.nic.in/sapcc.html.

Drone mapping project begins. The Hindu, 22 November 2017. Retrieved from, http://www.thehindu.com/news/national/tamil-nadu/drone-mappingproject-begins/article20629548.ece.

Elangovan, N.S., V. Lavanya& S. Arunthathi. Assessment of groundwater contamination in a suburban area of Chennai, Tamil Nadu, India. Environment, Development and Sustainability, 2017.

Encroachment of lakes and riverbeds caused Chennai floods: parliamentary panel.UK PressFrom, 17 August 2016. Retrieved from, http://uk.pressfrom.com/news/world/india/-61226-encroachment-of-lakes-and-riverbeds-caused-chennai-floods-parliamentary-panel/.

Environment and Social Systems Assessment. Government of India.National Groundwater Management Improvement Program, 2017.The World Bank.

Environmentalist Foundation of India. Lake Conservation. Retrieved from, http://www.indiaenvironment.org/what_we_do.html#Lake_Conservation. Accessed 2 June 2018.

Esther, S.& M.D. Devadas. A calamity of a severe nature: case study – Chennai, India. WIT Transactions on the Built Environment, vol.165 (2016): 227-236.

Flood sensors at 16 locations in Chennai to offer real time data. The Hindu, 13 January 2018. Last modified 14 January 2018. Retrieved from, http://www.thehindu.com/news/cities/chennai/flood-sensors-at-16-locations-in-chennai-to-offer-real-time-data/article22438855.ece.

Freyberg, T. Four desalination plants to help Chennai meet increasing water demand. Water & Wastewater International Magazine, 25 January 2016. Retrieved from, http://www.waterworld.com/articles/wwi/2016/01/four-desalination-plants-to-help-chennai-meet-increasing-water-demand.html.

Gopalakrishnan, S. Why making sea water drinkable is not the solution India should look at. YourStory, 9 June 2017. Retrieved from, https://yourstory.com/2017/06/potable-sea-water/.

Gopalakrishnan, S. When wetlands refuse to wilt away. India Waterportal Database, 19 March 2017. Retrieved from, http://www.indiawaterportal.org/articles/when-wetlands-refuse-wilt-away.

Gosain, A.K. et al. Climate change impact assessment of water resources of India. Current Science, vol.101, No. 3(2011).

Government of India, Census Data. Tamil Nadu Population Census data 2011, 10 July 1016. Retrieved from, http://www.census2011.co.in/census/state/tamil+nadu.html.

Government of Tamil Nadu, Tamil Nadu Water Investment Company (TWIC), IIT Madras&Madras School of Economics. Achieving water security in Tamil Nadu: challenges and opportunities. Background paper. Report shared with us by TWIC, 2017.

Government of Tamil Nadu, Water Resources Organization, Public Works Department. Micro level study Chennai basin. Institute for Water Studies, vol. 1, Chennai, 2007.

Greater Chennai Corporation. GCC disaster management plan 2017, Chapter II, Major and Minor Drainage Network, 2017. Retrieved from, http://www.chennaicorporation.gov.in/online-civic-services/northmonsoon_index.html.

Greater Chennai Corporation. GCCbudget, 2017-2018. Retrieved from, http://www.chennaicorporation.gov.in/budget/Budget_2017-18/.Accessed 2 June 2018.

Greater Chennai Corporation. Solid waste management department. Retrieved from, http://www.chennaicorporation.gov.in/departments/solid-waste-management/index.htm. Accessed 2 June 2018.

Greater Chennai Corporation. Development plan for Chennai metropolitan area. JNNURM, 2006. Retrieved from, http://www.transparentchennai.com/wp-content/uploads/downloads/2013/03/CDP_CHENNAI.pdf.

Greater Chennai Corporation. Storm water drain. Retrieved from, http://www.chennaicorporation.gov.in/departments/storm-water-drain/introduction.htm. Accessed 3 January 2018.

Groundwater falls by 1.5m since 2016. Times of India, 3 July 2017. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/groundwater-falls-by-1-5m-since-2016/articleshow/59417529.cms.

Harvey, D. From managerialism to entrepreneurialism: the transformation in urban governance in late capitalism. Geografiska Annaler. Series B, Human Geography,vol. 71, No. 1: 3-17. The roots of geographical change: 1973 to the present (1989).

Heynen, N., M. Kaika & E. Swyngedouw. In the Nature of Cities: Urban Political Ecology and the Politics of Urban Metabolism. Abingdon: Routledge, 2006.

Ilayaraja, K.&A. Ambica. Spatial distribution of groundwater quality between Injambakkam Thiruvanmiyur areas, southeast coast of India. Nature Environment and Pollution Technology, vol. 14,No. 4 (2015): 771-776.

India to remain the fastest growing economy in 2016: World Bank. India Today, 25 January 2016. Retrieved from, https://www.indiatoday.in/education-today/gk-current-affairs/story/fastest-growing-economy-305186-2016-01-23.

Indian Network for Climate Change Assessment, 2010. Retrieved from, http://www.envfor.nic.in/division/indian-network-climate-change-assessment.Accessed 6 July 2016.

Jadhav, R. 19% of Indians drink water with lethal levels of arsenic. Economic Times, 24 December 2017. Retrieved from, https://economictimes.indiatimes.com/news/politics-and-nation/19-of-indians-drink-water-with-lethal-levels-of-arsenic/articleshow/62228448.cms.

Jameson, S. & I. Baud. Varieties of knowledge for assembling an urban flood management governance configuration in Chennai, India. Habitat International,vol. 54 (2016): 112-123. Retrieved from,https://doi.org/10.1016/j.habitatint.2015.12.015.

Janakarajan, S. Optimising local water resources and availability in urban and peri-urban Chennai. Centre for Science and Environment. Workshop Presentation on Anil Agarwal Dialogues: Excreta Does Matter, 2013.

Jayaprakash, M. et al. Bioaccumulation of metals in fish species from water and sediments in macrotidal Ennore creek, Chennai, SE coast of India: A metropolitan city effect. Ecotoxicology and Environmental Safety, vol.120 (2015): 243-255.

Kabirdoss, Yogesh. Groundwater level in Chennai hits “critical state”. Times of India, 30 March 2017. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/groundwater-dips-20cm-per-year-as-chennai-overexploits-aquifers/articleshow/57905446.cms.

Kaur, Surinder&M.K. Purohit. Rainfall Statistics of India. India Meteorological Department. Ministry of Earth Science. New Delhi, 2015 & 2016.

Keil, R. & J. Graham. Reasserting Nature: Constructing Urban Environment after Fordism. In Braun, B. and N. Castree, eds. Remaking Reality: Nature at the Millennium. London and New York: Routledge, 1998.

Keil, R. Urban political ecology. Urban Geography, vol. 24 (2003): 723-738.

Kennedy, L. et al. Engaging with Sustainability Issues in Metropolitan Chennai. Chance2Sustain. Bonn: EADI, 2014.

Kolappan, B. What drives urbanisation in Tamil Nadu. The Hindu, 5 July 2015.Retrieved from, http://www.thehindu.com/news/national/tamil-nadu/what-drives-urbanisation-in-tamil-nadu/article7386961.ece.

Kotteswaran, C.S. Rising sea eroding Tamil Nadu coastline: GSI team. Deccan Chronicle, 17 June 2016. Retrieved from, https://www.deccanchronicle.com/nation/current-affairs/170616/rising-sea-eroding-tamil-nadu-coastline-gsi-team.html.

Krishnan, Raghu. Climate experts say El Nino responsible for heavy Chennai rains. Business Standard, 3 December 2015. Retrieved from, http://www.business-standard.com/article/current-affairs/climate-experts-say-el-nino-responsible-for-heavy-chennai-rains-115120201026_1.html.

Kumar, Pradeep. In Rs 274cr smart city projects, every drop of water to be measured. Times of India, 13 January 2018. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/in-rs-274cr-smart-city-projects-every-drop-of-water-to-be-measured/articleshow/62479928.cms.

Lakshmi, K. Reservoirs recorded the lowest rainfall in 2003. The Hindu, 5 January 2004. Retrieved from, http://www.thehindu.com/2004/01/05/stories/2004010509170300.htm.

Lakshmi, K. Work on pipeline for Nemmeli desalination plant complete. The Hindu, 19 April 2012. Last modified 12 July 2016. Retrieved from, http://www.thehindu.com/news/cities/chennai/work-on-pipeline-for-nemmeli-desalination-plant-complete/article3329190.ece.

Lakshmi, K. One check dam to save many litres of water. The Hindu, 15 January 2013. Last modified 12 July 2016. Retrieved from,http://www.thehindu.com/news/cities/chennai/one-check-dam-to-save-many-litres-of-water/article4310290.ece.

Lakshmi, K.A fourth desalination plant for Chennai. The Hindu, 20 January 2016. Last modified 23 September 2016. Retrieved from, http://www.thehindu.com/news/cities/chennai/A-fourth-desalination-plant-for-Chennai/article14009579.ece.

Lakshmi, K. Metrowater plans digital water meters in commercial buildings. The Hindu, 5 April 2017. Retrieved from,http://www.thehindu.com/news/national/tamil-nadu/metrowater-plans-digital-water-meters-in-commercial-buildings/article17819571.ece.

Lakshmi, K. Online platform to collate data on lakes. The Hindu, 4 August 2017. Retrieved from, http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/online-platform-to-collate-data-on-lakes/article19423412.ece.

Lakshmi, K. Water table around check dams sees a rise. The Hindu, 8 February 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/Water-table-around-check-dams-sees-a-rise/article17245352.ece.

Lakshmi, K. Water tankers to be tracked real-time. The Hindu, 27 July 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/water-tankers-to-be-tracked-real-time/article19367017.ece.

Lakshmi, K. Work on 5th reservoir resumes. The Hindu, 8 September 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/work-on-5th-reservoir-resumes/article19639049.ece.

Lakshmi, K. In parched city, borewells proliferate, go deeper. The Hindu, 12 May 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/in-parched-city-borewells-proliferate-go-deeper/article18433642.ece.

Lavanya, Ar. K. Urban flood management – A case study of Chennai city. Architecture Research, vol. 2, No. 6 (2012): 115-121.

Loganathan, D. et al. Status of groundwater at Chennai city, India. Indian Journal of Science and Technology, vol. 4, No. 5 (2011): 562-577.

Lopez, A.X. Broaching the British legacy of arch drains in Chennai. The Hindu, 10 December 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/broaching-the-british-legacy-of-arch-drains/article21384586.ece.

Lopez, A.X. Civic body pinning hopes on volunteers for flood mitigation. The Hindu, 20 October 2017. Retrieved from, http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/civic-body-pinning-hopes-on-volunteers-for-flood-mitigation/article19885320.ece.

Maitra, S. Inter-state river water disputes in India: institutions and mechanisms. Japanese Journal of Political Science, vol. 8, No. 2 (2007): 209-231.

McKenzie, D. & I. Ray. Urban water supply in India: Status, reform options and possible lessons. World Bank Group, Open Knowledge Repository, Water Policy Journal, vol. 11 (2009): 442-460.

Menezes, L. et al. Report of fact-finding team's enquiry into alleged environmental and human rights violations arising from construction and operation of 100 MLD Nemmeli desalination plant in Kanchipuram, Tamil Nadu. Chennai Solidarity Group, 2013.

Munian, A. Dynamics of Residential Water Demand and Supply in India: A Case Study of Chennai City. New Delhi: Gyan Publishing House, 2010.

Municipal Administration and Water Supply Department. Municipal Administration and Water Supply Department Policy Note 2016-2017, Demand no.34. Retrieved from, http://www.tn.gov.in/documents/dept/21/2016-2017.

Murty, B.S., Balaji Narasimhan, Arpita Mondal, Subimal Ghosh and Pradeep Mujumdar. Chennai Flood 2015, A Rapid Assessment Report. Interdisciplinary Research Centre for Water Research, IISc Bengaluru, 2016.

Narain, Sunita. Conflict of Interest: My Journey through India's Green Movement. New Delhi: Penguin, 2017.

Narayanan, Chitra. Chennai offers a drinking water model for coastal India. The Hindu BusinessLine, 9 November 2016. Retrieved from, https://www.thehindubusinessline.com/specials/clean-tech/chennai-offers-a-drinking-water-model-for-coastal-india/article9325008.ece.

Narayanan, Nayatara. India's south east coast should learn from cyclone Vardah and build storm-proof infrastructure. Scroll, 2016. Retrieved from, https://scroll.in/article/824157/indias-south-east-coast-should-learn-from-vardah-and-hudhud-and-build-cyclone-proof-infrastructure.

Natarajan, P.M. & Shambhu Kalloikar. Urban resilient integrated water management pathways, to achieve sustainable water resources development in Chennai metropolitan city, Tamil Nadu, India. Water Practice and Technology, vol. 12, No. 3 (2017): 564-575.

Nikku, Bala Raju. Water rights, conflicts and collective action: case of Telugu Ganga Project, India. The Tenth Biennial Conference of the International Association for the Study of Common Property (IASCP), Oaxaca, México, 2004.

Nirmal, Rajalakshmi & BL Research Bureau. Is your house standing on one of Chennai's missing lakes?The Hindu BusinessLine, 10 December2015. Retrieved from, https://www.thehindubusinessline.com/news/national/is-your-house-standing-on-one-of-chennais-missing-lakes/article7971979.ece.

Open Government Data (OGD) Platform India, Government of India. Area Weighted Monthly and Seasonal Rainfall Annual Rainfall (1901-2015). Retrieved from, https://data.gov.in/resources/all-india-area-weighted-monthly-seasonal-and-annual-rainfall-mm-1901-2015.

Pannirselvam, R. Chembarambakkam Water Treatment Plant Chennai, India. JapanWater Research Centre, 2016.

Pattabiraman, B. There's a jackal out there in the heart of Chennai, did you know? Citizen Matters, 12 September 1017. Retrieved from, http://chennai.citizenmatters.in/chennai-rivers-restoration-trust-adyar-eco-park-chennai-2656.

Pattabiraman, B.With the CRRT in charge, can Chennai look forward to a cleaner Cooum?Citizen Matters, 12 September 2017. Retrieved from, http://chennai.citizenmatters.in/crrt-chennai-rivers-adyar-cooum-restoration-2724.

Pawariya, A. 95 per cent science: lessons for India from Israel's farms. Swarajya, 5 June 2017. Retrieved from, https://swarajyamag.com/amp/story/magazine%2F95-per-cent-science-lessons-for-india-from-israels-farms?__twitter_impression=true.

PTI. 10 crore people drinking contaminated water in India. Economic Times, 21 December 2017. Retrieved from, https://economictimes.indiatimes.com/news/politics-and-nation/10-crore-people-drinking-contaminated-water-in-india/articleshow/62191841.cms.

PTI. Rs 5300 crore desalination plant sought for Chennai's water needs. New Indian Express, 31 July 2017. Retrieved from, http://www.newindianexpress.com/cities/chennai/2017/jul/31/rs-5300-crore-desalination-plant-sought-for-chennais-water-needs-1636189.html.

PTI. Now, online booking must for Metro Water supply. New Indian Express, 23 May 2017. Retrieved from, http://www.newindianexpress.com/cities/chennai/2017/may/23/now-online-booking-must-for-metro-water-supply-1607945.html.

Qadir, M. et al. "Superbugs" evolving from poorly or untreated wastewater. Institute for Water, Environment and Health, 2011. Retrieved from, http://inweh.unu.edu/superbugs-evolving-from-poorly-or-untreated-wastewater.

Quiet flows people's power: How Kerala revived 10 rivers and numerous tanks and canals. Manorama, November 2017. Retrieved from, http://english.manoramaonline.com/news/kerala/2017/10/31/how-kerala-revived-rivers-tanks-canals-paddy.html.

Ragu Raman, A. Tamil Nadu tops in country with 46.9 per cent gross enrollment ratio. Deccan Chronicle, 06 January 2018. Retrieved from, https://www.deccanchronicle.com/nation/current-affairs/060118/tamil-nadu-tops-in-country-with-469-per-cent-gross-enrollment-ratio.html.

Raj, Y.E.A. Onset, withdrawal and inter-seasonal variation of northeast monsoon over coastal Tamil Nadu. 1991-2000. Regional Meteorological Centre, Chennai, 2013.

Rajagopalan, K. Waving or drowning? The battle of Chennai's vanishing waterways. Next City, 26 August 2013. Retrieved from, https://nextcity.org/features/view/waving-or-drowning-the-battle-for-chennais-vanishing-waterways.

Rajamanickam, R. & S. Nagan. A study on water quality status of major lakes in Tamil Nadu. International Journal of Research in Environmental Science, vol. 2, No. 2 (2016): 9-21.

Ramakrishnan, T. A dream will come true tomorrow. The Hindu, 28 September 1996a.

Ramkumar, Mu. & David Menier. The Cauvery basin of south India: A test case. InEustasy, High-Frequency Sea Level Cycles and Habitat Heterogeneity, 2017: 21-49.

Rao, Prakash & Yogesh Patil. Reconsidering the impact of climate change on global water supply, use and management, Chapter7: Characterizations and management concerns of water resources around Pallikaranai Marsh, South Chennai. Advances in Environmental Engineering and Green Technologies, 2017: 102-121.

Renganayaki, S.P.& L. Elango. A review on managed aquifer recharge by check dams: A case study near Chennai, India. International Journal of Research in Engineering and Technology, vol. 2, No. 4 (2013): 416-423.

Renganayaki, S.P. &L. Elango. Assessment of effect of recharge from a check dam as a method of managed aquifer recharge by hydrogeological investigations. Environmental Earth Sciences, vol. 73, No. 9(2015).

Rohit, T.K. Centre defers clearance for 400 MLD desalination plant. The Hindu, 25 December 2017. Retrieved from, http://www.thehindu.com/news/national/tamil-nadu/centre-defers-clearance-for-400-mld-desalination-plant/article22272171.ece.

Ruet, J., M. Gambiez & E. Lacour.Private appropriation of resource: Impact of peri-urban farmers selling water to Chennai Metropolitan Water Board. Cities, vol. 24, No. 2 (2007): 110-121.

Ruet, Joel et al. The water & sanitation scenario in Indian metropolitan cities: Resources and management in Delhi, Calcutta, Chennai, Mumbai. CSH Occasional Paper by French Research Institute of India, 6, 2002.

Sakthivel, P. et al. Managed aquifer recharge: the widening gap between law and policy in India. Water Science and Technology, vol. 15, No. 6 (2015): 1159-1165.

Seddon, Jessica et al. Metrics, monitoring and motivation: Contracting for solid waste management in Chennai. Okapi Research and Advisory. Chennai, 2014.

Sharad Raghavan, T.C.A. Linking urban India to drive growth. Livemint, 28 January 2015. Retrieved from, http://www.livemint.com/Opinion/VZ2ZW6DSRqTj7PIxbVLcIK/Linking-urban-India-to-drive-growth.html.

Shekar, L.Demolition of religious structures in Chitlapakkam raises hope for Chennai lakes. Citizen Matters, 2 January 2018. Retrieved from, http://chennai.citizenmatters.in/demolition-temple-church-mosque-encroachment-in-chitlapakkam-chennai-lake-3276.

Sivakumar, B. Census 2011: Tamil Nadu 3rd most urbanised state. Times of India, 20 July 2011. Retrieved from, http://timesofindia.indiatimes.com/city/chennai/Census-2011-Tamil-Nadu-3rd-most-urbanised-state/articleshow/9292380.cms.

Skymet Meteorology Division, India. Chennai rains rewrite highest rainfall record in December. Skymet Weather Services Pvt. Ltd, 9 December 2015. Retrieved from, https://www.skymetweather.com/content/weather-news-and-analysis/record-breaking-december-for-chennai-rains/.

Smith, N. The New Urban Frontier: Gentrification and the Revanchist City. London: Routledge, 1996.

Special Correspondent. Water quality in several lakes deteriorating: study. The Hindu, 21 April 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/water-quality-in-several-lakes-deteriorating-study/article18165174.ece.

Sridhar, V. A pipe dream? Frontline Magazine by The Hindu, vol. 21, No. 10 (2004). Retrieved from, http://www.frontline.in/static/html/fl2110/stories/20040521004009700.htm.

Srinivasan, R.K. Villagers in Tamil Nadu face groundwater crisis. Down To Earth, 31 July 2006. Retrieved from, http://www.downtoearth.org.in/news/villagers-in-tamil-nadu-face-groundwater-crisis-8162.

Srinivasan, V. An integrated framework for analysis of water supply strategies in a developing city: Chennai, India (Doctoral Dissertation), 2008. Retrieved from India Waterportal Database, http://www.indiawaterportal.org/articles/integrated-framework-analysis-water-supply-strategies-developing-city-chennai-india.

Srinivasan, V. et al. The impact of urbanization on water vulnerability: A coupled human-environment system approach for Chennai, India. Global Environmental Change, vol. 23, No. 1 (2013): 229-239.

Srinivasan, V.,S.M. Gorelick& L. Goulder. A hydrologic-economic modeling approach for analysis of urban water supply dynamics in Chennai, India. Water Resources Research, vol. 46, No. 7 (July 2010).

Srinivasan, V., S.M. Gorelick&L. Goulder. Sustainable urban water supply in south India: Desalination, efficiency improvement, or rainwater harvesting? Water Resources Research, vol. 46, No. 10 (October 2010).

Srinivasan, V. Coevolution of water security in a developing city. Hydrology and Earth System Sciences, vol. 10, No. 11 (2013): 13265–13291.

Srinivasan. Cauvery Delta Zone: Climate Data and Future Scenarios. Manila: ADB, 2013.

Sriram, V. A Chola gift to Chennai. The Hindu, 10 April 2015. Retrieved from, http://www.thehindu.com/features/metroplus/society/a-chola-gift-to-chennai/article7089318.ece.

Stephen, A. et al. Water quality status of three vulnerable fresh water lakes of suburban Chennai, India. Indian Journal Environmental & Ecoplanning, vol. 15, No. 3 (2008): 591-596.

Sudha, M., S. Ravichandran & R. Sakthivadivel. Waterbodies protection index for assessing the sustainability status of lakes under the influence of urbanization: a case study of south Chennai, India. Environment, Development and Sustainability, vol. 15, No. 5 (2013): 1157-1171.

Sunantha, G. & N. Vasudevan. Assessment of bacterial indicators and physico-chemical parameters in Tiruppur, Erode and Chennai, Tamil Nadu (India). Environmental Nanotechnology, Monitoring & Management, vol. 6 (2016): 219-260.

Sustainable water security mission for Chennai soon: Jaya. New Indian Express, 29 September 2016. Retrieved from, http://www.newindianexpress.com/cities/chennai/2015/sep/29/Sustainable-Water-Security-Mission-for-Chennai-Soon-Jaya-821809.html.

Sustainable Water Security Mission, Government of Tamil Nadu. Retrieved from, http://www.chennaiwatermission.in/?page_id=793. Accessed2March 2018.

Swyngedouw, E.& M. Kaika. The environment of the city or...the urbanization of nature. In G. Bridge, S. Watson, eds.Reader in Urban Studies, 567-580. Oxford: Blackwell Publishers, 2000.

Swyngedouw, E. & N. Heynen. Urban political ecology, justice and the politics of scale. Antipode,vol. 35, No. 5 (2003): 898-918.

Tamil Nadu Urban Infrastructure Financial Services Limited (TNUIFSL). KfW– Tamil Nadu Sustainable Municipal Infrastructure Financing through TNUIFSL. Retrieved from, http://tnuifsl.com/gf1kfw.asp.

The Hindu-Sci-Tech.The city's flood map goes global. The Hindu, 31 October 2016. Retrieved from, http://www.thehindu.com/sci-tech/technology/The-city%E2%80%99s-flood-map-goes-global/article15879880.ece.

TNM. Water respite for TN? Centre mulls transfer of surplus water from Godavari to Cauvery. News Minute, 24 November 2017. Retrieved from, https://www.thenewsminute.com/article/water-respite-tn-centre-mulls-transfer-surplus-water-godavari-cauvery-72099.

TNN. Robotic excavators to clean drains, waterways in city. Times of India, 7 July 2015. Retrieved from, https://timesofindia.indiatimes.com/city/chennai/Robotic-excavators-to-clean-drains-waterways-in-city/articleshow/47965951.cms.

Vadivukkarasi , P. et al. Studies on the influence of climatic conditions on pH and temperature of southeast coast, Chennai, Bay of Bengal. International Journal of Engineering Research & Technology, vol. 3, No. 8 (2014): 1478-1482.

Veena, S. & K. Seema. Examining the emerging role of groundwater in water inequity in India. Water International, vol. 39, No. 2 (2014): 172-186.

Venkatachalam, L. Informal markets and willingness to pay for water: A case study of the urban poor in Chennai city, India. International Journal of Water Resource Development, vol. 31, No. 1 (2014): 134-145.

Venkat, Vidya. Drought in Tamil Nadu mostly man-made. The Hindu, 30 June 2017. Retrieved from, http://www.thehindu.com/news/cities/chennai/drought-in-tamil-nadu-mostly-man-made/article19181865.ece.

Water Resources Department, Government of Tamil Nadu. Ongoing schemes under augmenting Chennai city water supply, 2012. Retrieved from, http://www.wrd.tn.gov.in/chennairegion_ws.html.

Water Resources Department, Government of Tamil Nadu. Tamil Nadu water quality maps for fluoride, nitrate and total dissolved solids (tds). Water Resources Department, 2015. Retrieved from, http://www.groundwatertnpwd.org.in/wqmaps15.htm.

Water Resources Department, State Ground and Surface Water Resources Data Centre, Government of Tamil Nadu. Groundwater investigation. Retrieved from, http://www.groundwatertnpwd.org.in/gwinvestigation.htm. Accessed 2 June 2018.

Water Resources Department, State Ground and Surface Water Resources Data Centre, Government of Tamil Nadu. Intensive survey for groundwater potential assessment on water shed basis. Retrieved from, http://www.groundwatertnpwd.org.in/intensivestudy.htm. Accessed 2 June 2018.

Water security mission will be extended across TN: Phanindra. New Indian Express, 23 March 2017. Retrieved from, http://www.newindianexpress.com/cities/chennai/2017/mar/23/water-security-mission-will-be-extended-across-tn-phanindra-1584671.html.

White, C. Understanding water markets: Public vs. private goods. Global Water Forum, 2015. Retrieved from, http://www.globalwaterforum.org/2015/04/27/understanding-water-markets-public-vs-private-goods/.

World Bank. 2018. India - Atal Bhujal Yojana (ABHY) - National Groundwater Management Improvement Program (English). Washington, D.C. : World Bank Group.

World Bank Group. Mainstreaming Water Resources Management in Urban Projects: Taking an Integrated Urban Water Management Approach.Washington, D.C.: World Bank, 2016.

APPENDIX 1

List of organizations interviewed	Nature
Chennai Metropolitan Development Authority	Government
Chennai Metropolitan Water Supply and Sewerage Board	Government
Greater Chennai Corporation	Government
Public Works Department	Government
Tamil Nadu Water Investment Company	Private
Tamil Nadu Urban Infrastructure and Financial Services Ltd	Public Private Partnership
Tamil Nadu Urban Finance and Infrastructure Development Corporation Limited	Public Private Partnership
Urban Labs	Private
Coastal Research Centre	NGO
Care Earth	NGO
Civic Action Group	NGO
Indo-German Centre for Sustainability	Think tank
Rain Centre	NGO
South Asia Consortium of Interdisciplinary Water Resources Studies	Academic