STRATEGY REPORT

A PLATFORM FOR INTEGRATED WATER GOVERNANCE IN METROPOLITAN CHENNAI:

DEVELOPING FUTURE SCENARIOS AND STRATEGIES THROUGH PARTICIPATORY SIMULATIONS

— 2019 —

FUNDERS

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AUTHORS

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ABOUT THE ORGANIZATIONS

FUNDERS

TAMIL NADU STATE LAND USE RESEARCH BOARD (TN SLURB)

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.

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.

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 (RWH). The organization's continued investments in clean practices and processes that often go beyond statutory requirements reflect its commitment to the environment.

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 IIT Madras' alumni, students and faculty. They provide financial and technical collaboration and support for cutting-edge applied and 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.

TECHINCAL 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 the private 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.

Settlement on the banks of a waterway inundated in the 2015 Floods © Nikhil Mehare

EXECUTIVE SUMMARY

With an aim to foster more holistic and informed urban governance, this project, titled "***A Platform for Integrated Water Governance in Metropolitan Chennai: Developing Future Scenarios and Strategies through Participatory Simulations,***" is an effort to develop an integrated platform for decision making and planning with the goal to bring all relevant stakeholders and interest groups together.

Between September, 2017 and March, 2019, the project team has worked with a coalition of public, private and community stakeholders representing the Chennai Metropolitan Area (CMA) to examine how policy-makers can use a simulation-based tool to take more integrated decisions for better management of water while considering aspects of land use development and waste management. This exercise functions as a platform to strengthen coordination within government and between public, private and community stakeholders in advancing a more sustainable and resilient future for the CMA.

This report is the culmination of efforts to identify the institutional dynamics among the actors and the processes shaping Chennai's urban ecosystem, with a focus on land, water and waste, offering a list of strategic and targeted recommendations to address the current predicaments and guide the future planning process around these issues. Further, this document comes on the heels of the following three elaborate policy-oriented reports published under the ambit of this project:

1. Chennai: Urban Visions – A report on the city's socio-economic drivers, their visions and the overall trajectory of development.
2. Chennai: State of Water – A report on the current state of water and associated risks.
3. 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 to address the city's water woes.

In addition to a series of policy-oriented reports, the final output includes an Agent Based Modelling tool that would assist policy-makers and key stakeholders in the land-waste-water nexus make informed decisions.

To begin with, the report delves deeper into three specific themes: Land-use, water and waste and the associated challenges identified by government officials and policy-makers, through a series of stakeholder workshops, semi-structured interviews with key actors, analysis of public data-sets, planning, policy and budget documents. While discussing the challenges related to these themes in the context of CMA, the report unpacks the involved actors' roles, relationships, processes and gaps in order to identify what needs to change or improve for better governance of these areas of concern.

Based on the analysis, the following key points emerged under each area:

I. LAND-USE

a. The marked increase in the informal economy with its associated housing challenges will intensify encroachments along waterbodies and in vulnerable areas.

b. The proposed CMA area expansion, though still in its early stages, has yet to account for the developmental pressures on natural resources that it is likely to result. As in the existing CMA area, this will only result in induced and inorganic urbanization and rampant land use reclassification.

c. Increases in migration into city's peripheral areas due to high population density within the city will increase land prices with limited access to affordable housing.

d. Increasing water-related challenges in the city, along with land scarcity, may push industries to city peripheries. The inevitable migration is bound to disrupt the land use, water and waste dynamics in these areas. The pressure experienced by government to provide infrastructure, stemming from the migration of people and industries, will only exacerbate loss of waterbodies and ecologically vulnerable areas.

e. While the government attempts to transform Chennai into a ' world-class' city, the dominant visions (social equity, environmental sustainability, sustainable economic growth) and aspirations of non-governmental stakeholders representing academia, civil society, private sector and vulnerable communities should be taken into account in order to make way for inclusive development.

II. WATER

a. The issue of water management in Chennai is highly complex and multi-layered. The presence of multiple public as well as private/civic agencies contributes to a fragmented governance ecosystem that needs to coordinate and collaborate more effectively in order to address the systemic issues around water management.

b. The existing gaps in integrated and collaborative management of water is the key driver of inefficiencies in operations, policies, and infrastructure maintenance, thus bloating the influence and market share of informal actors.

c. In addition, domestic customers' unmonitored consumption patterns are only exacerbated by a policy environment that provides neither incentive nor penalty mechanisms to support/enforce water conservation unlike other state-supplied commodities such as electricity.

d. Without a comprehensive water metering policy and improvements in infrastructure and holistic management of water, these trends are poised to continue, in all likelihood leading to undesirable outcomes for the city's natural resources and its residents.

III. WASTE

a. The consequences of a bourgeoning population, unbridled urbanisation and associated consumerism are bound to increase the amount of waste generated in Chennai.

b. An effective intervention needs concerted cooperation between governmental and non-governmental stakeholders.

c. Improper landfill management and the selection of ecologically vulnerable areas for future landfill sites will exacerbate groundwater and air pollution problems and negatively impact overall quality of life.

d. Poor enforcement and monitoring of existing laws further compound the impact of the issue. Exnora, Hand-in-Hand and RWA success stories are fragmented and get lost in the prevailing SWM practices, which are typically insufficient.

e. The state's recent SWM policy, which strengthens Urban Local Body (ULB) authority to address SWM and GCC's SWM by-laws are likely to soon lead to improved source segregation in Chennai as they include user fees for waste collection and penalties for failing to segregate waste.

Following the discussion on current state of affairs around land-water-waste nexus, the report analyses four possible scenarios for the CMA using the Agent-based Modelling tool in order to identify the temporal effects on land-use, water and waste.

SCENARIO 1: **BUSINESS-AS-USUAL**	This refers to a situation where no new interventions are added. Thus, no new infrastructure will be planned. Instead, everyday operations and maintenance are continued. The objective of this scenario is to provide an insight into the impact of planning as it currently happens in Chennai. It also provides an idea of the extent of the planning challenge and the amount of resources that may be required to tackle it.
SCENARIO 2: **NO SUSTAINABILITY INITIATIVES**	In order to draw focus on the importance of different sustainability initiatives, this scenario plans for an increasingly urbanised Chennai with new infrastructure but no additional sustainability initiatives (lake restoration, water metering, waste-water recycling etc.), while trying to meet all of the water demand.
SCENARIO 3: **LOW RAINFALL WITH FOCUS ON SUSTAINABILITY INITIATIVES**	In this scenario, Chennai and the surrounding area would experience less than normal rainfall. The reduction in the amount of water available for distribution, is also estimated. In this scenario, an increasingly urbanised Chennai will plan for new infrastructure to meet the increase in water demand but will also have to adopt water conservation initiatives to meet the water demand.
SCENARIO 4: **AVERAGE RAINFALL WITH NO NEW INFRASTRUCTURE:**	In this scenario it was analysed if Chennai will be able to meet all its waste, water sewerage services demand by completely relying on water conservation strategies. This scenario is designed to look at purely existing infrastructure and maintenance of the same, while the city pursues only water conservation initiatives.

These simulations will be able to show how the motivations, constraints, and actions of a specific government department aggregate up into city-level outcomes. It will allow users to understand the connection between the city's social micro-foundations (behaviour of particular stakeholders, or "agents,") and macro-level outcomes such as changes in land use, waste and water demand patterns. Further, the ABMs will illustrate how stakeholder decisions and interventions affect scenarios for critical risks in metropolitan development. The intersections that emerge out of this process will be visually presented as vulnerabilities and points of leverage to promote urban resilience. Such models have been shown to be useful reference points for helping disparate stakeholders a) understand the larger systems that they are trying to influence, b) test and refine their own theories of change and impact, and c) identify synergies and conflicts between their own efforts and others' initiatives.

In conclusion, the report presents a set of targeted recommendations for more sustainable management of land, water, and waste and the tensions that arise due to the interaction across these themes. These recommendations are based on our analysis and findings in this report and reflect a set of potential strategies which aim to facilitate 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.

The recommendations have been categorised under the following headers:

PARTICIPATORY AND DATA-DRIVEN PLANNING

Alternative forms of knowledge (for instance, community-based knowledge) and technology needs to be accommodated in planning and decision-making.

Example: Establishing a state-of-the-art data centre in partnership with reputed academic institutions for procuring and analysing quality data to test the outcome/projection of new policies/projects.

HOLISTIC/ INTEGRATED AND WELL-COORDINATED PLANNING

Master planning exercises should be prepared simultaneously and in conjunction with relevant agencies in order to ensure coordination between the planning agency and the rest of the implementing agencies.

Example: In order to improve groundwater levels and mitigate the impacts of floods, innovative designs with water conservation in the forefront like porous pavements and rain gardens, should be entrenched in the development of new public and private infrastructure.

STRINGENT ENFORCEMENT OF EXISTING RULES/ REGULATIONS

In order to ensure the protection and conservation of ecologically vulnerable areas including water bodies, marshlands and groundwater sources, the existing rules and regulations designed to guard the exploitation of natural resources needs to be effectively enforced.

Example: Reclassification process should be made institutionally more rigorous, involving multiple stakeholders/agencies especially in cases of transforming unbuilt or ecologically vulnerable land into built-up area.

FORMULATION OF COMPREHENSIVE POLICIES

The problems that exists in the land-use-water-waste nexus cannot be addressed by cosmetic and fragmented interventions but only through the formulation of targeted and comprehensive policies that address the root of the problem.

Example: A comprehensive water policy which would include water metering, water body restoration, waste-water recycling and usage, flood mapping etc.

AWARENESS CAMPAIGNS

Developing a comprehensive strategy for generating awareness amongst the public about water conservation, waste management to bring about a behavioural change in resource consumption.

Example: Targeted awareness campaigns to disseminate the merits in the usage of treated wastewater for domestic purposes should be clearly explained to the public, substantiated with data around quality and reliability.

ENHANCED RESOURCE SUPPORT AND CAPACITY BUILDING

Appropriate allotment of resources for daily operations and maintenance of existing infrastructure is key to ensure the proliferation and sustainability of new infrastructure.

Example: Existing inventory of machinery such as Excavators, Tipper, Jet rodding machine, desilting machines, electrical equipment, ladders, etc. that are required for maintenance, repair and restoration of infrastructure needs to be increased according to the requirement and demand.

The recommendations from this report along with the agent-based models are poised to guide the key stakeholder to identify short, medium- and long-term interventions along financial, technological, personnel and regulatory axes and help assess implications of specific land, water and waste related decisions on CMA's water vulnerability.

Stakeholders, irrespective of their affiliations, were forthcoming about sharing visions, aspirations and challenges. While they were aware of uncertainties around water security, it was clear that a lack of concerted efforts or poorly coordinated efforts provide few actual solutions. It is hoped that this report, in conjunction with the agent-based modelling tool, will act as a valuable resource for policy-makers to gain granular insights into the institutional relationships and pave the way for integrated governance.

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LIST OF ABBREVIATIONS

ABMs	Agent-based Models
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
CMWSSB	Chennai Metrowater Supply and Sewerage Board
CPCL	Chennai Petroleum Corporation Limited
CPHEEO	Central Public Health and Environmental Engineering Organization
Cr	Crore
CRC	Coastal Research Centre
CRRT	Chennai Rivers Restoration Trust
CRZ	Coastal Regulation Zone
DoE	Department of Environment
DTCP	Directorate of Town and Country Planning
EFI	Environmentalist Foundation of India
EIA	Environmental Impact Assessment
GCC	Greater Chennai Corporation
GIS	Geographic Information System
GoI	Government of India
Ha	Hectare
IMD	Indian Meteorological Department
IIT	Indian Institute of Technology
IT	Information Technology
JICA	Japan International Cooperation Agency
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KfW	Kreditanstalt für Wiederaufbau
LPA	Long Period Average
LPCD	Litres Per Capita per Day
MIDS	Madras Institute of Development Studies
MLD	Million Litres per Day
MSW	Municipal Solid Waste
NE	North East
NGO	Non-Governmental Organization
NoC	No Objection Certificate
NSSO	National Sample Survey Office
NRW	Non-Revenue Water
O&M	Operation and Maintenance
OECF	Japan's Overseas Economic Cooperation Fund
OMR	Old Mahabalipuram Road
PWD	Public Works Department
RDF	Refuse Derived Fuel
RTI	Right to Information
RWA	Residential Welfare Associations
RWH	Rain Water Harvesting
SaciWATERs	South Asia Consortium for Interdisciplinary Water Resources Studies
SEAC	State Expert Appraisal Committee
SIDCO	Small Industries Development Corporation
SIPCOT	State Industries Promotion Corporation of Tamil Nadu
SNA	Social Network Analysis
STP	Sewerage Treatment Plant
SWM	Solid Waste Management
TIDCO	Tamil Nadu Industrial Development Corporation Limited
TNHB	Tamil Nadu Housing Board
TNIDB	Tamil Nadu Infrastructure Development Board
TNPCB	Tamil Nadu Pollution Control Board
TNSAPCC	Tamil Nadu State Action Plan for Climate Change
TNSCB	Tamil Nadu Slum Clearance Board
TNUIFSL	Tamil Nadu Urban Infrastructure and Financial Services
TUFIDCO	Tamil Nadu Urban Finance and Infrastructure Development Corporation
TWAD	Tamil Nadu Water Supply and Drainage Board
ULB	Urban Local Body
WTE	Waste To Energy

CHAPTER 1: INTRODUCTION

A panoramic view of Chennai | © Naufal MQ

CHAPTER 1: INTRODUCTION

BACKGROUND

A recently-released Indian Meteorological Department (IMD) "Statement on Climate in India during 2018" observes that the total rainfall received in India during the 2018 north east (NE) monsoon (which occurs between the months of October and December) was just 56 percent of the long period average (LPA). It further states that this "*substantially below normal*" figure occurred for only the sixth time since 1901. The rainfall deficit was acute throughout the south of India, where the NE monsoons were just 66 percent of the LPA. In Chennai, the situation was no different, with the city receiving just 55 percent of the normal, NE monsoon average. As a result, the city is facing an impending drought, its second in the last three years.

Frequent droughts, along with occasional flooding (for example, the 2015 floods that caught Chennai completely off guard and brought the city to a grinding halt), signify Chennai's contentious relationship with its water resources and water management. The government's immediate response to the current impending drought has been to make significant cuts to drinking water supply. However, as Chennai continues to grow rapidly and, as a coastal city, begins to face the effects of climate change, it is important to frame more holistic and integrated responses to water-related crises and mitigate their impact on the city's people and infrastructure.

Further, as the city's portfolio as the manufacturing and Information Technology (IT) hub of India strengthens, there is a strong desire and aspiration to transform it into

Top: Residents using a community well after reservoirs run dry, June 2019 © Arun Sankar/AFP; Bottom: Aerial view of Chennai during the Nov 2015 Floods © Veethika/Wiki;

a world class city with access to modern infrastructure and services. Yet, recent extreme weather events, often aggravated by human actions, serve as reminders of the environmental limitations and restrictions that should be kept in mind while attempting to implement this largely economically-driven world class city agenda.

In addition, Chennai's system of urban governance, which consists of governmental and various para-statal agencies working at various scales, each with overlapping jurisdictions and unclear roles and responsibilities, is inherently fragmented. While several steps/initiatives have been undertaken by the public, private groups and civil society to make Chennai more resilient and sustainable, particularly with respect to water-related challenges, the haphazard nature of these efforts has yielded mixed results.

In this context, this project, which is titled "A Platform for Integrated Water Governance in Metropolitan Chennai: Developing Future Scenarios and Strategies through Participatory Simulations," is an effort to develop a more integrated process of decision making and planning with the goal of helping to bring all relevant stakeholders and interest groups together. The proposed model of integrated governance is envisaged at two levels:

i. Integration of knowledge and efforts across government, private and civil society, and

ii. Integration of knowledge and actions across sectors (specifically urban land use, waste and water).

This project has been funded and supported by a unique constellation of actors, including the State Planning Commission (Government), Cholamandalam Finance (Private Sector) and Tata Trusts (Non-profit arm of Private Sector), and was implemented by Okapi Research & Advisory Services, Centre for Buildings, Urbanization and the Environment (CUBE), IIT Madras and Fields of View.

PURPOSE

Between September, 2017 and March, 2019, the project team has worked with a coalition of public, private and community stakeholders representing the Chennai Metropolitan Area (CMA) to examine how policymakers can use a simulation-based tool to take more integrated decisions for better management of water while considering aspects of land use development and waste management. This exercise functions as a platform to overcome existing coordination problems within government and between public, private and community stakeholders in advancing a more sustainable and resilient future for the CMA.

METHODOLOGY

The project process followed a three-step methodology:

I. **Context Development:** First, primary and secondary research was carried out to gather background information on current trends around city development, its state of water and emerging tensions, particularly with respect to institutional and governance-related challenges.

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

III. **Strategy Development:** Finally, using the context development research and the simulations from the model, a set of strategic recommendations were identified to help address current challenges characterizing the city's development and its intersection with water-related risks.

OUTCOME

This report is the culmination of efforts to identify the institutional dynamics among the actors and the processes shaping Chennai's urban ecosystem, with a focus on land, water and waste, offering a list of strategic and targeted recommendations to address current predicaments and guide the future planning process around these issues. Further, this document comes on the heels of the following three elaborate policy-oriented reports published under the ambit of this project:

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

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3. **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 to address the city's water woes.

In addition, this final output includes Agent-based Models (ABMs) that can function as a supporting tool for policy makers and key stakeholders in the land-waste-water nexus to consider multiple scenarios and compare trade-offs before taking specific decisions.

SIGNIFICANCE

This initiative will serve as an example for other cities in India to learn from and replicate.

Further, this study realizes the following goals:

- Aiding policy makers to make better/more integrated decisions that simultaneously address challenges associated with water, waste and land use.

- Developing a systemic public understanding of Chennai's urban and ecological setting and mutual implications on the city's water woes.

- Helping stakeholders develop a more sophisticated recognition of the consequences of both their individual and collective actions, and how they are in turn impacted by other actors' decisions and behaviours. This evidence-based knowledge sharing provides a practical basis and greater emphasis for systems-level collaboration.

CHAPTER 2: METHODOLOGY

Fishermen at sea, Marina | © Irfan Ahmed

CHAPTER 2: METHODOLOGY

This project followed a three-part project methodology to help Chennai address its water-related challenges through an integrated approach *(see Fig. 1)*. The three parts/phases are not sequential. Rather, they proceeded simultaneously as shown in the figure.

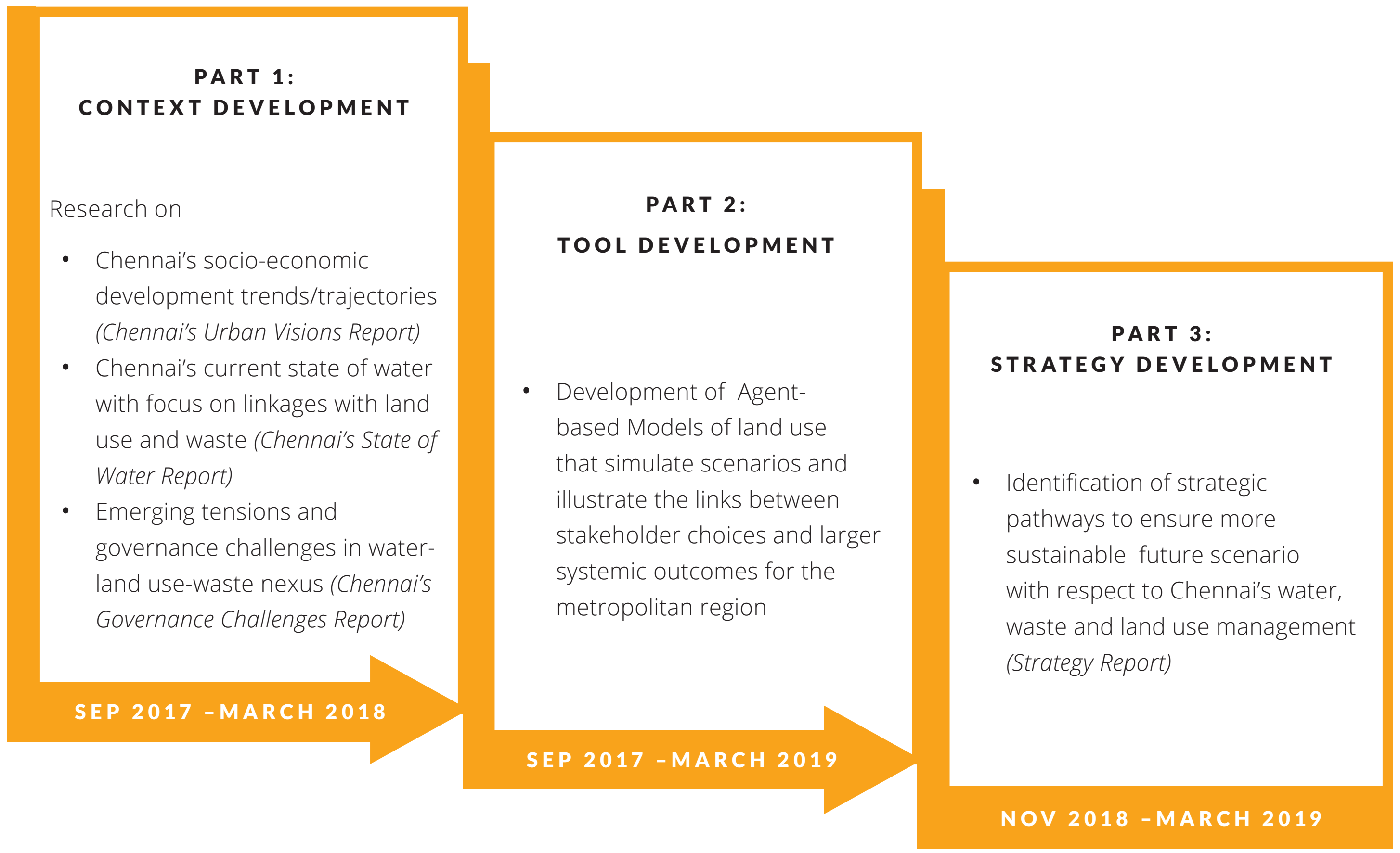

Figure 1. The three part/phase project methodology

CONTEXT DEVELOPMENT

The project context development phase involved gathering and mobilizing evidence to refine problem statements. Evidence gathered was divided into three areas of interest or research questions:

1. What/who are the drivers of urban change in Metropolitan Chennai and how do they shape the city's urban development?
2. What is the current state of water and how does this relate to land and waste management?
3. What are the emerging governance related tensions at the intersection of land-water-waste management?

A) SOCIO-ECONOMIC DRIVERS AND TRENDS OF URBAN CHANGE

A comprehensive primary and secondary research effort were undertaken to identify key drivers of urban expansion and transformation in the region. This work included review of planning and development documents, analysis of socio-economic and land use data and interviews with relevant urban stakeholders to gain insight into decision making processes, long-term aspirations and concerns and current and future trends that influence growth patterns in the CMA. The findings from this work are presented in the policy-oriented report Chennai – Urban Visions.

B) STATE OF WATER

Data around Chennai's current state of water was aggregated and analysed in relation to a spectrum of available information, illustrating the need for more integrated actions across these multiple sectors for Chennai's sustainable future. Focal points of this study include an assessment of trends in ground and surface water use, wastewater and solid waste.

Scientific literature around Chennai water vulnerabilities was also aggregated and potential instruments that policymakers and other stakeholders can use to reduce vulnerabilities articulated. The findings from this work are presented in the Chennai – State of Water report.

C) EMERGING TENSIONS AND GOVERNANCE CHALLENGES

Finally, the findings from the above two sections are critically analysed to understand how socio-economic and development trajectories conflict, interact and coexist with environmental realities in the Chennai metropolitan context. In addition to synthesizing the findings from the previous two reports, three key focus areas are used to highlight emerging tensions between Chennai's development goals and its environmental vulnerabilities. These three focus areas are: the Environmental Impact Assessment (EIA) process, solid waste management and water supply and demand mismatch.

Using secondary research, interviews and inputs from nine workshops, an in-depth understanding of the current challenges that urban governance structure and processes present is also provided. This part of the study gave a comprehensive understanding of the governance structure/processes of Chennai's institutional environment within which the city's development and environment is managed. It provides an essential input for developing the ABMs. The results of this work are presented in the third policy-oriented report: Chennai – Emerging Tensions and Governance Challenges.

TOOL DEVELOPMENT

DEVELOPING ABMS:

ABMs allow simulations around specific individual motivations, constraints and actions and how they aggregate up into city-level outcomes. They allow users to understand the connection between social micro-foundations (particular stakeholder, or "agent", behaviours) and macro-level outcomes such as changes in land use, density, mobility and transport patterns. As part of this project, interactive Agent-based Models (ABMs) were created to illustrate how individual/stakeholder group actions affect system-level outcomes around the critical risks identified in Part 1: Context Development Phase. The ABMs illustrate how stakeholder decisions and interventions affect scenarios for critical risks in metropolitan development. The tradeoffs that emerge out of this process are visually presented as vulnerabilities and points of leverage to promote urban resilience. Such models have been shown to be useful reference points for helping disparate stakeholders a) understand the larger systems that they are trying to influence, b) test and refine their own theories of change and impact and c) identify synergies and conflicts between their own efforts and others' initiatives.

STRATEGY DEVELOPMENT

DEVELOPING STRATEGIES:

During the stakeholder workshops, participants were asked to prioritize different sets of scenarios and identify potential pathways to reach these scenarios. Their inputs were crucial to identifying strategy recommendations. The aim was to ensure that outcomes are those that have been favoured, prioritized and created by the stakeholders as plausible 'future scenarios'. These exercises will ultimately help stakeholders develop a strategic blueprint that sets the road map for resilient future scenarios. The deeply deliberative workshop process was designed to strengthen recognition among stakeholders around how their individual actions contribute to systemic change, develop a more sophisticated understanding of the ecological constraints within which development occurs and foster/support new alliances among stakeholders to collaboratively solve problems in the future.

This Strategy report is the final outcome of the study. It is based on workshop transcripts, research findings and simulation results. This report presents a) a comprehensive understanding of the water-waste-land-use nexus and related challenges in the Chennai context, b) a discussion of what the future scenario will likely look like in absence of any concerted effort, c) a reflection on how the ABM can help assess different scenarios based on a set of trade-offs and therefore help policymakers take decisions and finally d) a set of strategic guidelines to steer Chennai's growth in a more sustainable direction.

PARTICIPATORY METHODOLOGY

The data for this project have been collected and analysed using a mixed-method approach. Both quantitative and qualitative data have been collected and qualitative and quantitative data analysis methods used (for example, land use reclassification data analysis, time series analysis of population or rainfall, comprehensive social network analysis through coding of interview data and workshop inputs, etc.). The stakeholder workshops were crucial to the

Kick-off Meeting

Follow-up Workshops

foundation of this project and a main source of input for understanding the varied/dynamic stakeholder priorities, mapping systemic issues in the urban governance ecosystem and identifying discernible solutions.

Given the multiplicity of institutions influencing urban development in Chennai, it was crucial to identify all relevant actors by drawing on existing literature and experiential knowledge on government, civil society and industrial agencies working in the CMA. The initial stakeholder identification process was then corroborated through direct stakeholder engagement in a series of interviews and workshops held from September 2017 to January 2019. During these interactions, initially identified stakeholders helped in validating the list and identifying additional key agencies.

Between October 2017 and January 2019, twenty-one interviews were conducted with stakeholders from government agencies primarily responsible for Chennai's urban development, including water and waste-related policymaking and representatives from the Chennai Metropolitan Area (CMA)'s business community and civil society organizations *(see Appendix 1 for a list of agencies interviewed).* The interviews were semi-structured in nature, with a set of guiding questions that helped keep the 1-2-hour conversations focused on issues related to Chennai's development and environmental, specifically water-related, challenges.

In addition, the project team conducted nine stakeholder workshops between December 2017 and January 2019, primarily with key government departments. Alongside is an elaboration on the timeline and outcomes for these workshops *(see Fig. 2).*

The context development workshops were vital in identifying the problem areas, visions and aspirations of various government departments and gave crucial inputs for the scenario and tool development workshops. Stakeholders, irrespective of their affiliations, were forthcoming about sharing visions, aspirations and challenges. While they were aware of uncertainties around water security, it was clear that a lack of concerted efforts or poorly coordinate efforts provide few actual solutions. It is hoped that this report, in conjunction with the ABM tool, will act as a valuable resource for policymakers to gain granular insights into the institutional relationships and pave the way for data driven and integrated governance.

Figure 2. Workshop timeline and outcomes

CHAPTER 3: LAND USE, WATER AND WASTE NEXUS

Waste & encroachments on Adyar River (2017) | © Denis.Vostrikov

CHAPTER 3: LAND USE, WATER AND WASTE NEXUS

The following chapter offers a detailed analysis of the three focus areas for this project: land use, water and waste. For each of the areas, an elaborate description of the past efforts, current status and rising conflicts is presented in detail. The discussion in this chapter builds on the research and recommendations offered in the three earlier reports developed under this project.

CHENNAI'S URBAN GROWTH: POPULATION AND ECONOMY

Chennai's urban and administrative history has played an important role in establishing its status as the fourth largest metropolis in India after Delhi, Mumbai and Kolkata. The Greater Chennai Corporation (GCC) area is demarcated at 426 sq. km. with a population of 7.1 million, according to the GCC website (Government of India, 2011). The larger Chennai Metropolitan Area (CMA), with a population of 86,535,621, comprises of 1189 sq. km (GoI, 2011). The region is poised for further economic and population growth, underwritten by a proposed metropolitan expansion covering 8878 sq. km, whereby the adjacent districts of Kanchipuram and Tiruvallur, along with the Arakkonam division within the Vellore district, will come within its boundaries (Kabirdoss, 2018). Overall, the CMA growth rate has averaged approximately 2 percent on an annual basis from 1971 onwards, which is comparatively slower than some of the other major metropolises (Arabindoo, 2011; CMDA, 2006).

It is important to note that the relatively slow growth has still nonetheless involved more than doubling of the entire metropolitan area population in four decades, increasing from 35.06 lakh in 1971 to 86.53 lakh in 2011. Furthermore, the prominence of the metropolitan area is reflected in the region's increasing share of the state's population, rising from 8.51 percent in 1971 to 11.28 percent in 2011. This reality is brought into sharp relief when one considers the fact that this current proportion of the population resides within the borders of what amounts to only 1 percent of the entire state of Tamil Nadu (Chennai Metropolitan Development Authority (CMDA), 2006).

Figure 3 indicates that the decadal population growth in the GCC and the CMA have taken a downward trend, while the observed decadal growth for the CMA is higher decadal than that in Chennai city. The marked decrease in population growth in Chennai city can be attributed to the high population density (247 individuals per hectare (ha)) which has led the CMA (with 59 individuals per ha) to accelerate much-needed infrastructure development to accommodate the growing urban populace (Sekar & Kanchanamala, 2011).

Until 1981, just 24 villages with a population of more than 10,000 existed in the CMA, and Thiruvottiyur municipality held the position of being the most populous with 134,000 residents. But it was replaced by the Ambattur municipality in 1991 with a population of 215,000, which rose to 310,000 by 2001. This sharp increase can be attributed to the post-1991 liberalization reforms which pronounced an industrial estate role for Ambattur, which in turn augmented development. Nonetheless, villages on the outskirts of the city boundary (Thiruvottiyur, Madhavaram, Ambattur, Valasaravakkam, St. Thomas Mount Cantonment and Alandur) have been steadily developing since 1971. Similar patterns can be observed in villages along the Old Mahabalipuram Road (OMR) and the East Coast Road, which indicate a marked increase in population growth, which is allied with the development of the IT corridor.

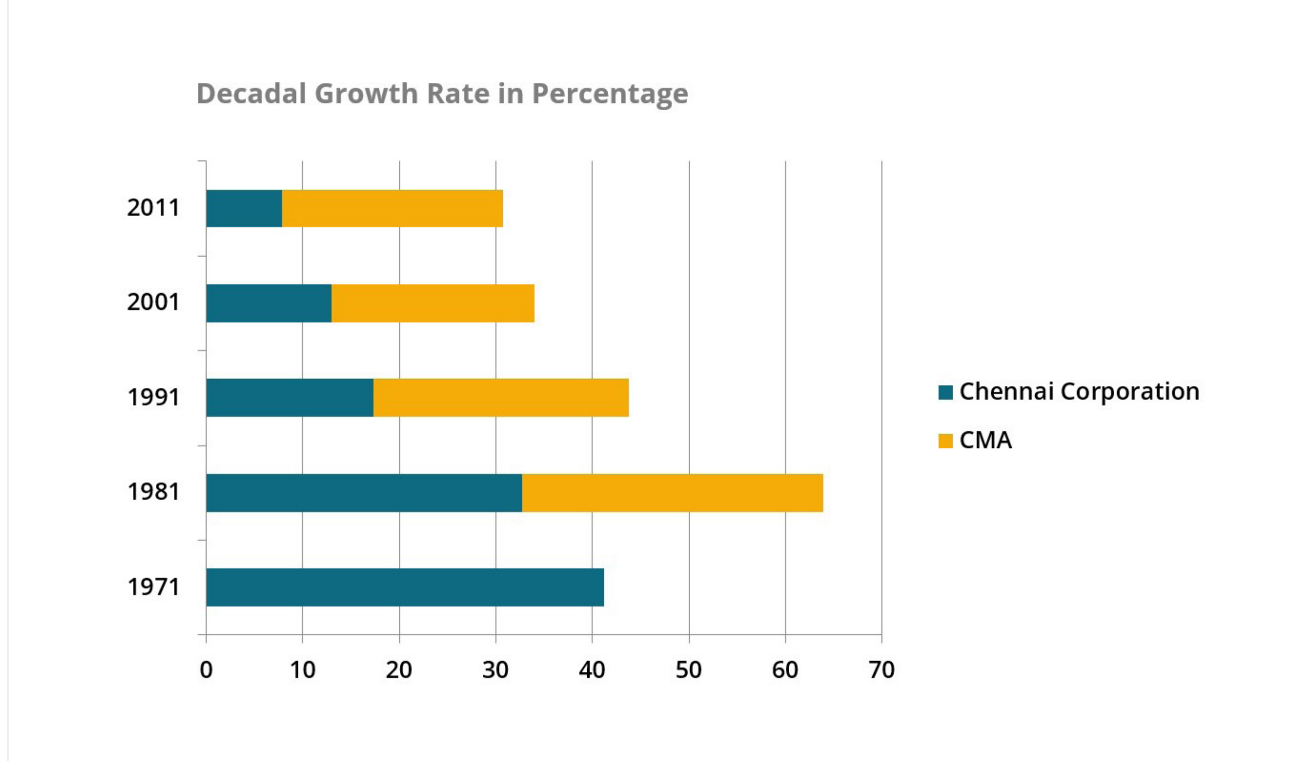

Figure 3. Decadal growth rate – GCC and CMA

Source: Census 2011 & Second Master Plan CMDA-2026

Based on the decadal growth rate from 1991-2001, Sekar and Kanchanamala (2011) divided all CMA villages into four categories: High growth, Medium growth, Slow growth and Decreasing growth. The majority of villages experiencing high growth were clustered around development epicentres along the southern and western fringes of the CMA, while only four villages with high growth rate were located in the northern CMA area. The north-south divide is further pronounced in villages with medium growth rate, where only five of the 28 villages are situated in the northern CMA.

Chennai city's growth rate is driven primarily by migration to meet demand for jobs. The proportion of in-state migrants has increased from 70 percent in 1961 to 75 percent in 2001. Migrants from the rest of India and the negligible figures from abroad often come for jobs in Chennai's newly established service sector. At the same time, the overall proportion of migrants in the city has declined considerably from 37 percent in 1961 to 21 percent in 2001 (CMDA, 2006). The total migrant population in the CMA was estimated in 2001, to be 1.6 million, of which 1 million were from Tamil Nadu. Nearly a quarter, i.e., 22 percent, of migrants chose work and employment as their reason to migrate, while, interestingly, just 2 percent chose education as their reason for migrating. A 1991 study commissioned by the CMDA observed that, out of the total migration taking place, urban areas accounted for 63.4 percent of all inward migration, while rural areas accounted for 36.6 percent of all inward migration. Similar migration trends can be observed in GCC, where migrants constituted 16 percent of the total population (Census, 2001).

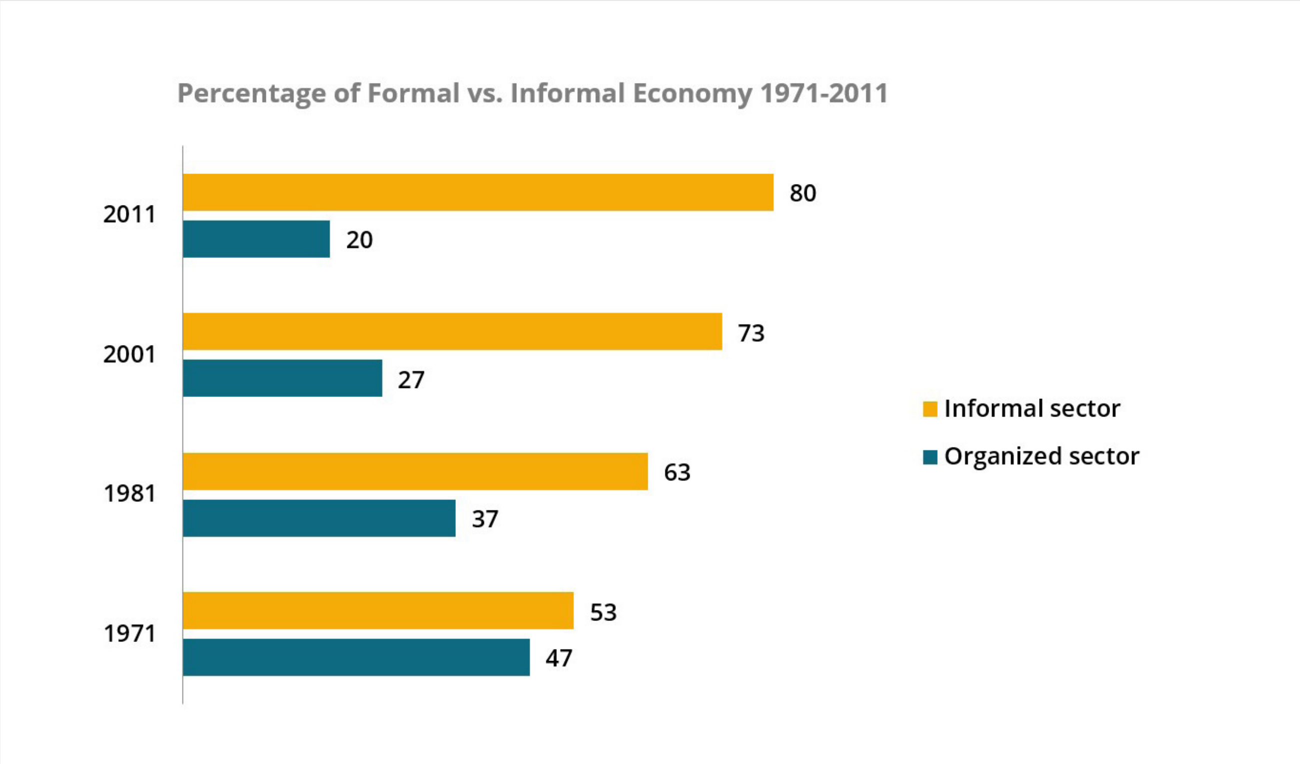

Figure 4. Formal and informal economy distribution

Source: Second Master Plan CMDA-2026 & TN Vision Document 2023

Economic growth in Tamil Nadu since the early 1960s has been slow in the primary sector, with parallel growth occurring in the secondary sector. The tertiary sector, which witnessed robust growth throughout the last many decades, experienced particularly high growth in the post-1980s period. The growing influence of IT/IT-enabled services/business process outsourcing industries has tilted Chennai city's diverse economic base from trade and commerce to administration and services.

However, Chennai's port infrastructure and its significant contribution to the automotive sector (local and export) at the state and central levels has sustained employment in the secondary and tertiary sectors.

Furthermore, the city's economy has witnessed a considerable shift, with the informal sector making up 80 percent in 2011, an increase from 53 percent in 1971 *(Fig. 4)*. However, the organized sector witnessed a drop from 47 percent in 1971 to 20 percent in 2011 during the same time period. These findings can be attributed to the diversification of economic activities away from traditional agricultural practices to the adoption of modern technologies and the ensuing rise in manufacturing, real estate and trade.

The shift in Chennai's economic base from trade and commerce to administration and services occurred in the early part of the twentieth century. As of today, Chennai shows a growing contribution of IT/IT-enabled services and is also seen as an emerging major export hub for automobiles in South East Asia.

Currently, a diverse economic base feeds into the city's GDP (US $58 billion), including IT, automobile and hardware manufacturing, health care and financial services (Global Metro Monitor, 2015). The port city contributes 60 percent to Tamil Nadu's manufacturing and produces 60 percent of India's automotive exports, thus playing a significant role in the state and central economy (Ramesh, 2015).

SPATIAL GROWTH AND LAND USE CHANGE

The way that Chennai's population and economic growth have played out in terms of spatial land transformation can be illustrated in various ways. For instance, it can be illustrated by comparing old, large-scale topographic maps with current Google maps; these reveal the extent to which rapid and dense urban development has encroached upon and in some cases completely replaced natural land use such as vegetation and waterbodies (Govindarajan, V., 2017).

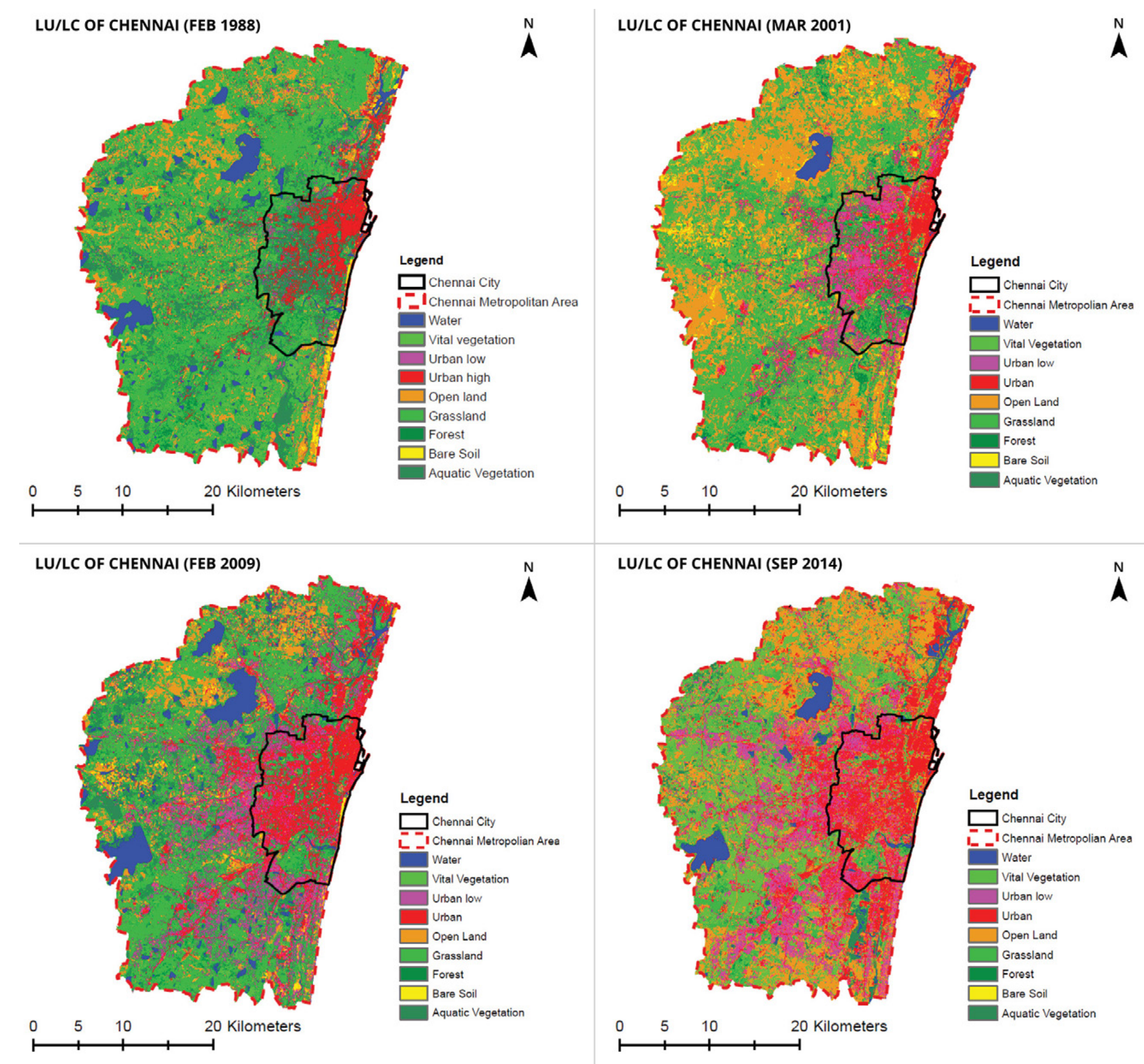

Figure 5. Land use and land cover change

Source: Ramachandran (2016)

Remote-sensing mapping exercises more comprehensively demonstrate a dramatic decline in agricultural and natural land use from the 1980s onwards. For example, in studying an area that includes Chennai city and a significant portion of the CMA outer regions, Rajendran and Kaneda (2014) find that built-up land has increased from 16 percent to 44 percent.

The analysis conducted by this project team *(see Fig. 5 - preceding page)* shows that Chennai's land use, land classification classes have changed rapidly, particularly in the built-up category. Built-up areas in Chennai witnessed an overall increment of 24 percent of the total area during the study period 1988-2014. Waterbodies, bare land and vegetation show a decreasing trend in the extent of area from 1988-2001 to 2009-14.

Between 1971 and 2001, approximately 60 percent of agricultural land was converted for non-agricultural use *(Fig. 6)*, while built-up area increased by 65 percent and water body area decreased from 33 sq. km to 27.34 sq. km during the same time period.

This is also supported by the analysis of land reclassification presented later in this chapter, which shows that of the total land converted, 42.64 percent was agricultural land which was transformed to non-agricultural use between 2008 and 2017. Most of this CMDA-authorized reclassification of agricultural land for other uses remains concentrated in the southern and south western parts of the CMA.

This trend in spatial transformation of rural/peripheral agricultural land into built-up areas indicates a crucial intersection of urban planning/development and water-related vulnerabilities.

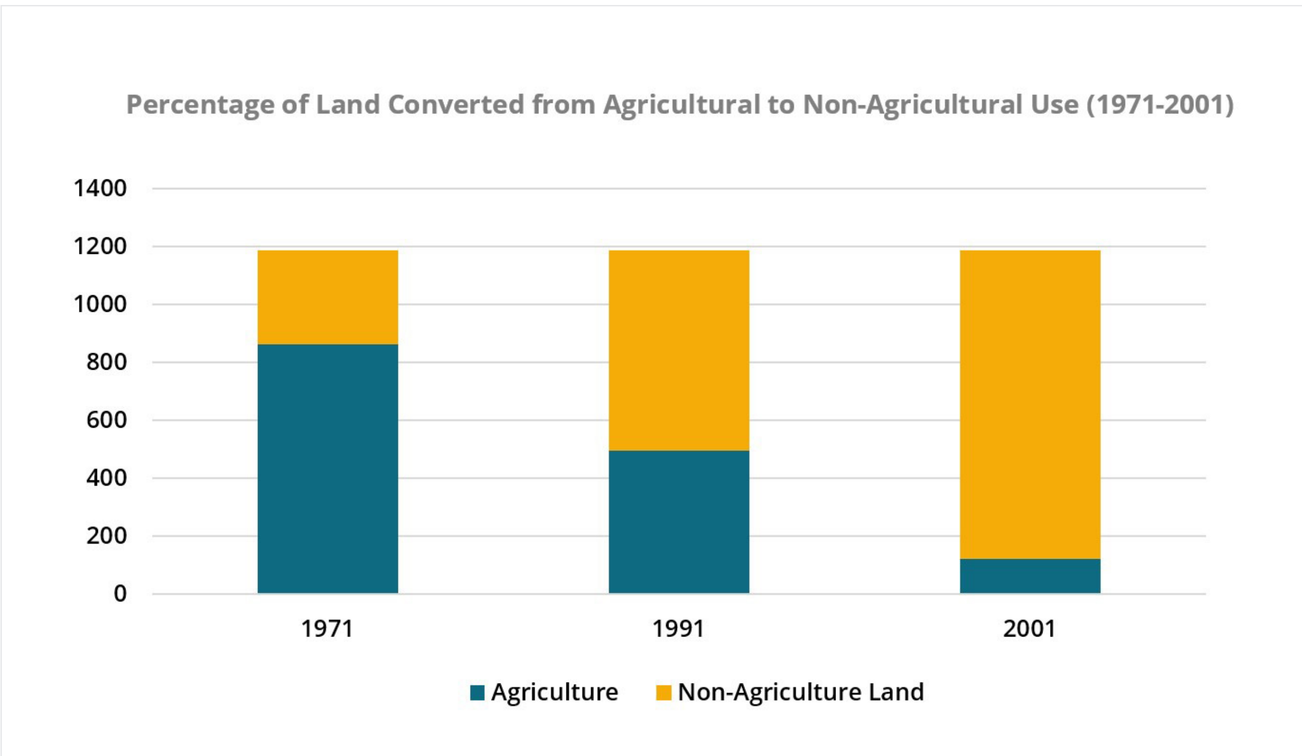

Figure 6. Agricultural land reclassification 1971-2001 Source: Second Master Plan CMDA, 2026 & Smart City Profile

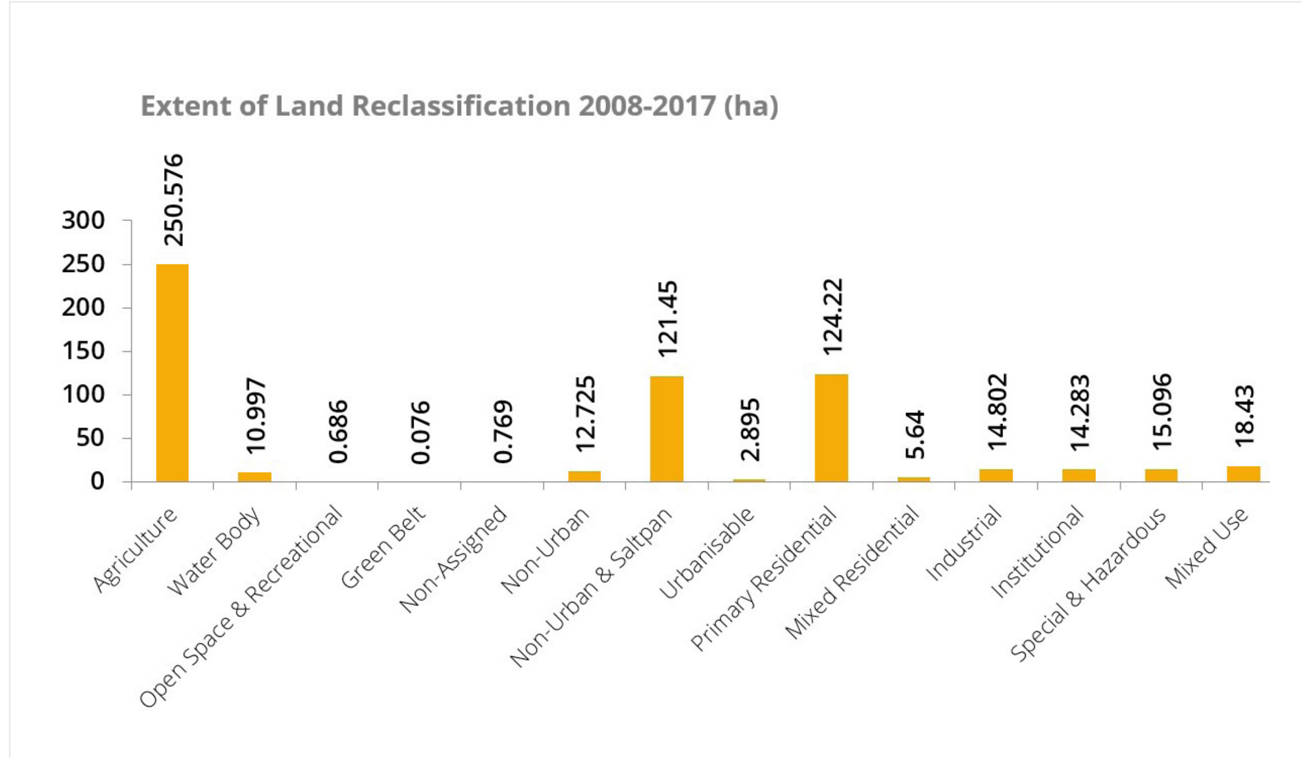

Figure 7. Land conversion data Source: CMDA

Based on an integrated view it is evident that there is a likelihood of a substantial low-income population (working in agricultural sector) moving to the CMA and the city and settling down, particularly in vulnerable and cheap locations such as flood-prone areas close to existing water bodies. This in turn presents all kinds of implications for water quality, flood risk, health risk, city access to water, etc.

LAND RECLASSIFICATION

The CMDA's Second Master Plan presents zonal classification of land use across the CMA, indicating the type of development permitted in specific areas. In other words, it presents a vision of development for specific locations. However, historically, the CMDA has allowed exceptions by reclassifying the zonal classification of specific plots based on applications from interested parties (individual citizens, real estate companies, industries, etc.). The following section presents an analysis of the CMDA's land reclassification decisions. This can help gauge the extent to which Chennai's nodal planning agency allows for changes in its original vision as responses to developmental pressures.

In order to understand the extent of reclassification, an in-depth analysis was conducted of land use reclassification data from 2008-2017. Total land conversion since 2008 is 586.623 ha, which accounts for 0.5 percent of the land in CMA. Within this, the agricultural land converted is 250.576 ha, which accounts for 42.64 percent of total land conversion *(see Fig. 7)*. The second highest land use conversion is for primary residential use at 124.22 ha or 21.17 percent. Finally, 10.997 ha of water bodies were converted to other uses, which accounts for 1.87 percent of the total land conversion.

Agricultural land was converted for other uses in 46 villages. In most cases, it was converted to primary residential use. Also, most of the villages that experienced conversion are located in the west, right outside the Greater Chennai Corporation's (GCC) boundary, and in the south along the fringes of the CMA limit. Similarly, the higher frequency of land use conversion remains concentrated in the west and the south, outside of the GCC ***(see Fig. 8)***.

The total amount of land converted from water bodies to other uses is 10.997 ha, which accounts for a 0.02 percent reduction in the total water body use for CMA land (total CMA land is 56,570 ha). This conversion was experienced in the villages of Palathandalam, Ambattur, Manapakkam, Nandambakkam, Varadharajapuram, Vaikkadu, Polichalur and Rajakilpakkam. Waterbodies were mostly converted into primary residential use with an extent of 5.7 ha.

The second highest conversion occurred in Vaikkadu village panchayat for special and hazardous use with an extent of 4.6 ha. Conversion to other uses includes mixed residential at 0.443 ha and institutional at 0.254 ha. In total, nine villages experienced conversion of waterbodies during 2008-2017, and only one village experienced land use conversion twice for different uses ***(see Fig. 9)***.

Key findings relate to the fact that rising needs for housing and commercial and industrial development have come with increasing quantities of land being converted from agricultural to non-agricultural use, mostly in the areas around the southern and western parts of the CMA. Much of the land reclassification to the north has transformed residential use into industrial/institutional use. Overall, these reclassification rates highlight the development pressures that the CMDA has had to accommodate, irrespective of its desire/vision/theoretical emphasis

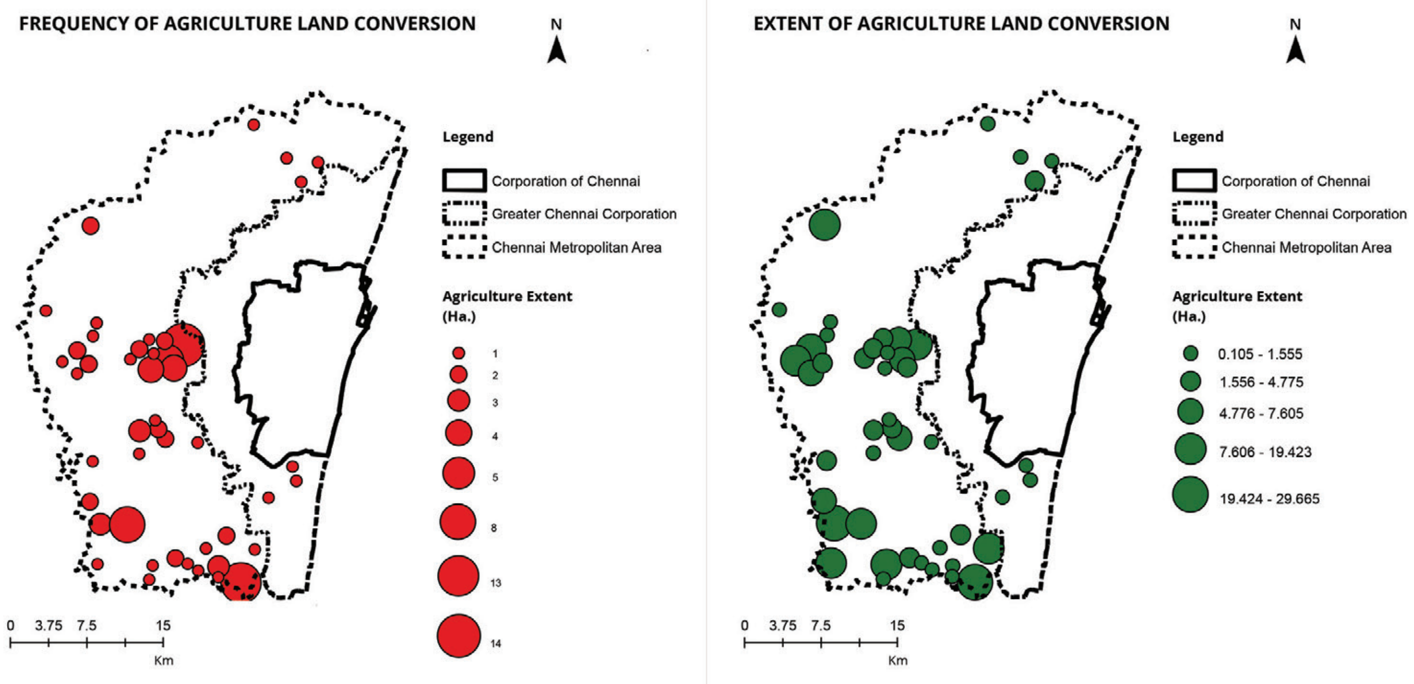

Figure 8. Agricultural land conversion map Source: CMDA Land Reclassification 2008-17

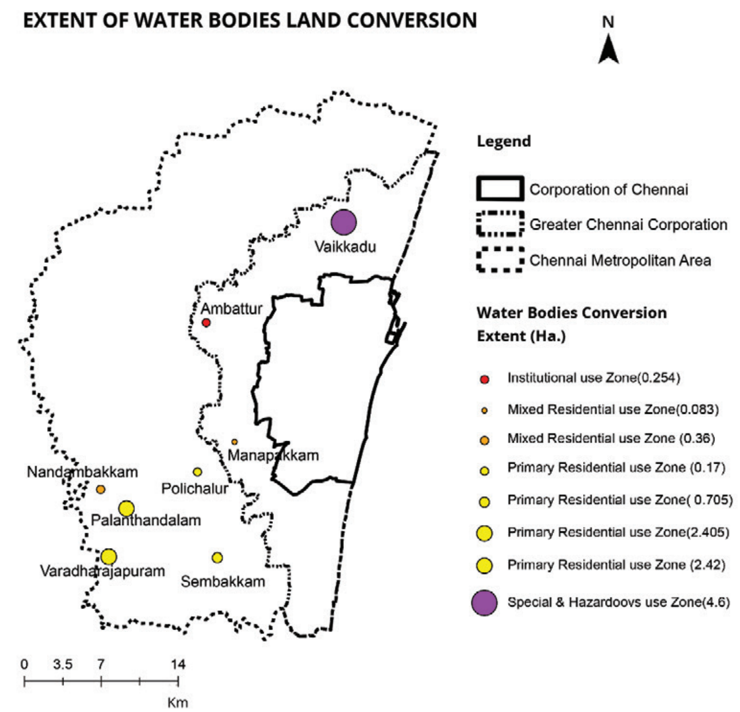

Figure 9. Water bodies conversion map Source: CMDA Land Reclassification 2008-17

on protecting agricultural land and the environment. According to this data set, conversion of waterbody use is not very high, both in terms of area and frequency. However, the fact that permission has on occasion been granted for waterbodies to be classified into other uses, particularly special and hazardous use, is alarming.

Also, it should be noted that reclassification data alone does not represent the whole picture in terms of how waterbodies have been transformed on the ground into infrastructural, industrial and residential uses. This is because many of the waterbodies and ecologically vulnerable areas (e.g., the Pallikaranai marshland) were historically and until the mid-2000s classified as "wasteland". As such, development on these waterbodies up until that time was authorized and did not require land use reclassification.

In fact, the Second Master Plan estimates the loss of waterbodies during the period between 1971 and 2001 at 5.659 sq. km, which is significant. This is a more accurate representation of the extent to which waterbodies across the CMA have been transformed in response to development pressure.

Overall, land reclassification decisions reflect the way developmental pressure tends to guide action on the ground at the expense of alternative visions to protect the environment or people's livelihood. Therefore, it remains a particularly difficult task for agencies such as the CMDA to balance their multiple visions, often prioritizing economic incentives over sustainable development.

For instance, the recent development of industries along and within the Ennore creek, despite the creek having been earmarked as a "no development zone" as far back as 1996, as well as the development of residential tracts along the Pallikaranai marsh, all indicate the government's intention to continue to cater to the needs of the rapidly growing urban population and maintain the image of Chennai as a world-class city.

Based on the above analysis of the CMA and Chennai city's growth trajectory, the following key points emerge:

1. The marked increase in the informal economy with its associated housing challenges will intensify encroachments along waterbodies and in vulnerable areas.

2. The proposed CMA expansion, though still in its early stages, has yet to account for the developmental pressures on natural resources that it is likely to result. As in the existing CMA, this will only result in induced and inorganic urbanization and rampant land use reclassification.

3. Increases in migration into the city's peripheral areas due to high population density within the city will increase land prices in the former, with limited access to affordable housing.

4. Increasing water–related challenges in the city, along with land scarcity, may push industries to the city peripheries. The inevitable migration is bound to disrupt land use, water and waste dynamics in these areas. The pressure experienced by government to provide infrastructure, stemming from migration of people and industries, will only exacerbate loss of waterbodies and ecologically vulnerable areas.

WATER

AVAILABILITY

According to the Chennai Metrowater Supply and Sewerage Board (CMWSSB), total water requirement for Chennai city and parts of CMA is currently 1000 million litres per day (MLD). The amount includes surface water, groundwater and water received from other sources (such as desalination). 650 MLD is the estimated amount coming through the CMWSSB piped supply system, which includes 180 MLD from desalination. During a 2017 drought period, availability was lower, with CMWSSB piped supply providing just 400-450 MLD (Interview with CMWSSB officials, 14 February, 2018). However, there is some disagreement on the extent to which water is being supplied. For example, one Chennai water-sector expert indicated total availability (and supply) may be just 550 MLD during normal years and 800 MLD during good years (inclusive of all sources).

Variations in the total amount of water available to Chennai make it difficult to determine per capita water availability. According to India's Central Public Health and Environmental Engineering Organization (CPHEEO), this should be 135 litres per capita per day (LPCD). CMWSSB officials say they aim to provide this. However, Chennai's Master Plan indicates the average per capita amount supplied at 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 water per capita availability of India's large cities (Kennedy, L. *et al.*, 2014).

SUPPLY INFRASTRUCTURE

Water supply in Chennai is characterised by three distinct systems: a) piped and "mobile" (tankers) supply from CMWSSB, which is sourced from wells, reservoirs and desalination plants; b) self-provision through privately-dug bore wells and c) a private market consisting of water tankers and packaged water. Piped supply from CMWSSB is highly intermittent and supplied only for a few hours a day, irrespective of rainfall levels. As a result of this and other issues such as poor water quality, illegal connections, theft and low water pressure at the end of pipelines, consumers are often forced to depend on other sources to meet their needs. These other sources include digging own bore wells and relying on informal actors such as water tankers and packaged drinking water producers. Undoubtedly, prices and water quality in the informal market are not regulated and consumers sometimes have no choice but to rely on poor quality water at high prices.

WATER SUPPLY AND DEMAND

At present, the issue of water supply is a key political debate, both in Chennai city and the state of Tamil Nadu. Decades of water resource mismanagement by government and non-governmental actors, including private individuals, combined with growing demand, have made water supply a sensitive and contentious issue with severe political implications.

Panorama of the Adyar Estuary © Planemad/Wiki

A mismatch between water supply and demand was also identified as a critical issue during the stakeholder workshops and interviews conducted during this study.

This water supply and demand mismatch is indicated by existing CMA water supply practices. The extent of the mismatch varies temporally and seasonally, with an obvious high during drought years and summer months. However, record rains during the 2015 north east monsoon that filled reservoirs and tanks entirely provided supply for just one year; the quantity of piped supply had to be reduced following a less than normal 2016 north east monsoon.

There are varied views on whether Chennai's water supply and demand equate. Several experts were interviewed to understand their take on this issue. One of them was Professor Janakarajan, president of the South Asia Consortium for Interdisciplinary Water Resources Studies SaciWATERs and former professor at Madras Institute of Development Studies (MIDS). Professor Janakarajan believes that the mismatch is artificially created and that actual supply and availability problems lie in poor storage infrastructure. Another advocate of this view is Sunita Narain of the Centre for Science and Environment. She argues that the city should move towards protecting its vast number of lakes and ponds and use them as its primary source of water supply (Narain, 2015). Other experts maintain that intermittency in most Indian cities, including Chennai, is caused not by a lack of sufficient water resources but as a result of poor management, pipeline leakage and excess demand spurred by low tariffs and a lack of metering (McIntosh, 2003; WSP, 2003). On the whole, this group believes that there is enough water to serve Chennai needs, but that it is poorly managed; and that this is the cause behind any supply and demand mismatch.

Despite such expert opinions, current CMWSSB investments are inclined towards augmenting supply. This is evident in increasing government investments in desalination technology (rather than focusing energy and resources on increasing storage capacity).

Two desalination plants, Nemmeli and Minjur, each with a capacity of 100 MLD, currently supply water to the city. Nemmeli supplies southern parts of the city and Minjur the northern areas. The government plans to increase this capacity to 750 MLD by adding at least two more plants in the near future: another plant in Nemmeli with a capacity to treat 150 MLD and a fourth plant at Perur, beside Nemmeli, with a capacity of 400 MLD (Lakshmi, 2018b). The medium-term plan is to source at least 50 percent of total piped supply from desalination plants. The Tamil Nadu Water Supply and Drainage Board (TWAD) has also commissioned 17 additional plants outside the CMA area.

CMWSSB does agree that Chennai water is mismanaged, specifically as evidenced in a high percentage of Non-Revenue Water (NRW). NRW is defined as water lost as a result of pipeline leakage, theft and illegal connections. A senior CMWSSB official cited NRW as the organization's biggest concern (CMWSSB, personal communication, 2018). While NRW has been reduced over the years, the fact that water is not metered like electricity creates disparity in availability and usage patterns. Therefore, one of the CMWSSB's next steps, according to the same official, is to implement water metering and pricing. CMWSSB sees NRW as an 'infrastructural inadequacy' that needs to be addressed, he stated. However, the issue of NRW and water pricing is not an easy one to solve, and most Indian water utilities struggle with it. Residential connections are mostly not metered but utilities often face stiff resistance from consumers when attempting to introduce water meters through pilot projects (HPEC, 2011). In the case of Chennai, the flat pricing mechanism, which was recently increased after almost two decades from INR 50 to INR 80 per month per household for residences, is still extremely low and non-reflective of demand; introducing meters would mean households paying water tariffs based on their usage, which is very likely to be significantly more than what they pay now (Times of India, 2018b; Lakshmi and Lopez, 2018). Public resistance to metering is therefore not surprising.

CONFLICTS IN WATER MANAGEMENT

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 ***(Fig. 10)*** 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.

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. Loss of water bodies that act as natural sinks during floods or heavy rainfall is another result.

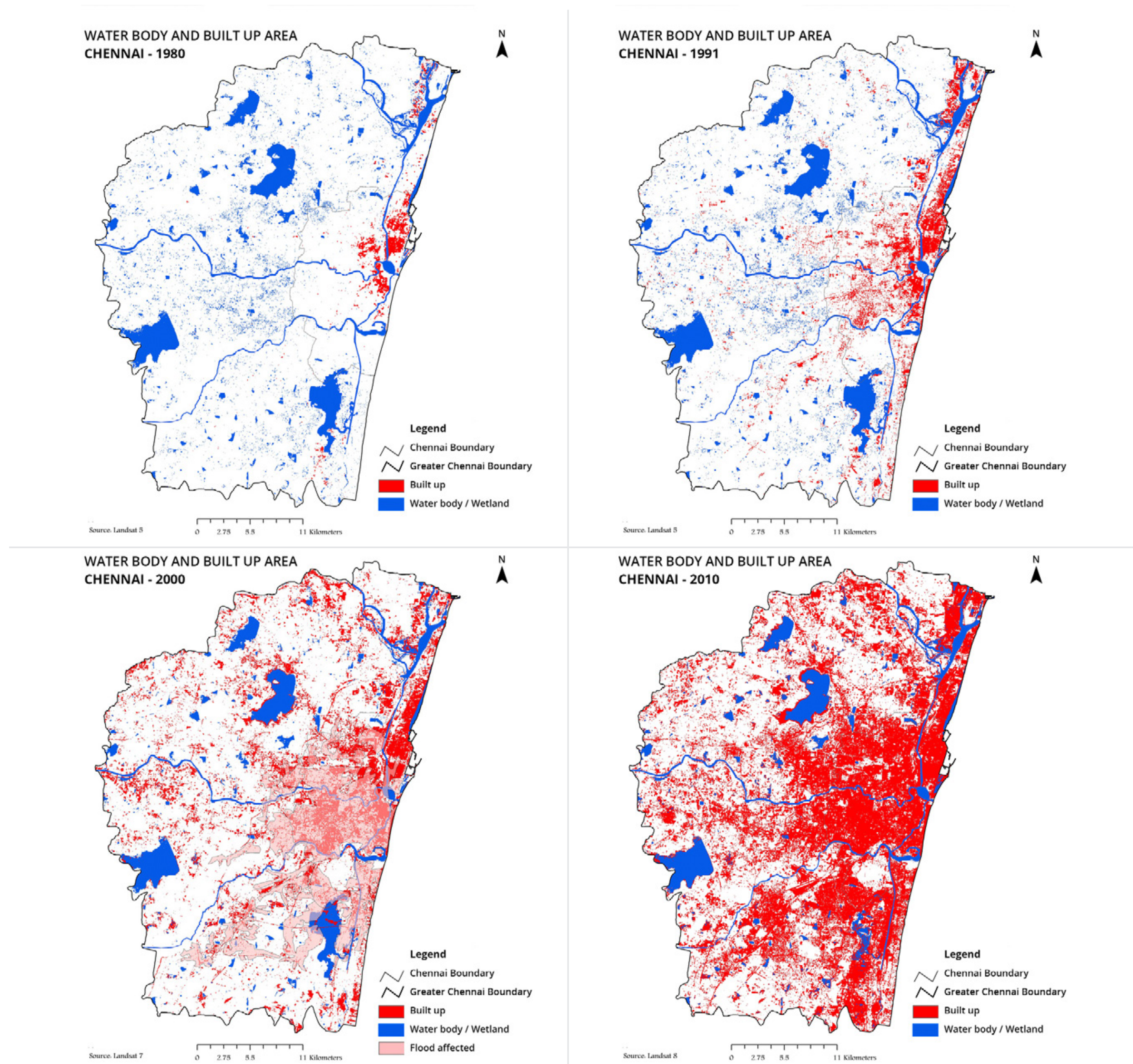

Figure 10. Land use and land cover change, 1980-2010

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

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 Water Bodies

Water body encroachment is a 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 ha of lake area in the 1980s had shrunk to 645 ha 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 water body shorelines; 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 water bodies 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 and BL Research Bureau, 2015).

Water body 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 water body. 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 coordination among the many government entities directly responsible, including the Tamil Nadu Pollution Control Board (TNPCB), the Public Works Department (PWD), the Revenue Department and local panchayat bodies.

Table 1 presents the many estimates that multiple sources have come up with on extent of encroachment on waterbodies in Chennai, highlighting the seriousness of the problem.

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 Environmentalist Foundation of India (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 contributes further to 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 they are also often clogged with waste, sewerage or silt. Further, the network in many areas of the city is ancient and collapsing: 22 drains were found to have collapsed in December 2017 (Lopez, A.X., December, 2017).

TABLE 1. LAND USE AND LAND COVER CHANGE, 1980–2010

SOURCE(S)	TIME PERIOD OF STUDY/ANALYSIS	AREA/SITE OF STUDY	FINDINGS
IIT Madras, National Institute of Disaster Management (NIDM), cited by Arabindoo (2017) [1]	Last three decades	Chennai city region	Of the more than 600 waterbodies in the 1980's (as detailed by an IIT-M study) only about 27 remain today (as detailed by NIDM)
Department of Geology, Anna University, Chennai [2]	1893 – 2017	Chennai city region and suburbs	Area of waterbodies reduced from 12.6 sq. km in 1893 to 3.2 sq. km in 2017
Care Earth Trust [3]	1900 – Present	Pallikaranai Marsh	Area of Pallikaranai Marsh reduced from 6000 hectares to 593 hectares
Public Works Department (PWD), Tamil Nadu [4]	2017	Area within 25 km radius of Chennai city	Nearly all 70 waterbodies studied were encroached upon
PWD reply to RTI query [5]	2017	Pallavaram taluk and Pallavaram lake	30% of eight waterbodies encroached upon in Pallavaram taluk. Pallavaram lake area reduced from 80.54 hectares to 34.96 hectares
Arappor Iyakkam [6]	1972 – Present	SIDCO Nagar, Villivakkam	Waterbody comprising an area of 250 acres reduced to 20 acres
Water Resources Department (WRD) [7]	Historic records *(date unspecified)*	Chennai city region	Area of 19 major lakes has reduced from 1130 hectares to 45 hectares
Public Works Department (PWD), Tamil Nadu [8]	2008	Chennai city region	50% of 19 major lakes encroached with nearly 20,000 illegal structures in this vicinity

1 *http://ficci.in/spdocument/20206/Safeguarding-Urban-FreshWater-Bodies.pdf and cited in Arabindoo Iin "An anatomy of Chennai floods (2017)*

2 *http://www.thehindu.com/news/cities/chennai/the-vanishing-waterbodies-of-chennai/article23404437.ece*

3 *https://www.firstpost.com/india/watch-tamil-nadu-rains-with-chennais-natural-water-system-destroyed-water-mafia-continues-to-tighten-its-hold-on-parched-city-4185413.html*

4 *Internal Memo shared with Okapi/IIT by PWD*

5 *https://timesofindia.indiatimes.com/city/chennai/one-third-of-pallavarams-water-bodies-gobbled-up-by-land-sharks/articleshow/59080413.cms*

6 *https://scroll.in/article/813912/with-incomplete-details-of-water-bodies-chennais-master-plan-is-a-recipe-for-yet-another-disaster*

7 *http://www.thehindu.com/news/cities/chennai/chennais-vanishing-waterbodies/article2099315.ece*

8 *http://www.nammachennai.co.in/Articles/lakesencroached.pdf*

Chembarambakkam reservoir runs dry, June 2019 drought © Palani Kumar/PEP Collective

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 Indian Meteorological Department (IMD) on the basis of percentage of deviation of rainfall from long-term annual mean rainfall. Essentially, it is caused by monsoon failure. Also, it can be complicated by climate factors such as El Niño and La Niña. 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 to fill the supply-demand gap. Despite their increasing frequency, these come as shocks to the Chennai system, undermining any gains that improvements may bring.

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 and it can also result from groundwater over-extraction. The number of over-exploited blocks in Tamil Nadu has increased from 21 percent in 1980 to 48 percent today (Tamil Nadu State Action Plan for Climate Change (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 (Interview with Tamil Nadu Urban Finance and Infrastructure Development Corporation (TUFIDCO) official, October, 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).

Therefore, saline water intrusion poses a major threat in further disturbing the balance between water demand and supply, and it is also likely to detract from any outcomes that may result from steps taken to improve the sector.

Water Pollution

Chennai water is increasingly polluted. This is in large part because solid waste and sewerage, including industrial waste and sewerage water, are dumped into water bodies, rivers and streams. This pollutes both the water bodies and groundwater, by seeping into it. Additional pollutants come from landfill leachate, which also contaminates groundwater tables, and from human activities such as fishing and washing clothes. All are further compounded by increasing population numbers and economic activity: while dumping into and bathing in water bodies has occurred across India for decades, the sheer numbers and amounts involved today mean outcomes are far more serious and less sustainable.

A significant amount of data exists around Chennai's water quality. Some are broad and others 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. 4300 water samples are collected from surface and groundwater sources, during pre- and post-monsoon periods. PWD's 2015 results from Chennai 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 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 the other eight 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 (TNPCB) data collected over a six-year period. Results indicate increasing levels of faecal 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).

A 2011 study of groundwater in Chennai collected samples from two Chennai zones – one northern and one southern. It found water quality to be within Indian standards, but requiring treatment before 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, 2017). Saline intrusion, mentioned above, is also an increasing threat to Chennai groundwater quality.

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).

Reuse of Wastewater

This option has been widely discussed by the government and concerned stakeholders. However, discussions have not been translated into large-scale projects. Existing projects cater to a few industries, which then treat water further before consuming it. Experts such as Professor Janakarajan are of the opinion that sewerage recycling and reuse are feasible for Chennai and the government needs to more actively pursue them (personal communication, Janakarajan, S., 2018). CMWSSB currently supplies 28.67 MLD of treated waste water to Chennai Petroleum Corporation Limited (CPCL), Madras Fertilizers and Manali Petro Products (MAWS, 2016).

Experience from Indian cities, including Chennai, reveals that perhaps the biggest constraint to large-scale wastewater reuse is cost. According to Hingorani (2011), the per liter cost of supplying fresh water, even when new conventional sources are added, is cheaper than supplying treated sewerage. This is because fresh water supply is highly subsidized across most Indian cities. For instance, CMWSSB reports that sewerage collection and treatment (using a secondary treatment process) across all its plants costs INR 8.9 per KL, excluding capital costs. By comparison, the cost of fresh water supply from surface water is much lower and ranges from INR 5 to INR 10.5 per KL. This estimate includes capital costs through addition of new sources other than desalinated water (ibid). Treating water through a tertiary treatment process, which is required to meet drinking water standards, will only add to production costs. However, recycling and reusing sewerage wastewater might still be more cost effective than desalination, which has a production cost of approximately INR 54 per KL (Dasgupta, 2016).

The role of wastewater recycling is steadily increasing in CMWSSB's future water supply framework. With respect to industry, as mentioned above, CMWSSB already supplies treated sewerage to three industries in North Chennai. It plans to increase its Sewerage Treatment Plants (STP) capacity by setting up two new plants, each with 45 MLD capacity, at Koyambedu and Kodungaiyur to provide water for nearby industries with the purpose of "overcoming water scarcity in Chennai" (MAWS, 2016). Further, our State of Water report finds that future water demand projections for commercial and industrial establishments will fall over the years leading up until 2050. This suggests that CMWSSB is relatively certain it will meet industrial demand by using some source other than fresh water (possibly recycled waste water). Certainly, these projections are subject to modification as a result of CMA expansion plans. Nevertheless, whether these systemic changes would impact water demand is questionable because a) the capacity of new plants is small, meaning they can only cater to a limited number of industries and b) a majority of industries do not depend on CMWSSB for supply, but instead draw groundwater from their own wells. Therefore, CMWSSB's push to use treated sewerage water in industry should include increasing STP capacity to cater to the industry requirement and reducing the price of treated sewerage water.

Solid waste thrown back to shore at the Adyar river mouth, Elliot's beach, November 2015 floods © Amirtharaj Stephen/PEP Collective

In terms of wastewater treatment for residential use, as of now, CMWSSB does not supply this. They did release a press statement on April 21, 2017 saying that they "will not provide new water and sewerage connections to special and multistoried buildings which do not have facility to separate toilet waste water (black) from other waste water (grey)." The press release also stated that this was mandatory since 2002, but compliance was low and that CMWSSB expects 15 percent of the city's future demand to be met by recycled wastewater. The latter is merely a supply target that the CMWSSB has set for itself (with no firm deadline) that can be modified as necessary. Further, future fresh water supply demand projections up until 2050 seem to contradict this move. Unlike the industrial and commercial sectors whose fresh water supply is projected to reduce, CMWSSB's domestic water demand projections for fresh water supply up to 2050 are increasing.

Role of Private Actors

Together, private tankers and packaged drinking water producers make up a large informal drinking water supply market. These actors supplement CMWSSB piped supply as well as groundwater supply. There are more than 400 registered bottled (including cans) water companies in the state, of which 220 are located in and around Chennai (Janakarajan *et al.*, 2007) and about 300 tankers serve just the customers along the Old Mahabalipuram Road and Adyar (The Hindu, 2017) – indicating the size of the market.

Women filling water from small tankers © Steevez Rodriguez/PEP Collective

Srinivasan *et al.* (2010c) found that, between January, 2002 and March, 2006, residential tanker demand emerged mainly during drought periods, was non-existent during wet periods and that changes in demand were driven by fluctuations in the regional groundwater table and piped water supply. Water tanker demand by large commercial consumers such as hotels, however, is determined by aquifer capacity and piped water supply. These consumers are virtually dependent on private tanker water at all times.

Being an informal market, both water tankers and packaged drinking water sellers are unregulated in terms of price and quality; they are not governed by the Food Safety and Standards Act 2006, nor do they conform to Bureau of Indian Standards. This also renders them inaccessible to the poorer residents of the city (because they can be priced very high).

Quality is also an issue with tanker and packaged water supply. Munian (2010) finds that tanker water is typically untreated and not fit for human consumption. A water quality test by the GCC and the Food Safety Department revealed that water transported through 90 tankers across the city did not have the minimum chlorine level of 0.2 parts per million (ppm) as per relevant specifications (Lakshmi, 2012). Further, there have been several raids and random water quality tests of water supplied through bubble-top cans over the past few years that also reveal inconsistencies. In 2013, the TNPCB and the State Food Safety and Drug Administration Department conducted tests in 85 units in and around Chennai and found that 34 of them did not conform to prescribed standards and the water supplied by these units contained aerobic microorganisms and higher residual chlorine than allowed (Mariappani, 2013).

In 2017, officials from the Food and Safety Drug Department found that several water cans being distributed in the city were unlabelled, soiled or damaged (Times of India, 2018c).

With respect to pricing, the wholesale rate for 20 litre drinking water bubble-top cans vary between INR 5 and INR 7. However, this price increases to INR 30 to INR 40 by the time customers purchase them, with major brands priced up to INR 80 (Lakshmi, 2017a). The price of water tankers (as already established) varies by season. Many residents across the city had to pay as much as INR 2,800 for a 12,000-litre tanker in July, 2017 due to high demand (Lakshmi, 2017b). Similarly, residents and commercial establishments on the IT corridor, where private borewells are not giving the yield and quality they once did, are relying on water tankers during dry and wet seasons, despite high prices and poor quality. Here, residences pay anywhere between INR 800 and INR 1,600 per 12,000 litre tanker (Citizen Matters, 2017). By comparison, CMWSSB charges either INR 670 or INR 850 for a 10,000-litre tanker, depending on customer type (domestic, commercial or institutional), irrespective of the season. The primary reason for such high private tanker pricing is the distance from which water is drawn, often from agricultural wells.

Ironically, the extent and size of the informal tanker market has made regional tanker associations a powerful force to reckon with. In 2017, around 1,200 truck drivers from the South Chennai Private Water Lorry Owners Association went on strike in response to a Revenue Department effort to begin levying fines and seizing trucks for indiscriminate groundwater withdrawals from peri-urban agricultural wells. The government claims it was trying to regularise groundwater extraction by asking tanker operators to get prior permission. The strike was finally called off after three days, not because of agreements with the government but because of public inconvenience (Govindarajan, 2017; Times of India, 2017b).

INVESTMENTS IN THE WATER SECTOR

The state of Chennai water today is that demand and supply may or may not equate. Further, drainage, sanitation and solid waste do significantly impede the functioning of the water sector. Regardless, investments are being made to improve the sector. Numerous bodies, including the CMWSSB, the GCC, the PWD and 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.

Additional Sewerage Treatments Plants

CMWSSB has proposed to improve sewerage 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 under way. The first is at Sholinganallur, with an anticipated capacity of 36 MLD and a total anticipated cost of INR 27.31 crore. Also, construction of two plants in the north of Chennai is under way: 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.

In terms of funding, the projects are all designed as public-private partnerships, with costs shared by the state and Central governments and CMWSSB, and loans and funding from entities such as the World Bank, Japan's Overseas Economic Cooperation Fund (OECF), the Japan

International Cooperation Agency (JICA) and Jawaharlal Nehru National Urban Renewal Mission (JNNURM) (Source: CMWSSB, Projects).

According to some officials, Chennai's sewerage 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, CMWSSB 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 1,371.86 crore, 60 percent of which will be covered by a loan from Kreditanstalt für Wiederaufbau (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 4,070.67 crore and then revised to INR 5,300 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).

Stormwater Drains

GCC's 2017-2018 budget estimate allocates INR 930 crore for storm water drains, with different entities having sanctioned different amounts, as detailed in *Table 2*. The GCC will spend these funds to upgrade and clean existing drains, as well as to construct new ones.

TABLE 2. STORM WATER DRAINS BUDGET ESTIMATE 2017-18

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**

In addition, the GCC is also taking steps to mechanize the desilting of Chennai's 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 is there any information about the frequency with which the robotic desilting will be carried out.

Restoration of Waterbodies

The Chennai Rivers Restoration Trust (CRRT) 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 CMWSSB, GCC, PWD, Tamil Nadu Slum Clearance Board (TNSCB), the Commissioner, the Municipal Administration and the Department of Rural Development.

CRRT is engaged with the task of restoring approximately 214 kms of waterways and 42 water bodies in the CMA by "desilting, diverting sewerage, scientific solid waste management, embankment protection, developing walkways for public use and so on" over a period of nine years beginning in 2014 (Tamil Nadu Urban Infrastructure and Financial Services (TNUIFSL) and CRRT, 2016). These 42 water bodies and 13 waterways include the Adyar, Cooum and Kosathalaiyur rivers and Buckingham Canal.

Additional Water Supply from Lakes and Other Water Bodies

CMWSSB has also been investigating the feasibility of drawing additional water supply from lakes and other waterbodies in the CMA. A CMWSSB study indicates that a total of 71 large water bodies 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 sewerage pollution.

The study recommends using 29 of the inspected water bodies as sites for constructing a total of 87 open wells and borewells. It also recommends that wells be dug in the vicinity of the water bodies, with three wells recommended around each of the 29 water bodies. 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 (CMWSSB, 2018, personal communication).

It is often argued that Chennai should look to its existing water body structures to increase metropolitan water supply. Experts, including those at India's Centre for Science and Environment and SaciWATERs, 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 to revitalize irrigation tanks and use them to capture and store the rainfall; doing so would solve most water supply woes.

CMWSSB's efforts to investigate the feasibility of drawing from these water bodies for additional supply appear to be in line with such recommendations; however, to dig borewells around existing water bodies appears to be more in line with shorter-term goals like extracting water rather than the long-term sustainable water management. Moreover, CMWSSB views efforts such as increasing desalination plant capacity as safer bets (over reviving existing water bodies for storage) because they see rainfall patterns as unpredictable and unreliable.

In addition to the above investments, the following initiatives have also been planned to improve Chennai's water security:

1. Electromagnetic flow meters in CMWSSB's distribution system and water treatment plants;
2. GPS trackers on CMWSSB tankers to improve delivery;
3. Automated filling stations;
4. Fifth reservoir for Chennai;
5. Citizen-led RWH and restoration initiatives; and
6. Public-Private Partnerships in waterbody revival.

However, a lack of coordination often appears to qualify Chennai water body 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.

From the above analysis of Chennai's water supply and governance ecosystem, the following key points emerge:

1 The issue of water management in Chennai is highly complex and multi-layered, further aggravated by the multiplicity of formal actors and unregulated informal actors.

2 In addition, domestic customers' unmonitored consumption patterns are only exacerbated by a policy environment that provides neither incentive nor penalty mechanisms to support/enforce water conservation unlike other state-supplied commodities such as electricity. The operational inefficiencies, incoherent policies and poor infrastructure and management of water resources by formal actors has bloated the influence and market share of informal actors (private tankers).

3 Without a comprehensive water metering policy or improvements in infrastructure, particularly on storage and treatment, this trend is poised to continue, in all likelihood leading to undesirable outcomes for the city's natural resources and its residents.

WASTE

In the immediate aftermath of the December 2015 floods, much criticism was levied against poor coordination between urban planning and Chennai's hydrology infrastructure. However, as the flood water receded, the city was confronted with its menacing solid waste problem and its role in exacerbating the impact of the floods. According to the GCC, 1.32 lakh tonnes of garbage was cleared from the city post-floods (Chandrababu, 2015a). To put that in perspective, the city generates around 5,200 tonnes of garbage per day, which essentially implies that the city was grappling with 25 days' worth of waste during the flood recovery period (GCC, 2018).

In the absence of efficient solid waste management (SWM) practices, uncollected garbage often finds its way into empty waterways. The once vibrant Adyar and Cooum rivers have consequently been reduced to mere garbage dumps. During the series of high intensity rainfalls in December, 2015, the rivers rose with the rains and, in addition to washing away the settlements in their vicinity, also spread garbage across the city. Many experts believe that the resulting flooding event was in fact a large-scale water inundation resulting from poor solid waste management which led to clogged open waterways and choked storm water drains.

The issue of solid waste management was also indicated as a primary urban governance challenge in Chennai by participants in workshops organized as part of this project. Stakeholders from the GCC, the TNSCB, the Tamil Nadu Housing Board (TNHB), Small Industries Development Corporation (SIDCO), Tamil Nadu Industrial Development Corporation Limited (TIDCO) and State Industries Promotion Corporation of Tamil Nadu (SIPCOT) all indicated this as a top challenge. Their concerns included the non-segregation of waste at source, the quantum of waste generated, the lack of availability of land for waste disposal, the clogging of storm water drains with waste and the contamination of groundwater and waterbodies. This corroborates the magnitude and the pervasive nature of the problem, which, if unresolved, will have far-reaching impacts on the city's ecology and long-term environmental sustainability.

Chennai city generates around 5400 tonne of garbage every day. This is collected, unsegregated, from 200 wards across 15 city zones. The collection of garbage is two-phased. The primary phase involves door-to-door source collection, collection from community bins and street sweeping. Garbage collected in this phase is transported to and unloaded into eight city transfer stations.

The second phase involves transportation of collected garbage from transfer stations to landfills. The city has two major landfills, situated on the city outskirts: Perungudi in the south and Kodungaiyur to the north. SWM is handled by the GCC in 12 of the 15 zones, and is privatised in three zones (9, 10 and 13). In both cases, the process is pretty much restricted to collecting, transferring and dumping waste into landfills.

Garbage piled at a landfill [representative only] © vchal

Boys scavenging in the municipal garbage dump © Paul Jeffrey

CONFLICTS AND CHALLENGES IN SOLID WASTE MANAGEMENT

Outsourcing Conservancy Operations

The practice of collaborating with the private sector for SWM started in 1989 when the GCC began partnering with Exnora International, a Chennai-based Non-Governmental Organization (NGO). Exnora worked with community organizations and informal waste workers to collect solid waste from households and deposit it into GCC-provided neighbourhood bins. Often, that waste was then collected and taken to the dumpsite by the GCC. Exnora's role was ultimately side-lined after a pioneering GCC effort to privatise conservancy operations by contracting a private company (CES Onyx), which meant that Exnora could not resume its operations. CES Onyx's modernisation of garbage clearance practices meant residents didn't have to pay fees (Sridhar, 2013). However, Exnora volunteers do, continue to carry out awareness campaigns around cleanliness and waste segregation at source (Chandrababu, 2015b).

Although CES Onyx's work was commended, the company did not comply with the Municipal Solid Waste (MSW) Rules 2000 provisions on segregation (Subramanian, 2007). These had not been specified in its contract (which predated the law) so the lack of segregation was not technically a violation of contract.

Neel Metal Fanalca, the second contractor, received legal notices from the GCC for irregular waste collection, failing to provide adequate dustbins and failing to execute door-to-door waste collection (Radhakrishnan, 2012). Neel Metal Fanalca also faced a shortage of manpower (because of attrition problems) and machinery -- to the extent that the GCC had to take over wards that were previously assigned to Neel Metal Fanalca (Times of India, 2013).

Ramky Enviro Engineers Pvt. Ltd., the third contractor, faced similar issues, particularly around hiring and retaining personnel, most of whom demanded higher salaries (The Hindu, 2012). In fact, a section of workers went on a flash strike demanding a salary hike, which seriously affected collection operations in some city zones (Ramakrishnan, 2012). Ramky was unable to step up its night conservancy operations by adding more workers to its operations. The GCC expressed its dissatisfaction over the performance by taking over some of the divisions under Ramky Enviro.

Further, the highly significant and critical role the informal sector plays in the entire waste process is largely ignored. This sector includes waste pickers and small-scale recyclers. The SWM process the GCC has followed over the years indicates a seeming preference for large scale, capital intensive, engineering and technological solutions over decentralised approaches that are in fact often better-suited to manage the diverse range of waste generated by households. The trade-off between modern waste management techniques and providing a livelihood for waste pickers is a complicated issue which needs to be addressed. The 2016 SWM Rules attempted to do this by mandating that state policies acknowledge the informal sector and provide guidelines for their integration into the formal system.

Going forward, the GCC plans to privatise the conservancy operations in all 15 Chennai city zones, a move that has been met with severe opposition from GCC conservancy workers and from Resident Welfare Associations (RWAs) (Deccan Chronicle, 2017). Private sector participation in solid waste management activities has some potential advantages, due in part to the extra latitude private providers often have in management, access to technology and financial structuring. But in the absence of an effective monitoring mechanism, which has encouraged the private operators to mix construction debris with domestic waste, thus illegally increasing their tonnage, and poorly written conservancy contracts, which does not offer flexibilities for adaptation in a changing policy environment, GCC's move may well lead to a worsening of the garbage menace.

Operation and Maintenance

SWM is one of the key issues that lie at the intersection of any city's developmental and environmental trajectory. To ensure future sustainability and water resilience in Chennai, rapid urban growth must be matched with substantial attention to effectively managing the large amounts of solid waste produced by the growing population and increased industrial and commercial activities. However, Chennai capital expenditure on SWM was limited, particularly in 2013-14 and 2017-18. A total of approximately INR 102 crores (Cr) was spent in five years (GCC, 2015; 2016; 2017). Bengaluru city, by contrast, released an INR 800 Cr grant in 2016 alone to maintain existing drains, remodel a portion of them and construct retaining walls. Chennai city's largest allocation between 2013 and 2017 was in 2016-17, while there was no allocation at all for SWM in 2014-15. Furthermore, the nature of SWM is such that it requires more revenue to maintain and operate existing systems. Regardless, INR 5.15 Cr spent in five years, representing a fairly insignificant amount – and indeed it was spent just on community bins (Budget documents, 2013-14 to 2017-18) ***(see Fig. 11 - following page).***

Landfill Management

Chennai city has two major landfills: Perungudi in the south and Kodungaiyur in the north. In addition, two smaller landfills also exist in Athipattu and Pallikaranai.

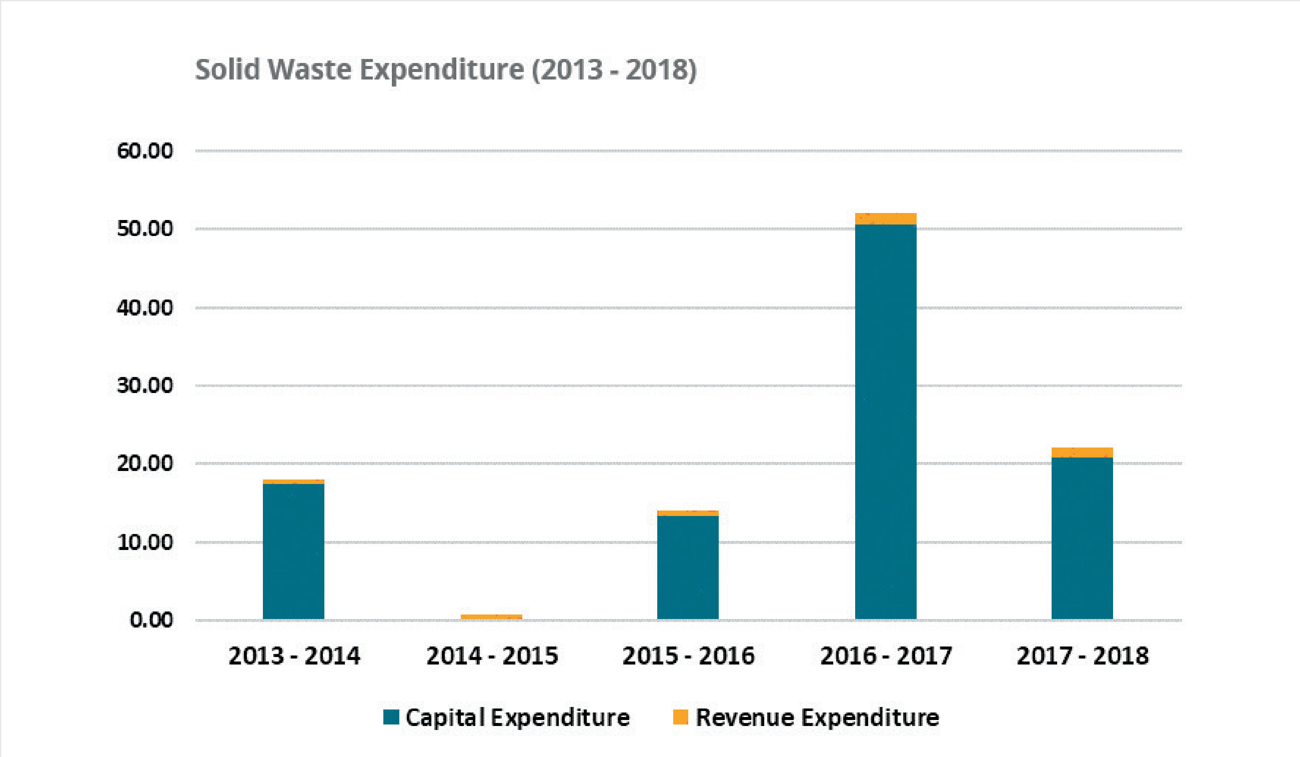

Figure 11. SWM expenditure (in crores) Source: Greater Chennai Corporation

These landfills have been the subject of ongoing debate, specifically around the environmental problems they pose. For instance, waste leaches into wetlands and pollutes groundwater. Also, emissions from burning trash (landfill waste is often set on fire to burn quantities down) and decomposing organic matter contribute to local air pollution. These issues are starting to matter politically as well, as air and water pollution get increasing media attention.

There is little knowledge around why sites were chosen for landfill purposes. One can only assume that, at the time of selection, these areas were considered to be on the fringes of the city. However, rapid urbanisation and the development of an IT corridor has stretched the core of the city and moved development into city outskirts. Inexplicably, real estate development and planning permissions have now placed many residents dangerously close to landfills. These sites are often plagued with increasingly frequent fires, which affect residents, pollute the air and groundwater and threaten ecological sites such as the Pallikaranai marsh (Janardhanan, 2012; The Hindu, 2014; Kumar, 2017; and The Hindu, 2017).

Several efforts are ongoing, both community-driven and government-led, to scientifically shut down Chennai's landfills. But doing so would require shifting the dumping to new locations, which is difficult because land within the city area is largely unavailable, and also because new proposed locations are invariably protested by residents and environmentalists. For example, two solid waste processing facilities were proposed at Minjur and Kuthambakkam but local residents protested, and environmentalists and scientists condemned the proposed

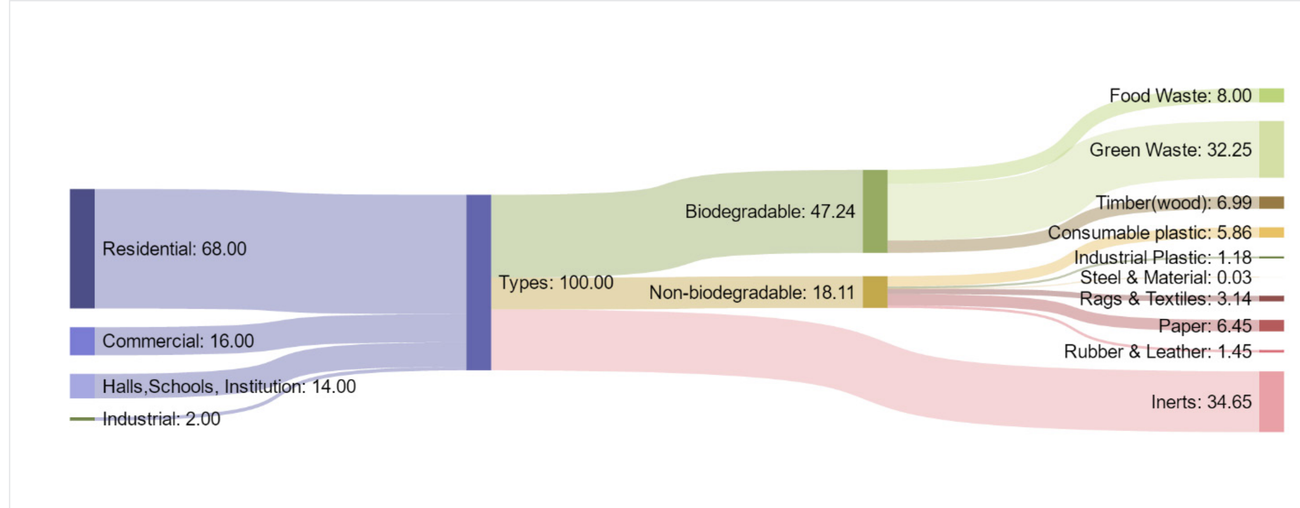

Figure 12. Solid waste composition Source: Greater Chennai Corporation

plant in Kuthambakkam for having been constructed within the Chembarambakkam lake catchment area, which contains a major water source for Chennai city. Protestors argued that the plant would pollute a primary Chennai water source and lead to a water shortage crisis (The Hindu, 2010). An Environmental Impact Assessment (EIA) carried out by the TNPCB found that, if completed, the project would indeed pollute the lake. Curiously, TNPCB gave a No Objection Certificate (NoC) for the proposal anyway, despite the recommendations of the environmental expert assessment committee (TNPCB, 2008). Eventually, the projects were shelved and, instead, waste to energy plants have been proposed in the existing dump yards at Kudangaiyur and Perungudi (TNPCB, 2008).

Community Engagement

Much of the blame around solid waste management is often placed on the government, while the role of waste generators is conspicuously overlooked. In fact, SWM problems stem in many ways from the irresponsible manner with which city's residents handle their waste Municipal solid waste typically consists of household waste, construction debris and street waste. With rapid urbanization, the amount of waste generated per capita in the city has increased from 300 grams per day in 1971 to 760.6 grams per day in 2016. According to the Chennai Corporation ***(see Fig. 12)***, residential waste contributes 68 percent of municipal waste, followed by commercial waste, which contributes 16 percent, institutional waste, which contributes 14 percent and industrial waste, which contributes 2 percent. Of the total waste generated, bio-degradable and inert waste make up 47.24 percent and 34.65 percent. The amount of waste going to landfills can be significantly reduced if waste is segregated at source and reused.

While the state of city landfills is abysmal, it is important to be mindful of how the government cannot continuously scramble to find new landfill locations. The current pace of waste generation and management will mean the GCC will have no option but to use incinerators (despite their environmental and health implications) as a way of reducing the mountains of garbage and reclaiming the land currently occupied by landfills.

Source segregation has not really taken off in Chennai, despite it being mandated in both iterations of SWM rules.

However, the state's recent SWM policy, which strengthens Urban Local Body (ULB) authority to address SWM and GCC SWM by-laws are likely to soon lead to improved source segregation in Chennai as they include user fees for waste collection and penalties for failing to segregate waste. In addition to reducing the waste that reaches landfills, source segregation has the potential to support the growth of business opportunities for start-ups and industries in the waste-to-energy value chain, including collection, segregation, recycling, transportation and energy recovery.

The above discussion on SWM gives an important insight into the systemic gaps that currently define Chennai SWM practices. Based on the analysis, the following key points emerge:

1. The consequences of a bourgeoning population, unbridled urbanisation and associated consumerism are bound to increase the amount of waste generated in Chennai.
2. The problem is manifold, and an effective intervention needs concerted cooperation between governmental and non-governmental stakeholders.
3. Improper landfill management and the selection of ecologically vulnerable areas for future landfill sites will exacerbate groundwater and air pollution problems and negatively impact overall quality of life.
4. Poor enforcement and monitoring of existing laws further compounds the impact of the issue. Exnora, Hand-in-Hand and RWA success stories are fragmented and get lost in the prevailing SWM practices, which are typically insufficient.
5. Addressing SWM problems in Chennai must be a starting point in GCC efforts to develop a Chennai Smart City.

GOVERNANCE CHALLENGES

The previous section discussed the status of Chennai's land-use, water and waste sectors. The following section will provide insight into Chennai's governance ecosystem and the challenges resulting from its multiplicity of institutions with varied interests.

In order to better understand the inter-organizational relationship between Chennai government agencies and the few NGOs perceived as part of the governance scene, this section resorts to a Social Network Analysis (SNA) approach. SNA provides a means to unpacking complex socio-institutional landscapes by mapping the institutional actors (organizations, individuals, interest groups) and their linkages or networks (socio-institutional relationships). SNA can serve multiple purposes. For instance, it can be used to map flows of funds, exchange of information or influence posed by multiple agents/institutions. It can also help provide an understanding of actors' world view, their problem framings and associated decision-framing, which can be synergistic or competing. In addition to mapping existing socio-institutional landscapes, SNA can also be crucial to identifying network strengths and weaknesses that are important leverage points for bringing desired transformation (for instance, towards becoming a more collaborative governance network).

In this report, two types of relational flows between multiple agencies working within Chennai's governance ecosystem are charted: first, functional dependency flows and second, data/knowledge flows.

Functional Dependency Flow

Functional dependency flow marks the linkages that represent agencies' dependency or influence on others for proper functioning, either through funding-related dependencies or process-approval dependencies (for example, TNHB or TNSCB depending on the Directorate of Town and Country Planning (DTCP) to access planning and building permissions beyond CMA boundaries, or the Department of Environment (DOE) providing funds to various other government departments based on project proposals submitted by them).

Data/Knowledge Flow

Data Knowledge Flow marks the communication pathways for data or knowledge-sharing between actors (for example, the CMDA gathering data from multiple agencies including the GCC, DoE or the PWD to prepare a master plan). ***Figure 13*** on the next page represents a visualization of the actors (nodes) and networks (links) that represent the CMA governance ecosystem, primarily reflecting functional dependency flows.

Panorama of George Town as seen from the High Court © Planemad/Wiki

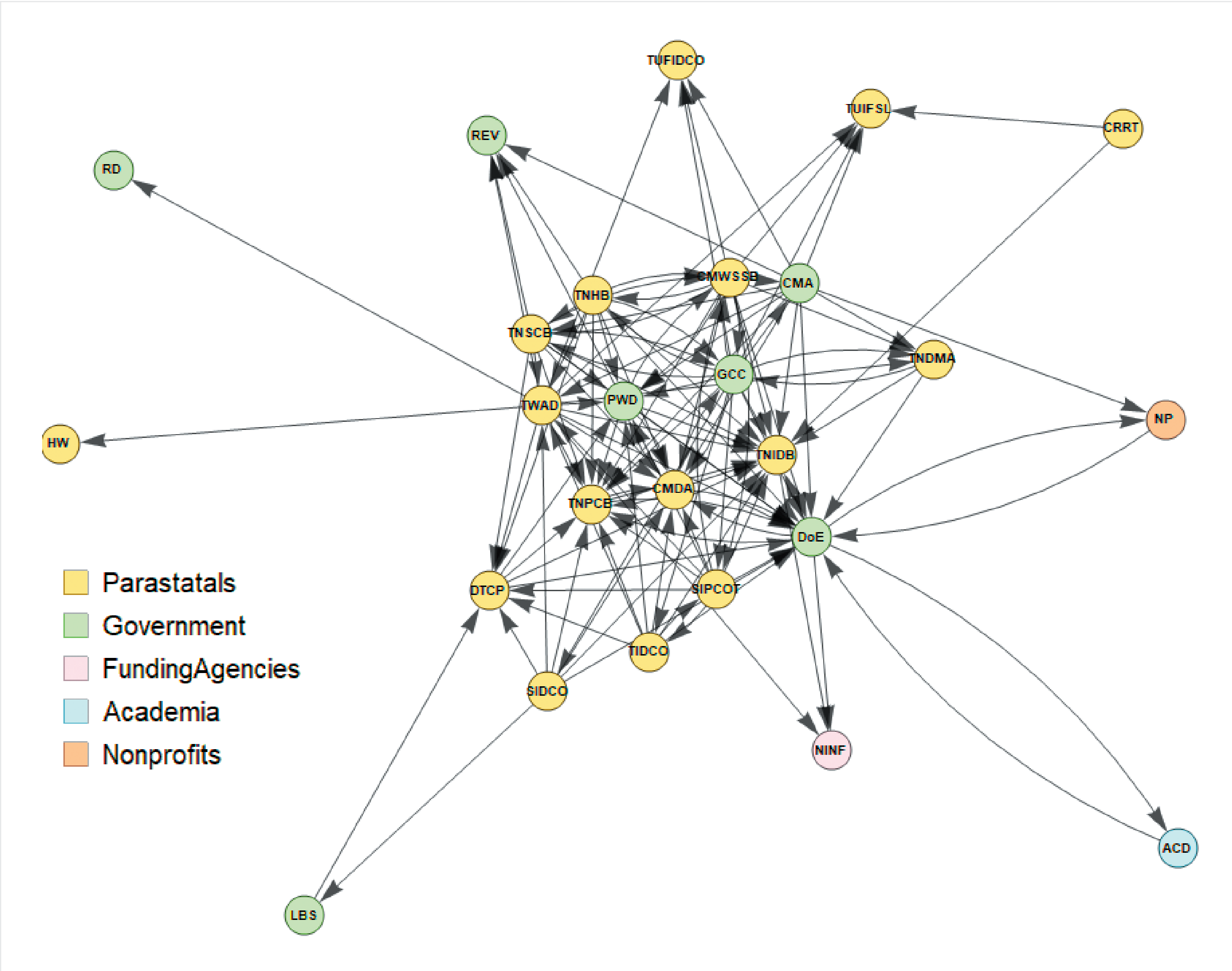

Figure 13. Functional dependency map for Chennai Metropolitan Area's urban-environmental governance ecosystem (as perceived by governance actors)

The diagram above is a visualization of the actors/ agencies and relations that, according to government stakeholders, define the core of land-water-waste decision making/policy realm. Analysis of this visual representation of the network of organizations/groups involved to different degrees in CMA's governance presents some interesting points. First, the *network density* of the governance ecosystem presented here seems to average at 0.4, indicating a limited scope for collaboration and/or inter-organizational coordination.[9] This corroborates the frustration expressed by government stakeholders during workshop engagements

9 Here we use the density figure of an undirected graph instead of a directed graph because, in the context of urban environmental governance, a connection between two agencies, even if it is not a two-way connection, is relevant for communication and/or collaboration. Typically, a directed graph density is half the density of an undirected graph with the same number of nodes. So, if we consider the former measure then the network density of the CMA governance ecosystem would be even lower (.20), implying even bigger constrains with respect to collaboration and/or coordination.

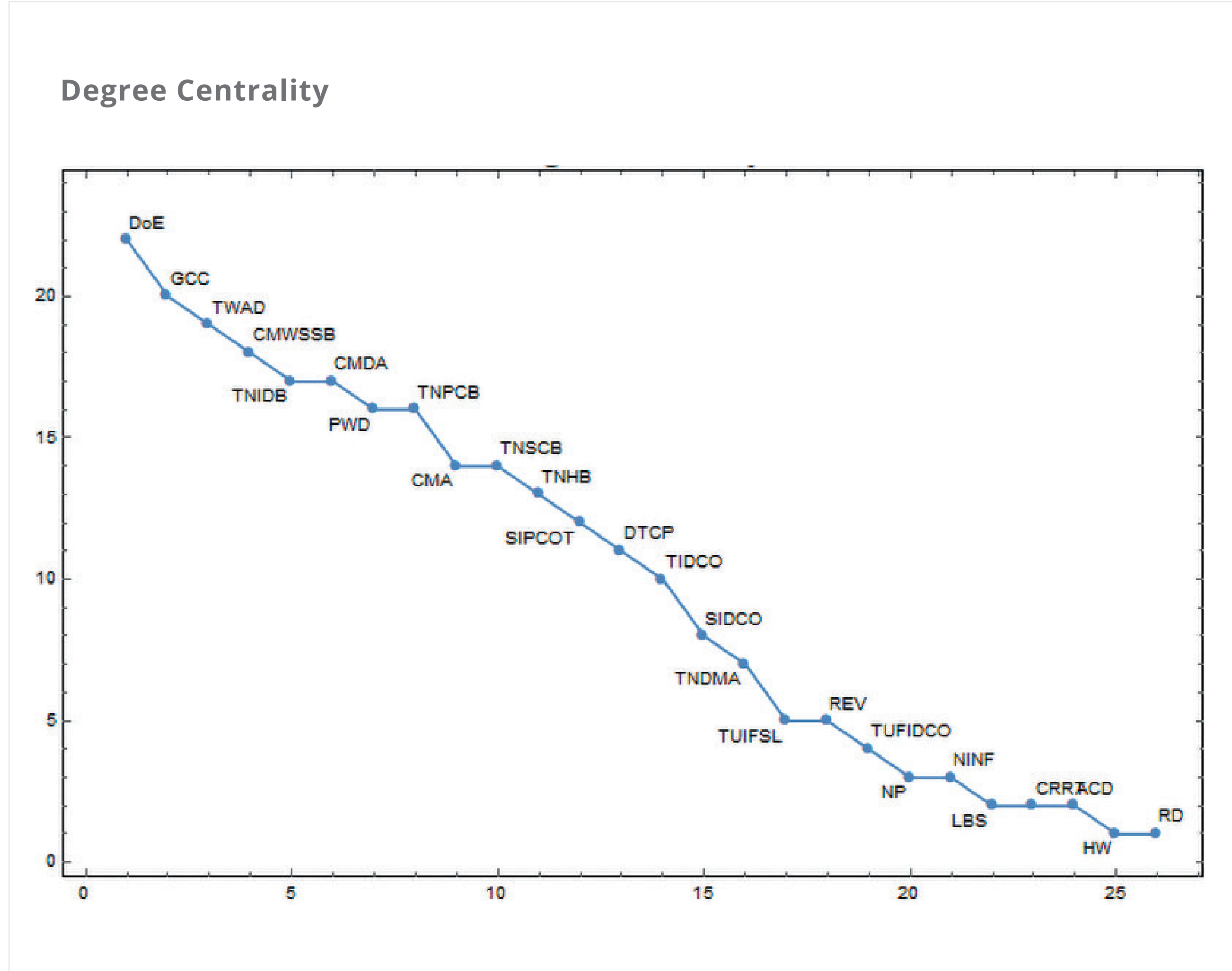

Figure 14. Degree Centrality: who are the key actors in CMA governance?

and interviews about a lack of communication across departments. To achieve better integrated governance, it will be crucial to improve on this density; in other words build such interactions across actors in this network.

However, the nature of the current network suggests that substantial time and dedicated effort will be needed to build trust and to develop a culture of more interactive governance. One limitation of network density measure is, however, that it fails to differentiate between variable nature/size/scope of agencies and uses the possibility of linkages between all types of agencies as a benchmark. Also, excessively high network density could lead to homogenization of information and less efficient resource use and reduced capacity to adapt to changes (Bodin and Norberg, 2005).

Figure 14 presents the degree centrality of agencies in the CMA governance network, highlighting the key or central actors in the network. From this graph it is evident that the DoE, GCC, TWAD, Tamil Nadu Infrastructure Development Board (TNIDB), CMDA, CMWSSB, PWD and TNPCB are key actors, with higher numbers of linkages (above 15 compared to 22 which is the total number of network linkages for any one agency). However, it is important to differentiate between those agencies where several links originate and those where they are incident.

The ones where the links are incident include agencies that remain primarily responsible for defining policies, rules and approving or overseeing that rules are properly implemented. This includes the CMDA, DoE, TNPCB, PWD and TNIDB. Any infrastructure development in the CMA, whether industrial, water or waste-treatment related must, as a first step, secure planning permission and building permits from the CMDA (or the GCC or other local bodies, depending on the scale and nature of the project). The CMDA is also responsible for preparing CMDA master plans and for laying out development control regulations. As a result, most organizations tend to depend on and interact with the CMDA to gain planning permissions. As a next step, organizations also have to secure EIA clearance, which means approaching the DoE and the TNPCB. When proposed development is in the close vicinity of water bodies, a NoC from the PWD must be obtained. As such, the PWD remain right behind the above-mentioned four agencies in terms of incident linkages. Smaller development projects, whether residential or commercial, do not readily require oversight by the DoE or the TNPCB – unless the planning-permission-granting authority (CMDA, GCC or other local bodies) gauge some degree of environmental or other risks and direct such developments to arrange for NoCs or pollution certificates from the DoE, PWD or TNPCB. As such, the CMDA, GCC and other local bodies play a more important role in regulating and monitoring smaller developments than do the DoE or TNPCB. Finally, the TNIDB emerges as a key actor because it is a major player in terms of fulfilling Tamil Nadu's Vision 2023; it funds all kinds of infrastructure projects initiated by other agencies in Tamil Nadu and the CMA governance ecosystem.

On the other hand, organizations such as the GCC, CMWSSB and TWAD are also key players – but more so because linkages originate from these nodes. In other words, as implementing agencies they are responsible for infrastructure and service delivery (water, waste, etc.) and remain dependant to varying degrees on the former set of agencies with respect to following rules, providing funds and accessing approvals that collectively shape their ability to fulfil their roles.

The *betweenness centrality* measure identifies the GCC as a key agency that sits between or connects several other actors in the network ***(see Fig. 15)***. As such, it has the potential to access resources from multiple agencies, initiate and facilitate exchange of knowledge and resources between such agencies and therefore play the critical role of a bridge in the network. With respect to triggering any change, for instance in terms of introducing a more integrated or participatory decision-making processes, the GCC could be a critical leverage point in the CMA's governance scene. That said the GCC's jurisdiction is limited to Chennai corporation boundaries, which limits the scope and scale of impact from their actions.

The graph in ***Figure 15*** makes it evident that Chennai's overall governance structure presents a moderately hierarchical network with not one but a handful of agencies playing central roles. While there are a sufficient number of linkages for the network not to be described as individualistic, the small number of linkages between government and other types of agencies (for example, NGOs or academia) suggests the network is not co-managerial. While a strongly hierarchical network is more likely to be authoritarian and insensitive to broader societal interests, a moderately hierarchical network indicates involvement of a number of agencies who can potentially maintain checks and balances on each other and address multiple needs. However, the colour coding in ***Figure 13*** reflects that most of the agencies across the entire system, including many of key actors playing a stronger role in the governance network, are parastatal agencies, including the CMDA, CMWSSB, TNPCB, TNIDB.

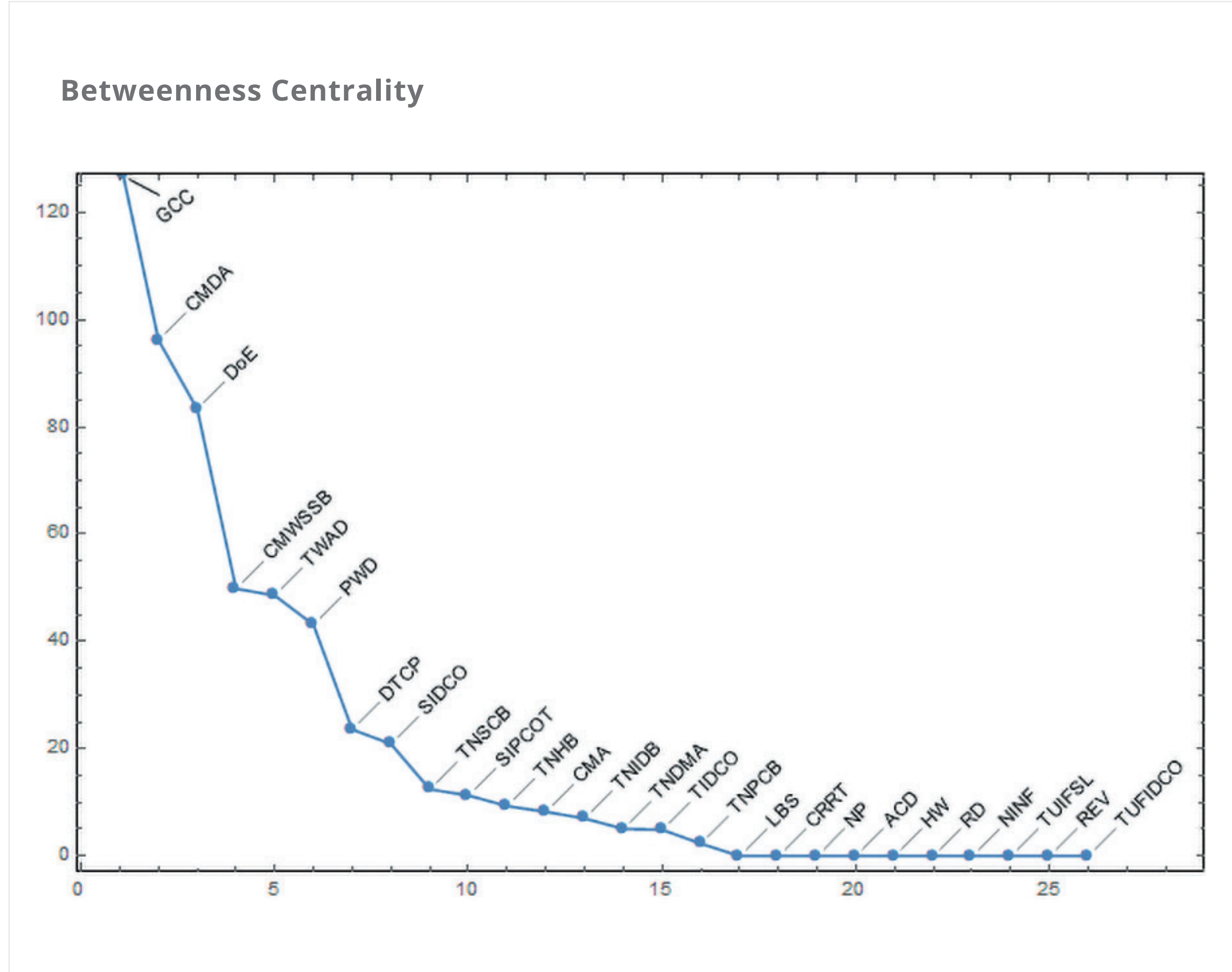

Figure 15. Who can mediate across multiple agencies in the CMA's governance network?

The birth of many Chennai parastatal agencies can be traced back to the 1970s, when specific acts were passed to create state-level bodies that were tasked with specific municipal functions, such as providing water and drainage (TN Water and Drainage Act, 1971), sanitation (Chennai Metro Water Supply and Drainage Act, 1977), housing (TN Housing Board Act, 1961 and TN Slum Clearance Board Act, 1971) or planning (Town and Country Planning Act, 1971). Despite the passage of the 74th amendment which aimed to provide greater planning authority and decision-making powers to ULBs, many aspects of city planning have nonetheless been captured by specialized parastatal agencies such as the CMDA and the DTCP. As a consequence, planning has remained primarily under the aegis of experts and bureaucrats who are primarily accountable to the State Government. The functioning of these bodies has created significant challenges to the effective devolution of powers to lower level local bodies (Coelho *et al.*, 2011). The lack of linkages assigned to local bodies by key actors in the governance network also suggests the limited role and power these agencies exercise.

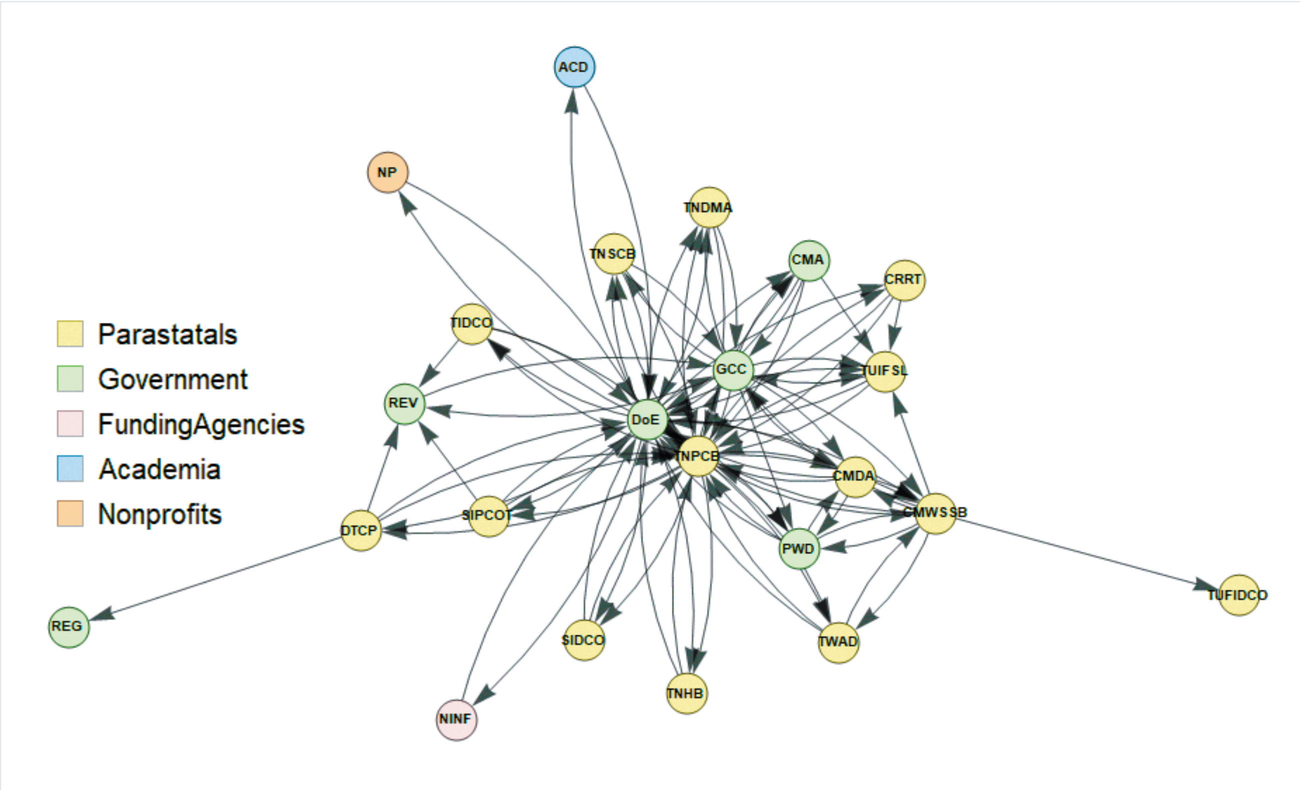

Figure 16. Knowledge flow map for Chennai Metropolitan Area's urban-environmental governance ecosystem (as perceived by governance actors)

Furthermore, the multiplicity of agencies performing various sectoral functions (such as water, sanitation, housing or drainage) also suggests the issue of 'functional fragmentation' (Coelho *et al.*, 2011). Associated problems relating to resource allocation, personnel management and insufficient coordination among these agencies have been identified as major challenges to effective governance (Coelho *et al.*, 2011; Datta and Chakravarty, 1981).

Knowledge Flows Network

Most government agencies who participated in the SNA exercise claimed to have two-way interaction with substantial data sharing across departments (*see Fig. 16*). For instance, the CMDA requires that other departments (such as the CMWSSB, GCC and PWD) share data in order to prepare master plans. These master plans then become (or at least in principal should become) the basis for other departments to develop their own plans (for example, the CMWSSB's master plan). In particular, the DoE and TNPCB appear to have a higher number of linkages, possibly because, along with interacting with other government agencies, the DoE in particular is one of the few public agencies that interacts frequently with academic institutions and NGOs for technical support. While government stakeholders themselves claim to interact through knowledge and data exchange, the overall density of the network is average (0.4), which is similar to the functional dependency map. Further analysis of the nature of these interactions and networks offer interesting revelations.

In particular, exchange of information between public agency departments seems problematic on many counts. Here, the discussion is centred around the CMDA – a key actor in the CMA governance ecosystem (*see Fig. 17*).

In principle, the CMDA does share knowledge and data, and does communicate with multiple agencies in the network. For instance, they collect data and feedback from disparate departments to prepare master plans and they present this plan for public review. However, interviews reveal dissatisfaction among several agency representatives around the level of engagement and continuous communication here. One point of contention is evident between the PWD (responsible for maintaining macro drainage in Tamil Nadu) and the CMDA (responsible for preparing the master plan). The CMDA's Master Plan Report identifies substantial sections of natural drainage channels for residential and commercial land use, which opens these spaces up for development. On the other hand, detailed old village maps on all drainage channels, which are maintained by the PWD, were not, until recently referred to during the master plan development process. The two organizations have begun to work together more closely, however, since the 2015 floods and a growing recognition of the intricate relation between land use classification, development and water vulnerabilities in Chennai.

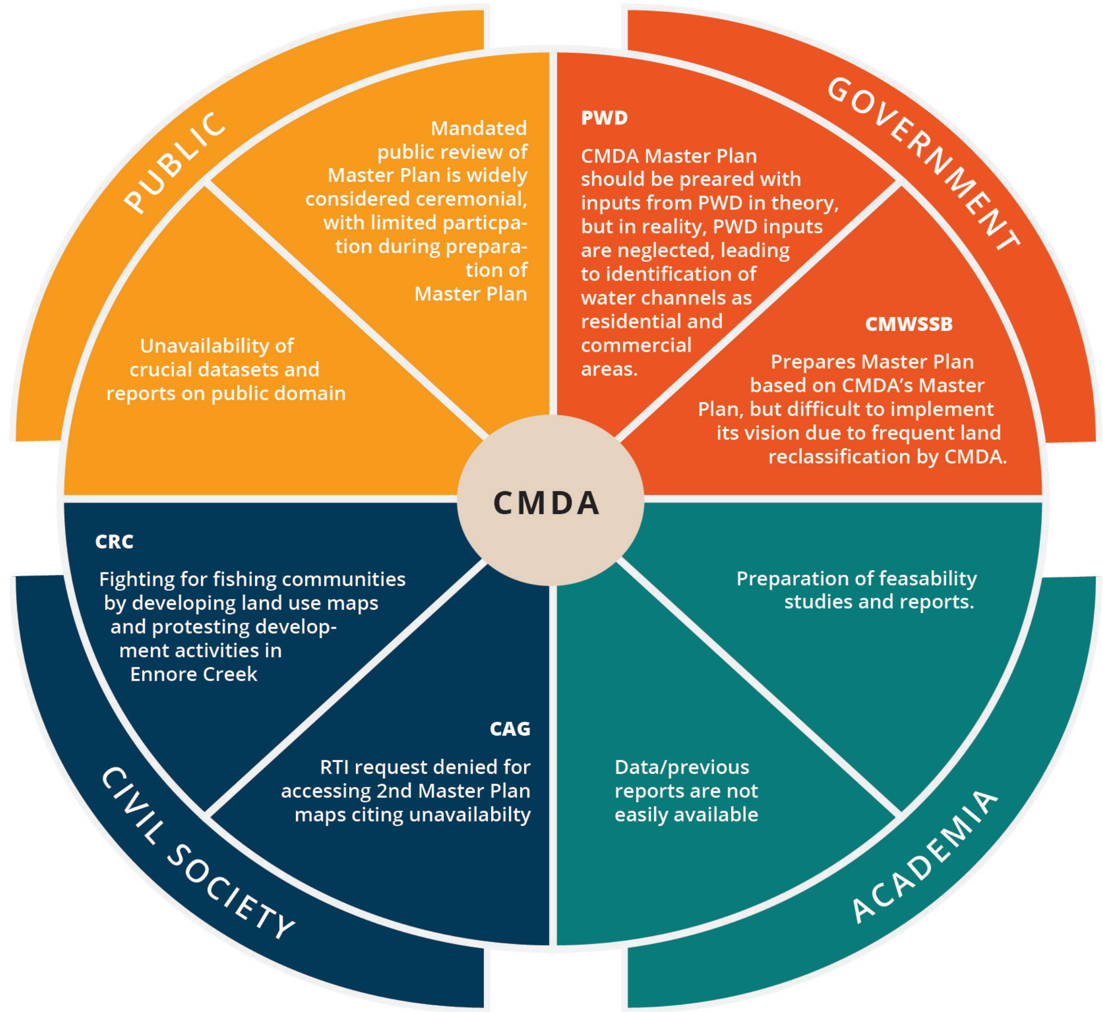

Figure 17. Various areas of contention around data/knowledge sharing and communication

Similarly, CMDA land reclassification exercises sometimes impede on CMWSSB operations. The CMWSSB's master plan is essentially derived from land use classifications defined by the CMDA in its initial master plan iteration. However, the CMDA's continuing land reclassification processes demand a complete overhaul of CMWSSB priorities if they are to meet the water supply requirements for the newly classified area. A land parcel classified as agricultural, for example, may be reclassified for residential or industrial use, with potentially significant water demand and sewerage infrastructure implications for the CMWSSB. This is just one example of the challenges faced within a network that is defined by limited cross departmental communication.

Furthermore, NGO experience makes it clear that, while data is available, it is not easy to access. Interviews with the Coastal Research Centre (CRC) revealed this limitation. Concerned about industrial development along the Ennore Creek region, the CRC filed for Right to Information (RTI) to view the Coastal Regulation Zone (CRZ) maps that were used to approve the development. The Ennore Creek area had been declared a no-development zone in 1996 but over the years has been systematically reclaimed with government intervention assisted by the CMDA, who finally declared it a special hazardous zone. At the same time, local fishing communities agitated against what they said was neglect as a result of the Master Plan Report having marked Ennore Creek areas as unused when they are in fact used for fishing. The "unused" marking of areas opens them up for development, as evidenced by government plans to construct an elevated expressway between Besant Nagar and Kottivakkam on coastal lands that have been classified as unused. The CRC's RTI filing, however, was refused -- on account of unavailable information.

Today, as a result of continuous CRC and local fishing community efforts, data sharing gaps are being bridged and channels of communication with the CMDA are being opened. Locally developed land use maps are being shared with the CMDA, and the next Master Plan and CRZ Plan iterations will incorporate that data. In general, multiple public agencies maintain datasets and commission studies that are useful, but these are not readily available to the general public or to civic, academic or other public agencies. For example, studies related to encroachment were carried out by the TNSCB. Also, the GCC commissioned a study on hydrology and topography which was carried out by Aarve associates. Further, the CMDA commissioned the Rain Centre to conduct an audit of Chennai's Rain Water Harvesting (RWH) effort. However, the results of all of these were unavailable to the public. Overall, an absence of data and data sharing, as well as a lack of easy-to-access data repositories, point to the challenges of advancing the cause of evidence-based policy making in Chennai's urban environmental governance. The above discussion indicates that, while there is some degree of recognition among stakeholders to collaborate better around knowledge, there is substantial scope for improvement in inter-departmental communication among public agencies, as well as for intra organizational communication across public, private and civic agencies. Perhaps one issue that seems to hinder more effective government-civil society knowledge sharing is the fact that most civic agencies in Chennai's governance scene are advocacy groups and government agencies feel insecure about sharing data with them, for fear the data will be used to highlight the problems.

This sentiment was evident among public officials during the workshops organized as part of this project. A few organizations do, however, maintain closer linkages with government agencies. For example, Care Earth, an organization that provides technical knowledge and assistance to public agencies (for instance, as it relates to strategies for scientific tree planting or effective wetland restoration methods), specifically collaborate closely with agencies such as the Department of Forestry.

The above analysis provides the following key findings regarding the nature of the CMA governance ecosystem:

1 Urban land, water and waste are governed primarily by a handful of public agencies with limited linkages between them, particularly across public and non-governmental stakeholder groups.

2 The ecosystem is moderately hierarchical in character, which is not particularly suitable for effective co-management of city resources. Substantial effort in trust-building will be required for the system to become more collaborative.

3 Within the system, the DoE, GCC, TWAD, TNIDB, CMDA, CMWSSB, PWD and TNPCB appear as key actors, but each for different reasons: the CMDA, DoE, TNPCB, TNIDB and PWD are agencies who provide approvals, permissions or funds, or set rules, while the GCC, TWAD and CMWSSB operate primarily as implementing agencies who depend on the former agencies. Interestingly, the CMDA plays a particularly important role since developers often approach the DoE, TNPCB or PWD for NOCs or permissions only after the CMDA or other local bodies with power to provide planning or building permits recommend that they do.

4 The GCC in particular appears to be an important linking agency because it connects several other agencies who do not interact directly with each other. Therefore, the GCC has the potential to act as an important bridge in helping spread sustainable and transformative changes across the network.

5 Parastatal agencies dominate the overall governance landscape with obvious implications for local-level governance structure empowerment. Very few agencies in the network recognize local bodies as important actors, highlighting their lack of power or influence.

The imposing challenges that exist around the land-use, water and waste nexus can be traced back to the layered and interconnected governance structures associated with these sectors. In order to effectuate meaningful interventions, there is an imminent need for coordination and collaboration among relevant government departments. But the complex institutional environment poses a key challenge and needs to evolve to accommodate integrated and cross-cutting actions across various agencies.

CHAPTER 4: AS-IS SCENARIO

The Metro Rail Viaduct | © M Karthic

CHAPTER 4: AS-IS SCENARIO

The previous chapter provides important insight into systemic gaps that are entrenched in Chennai's urban development. The problems are manifold and, to be effective, interventions will require concerted cooperation from governmental and non-governmental stakeholders. The consequences of a bourgeoning population, unbridled urbanisation and associated consumerism are bound to involve increased pressures on city natural resources. But what if discernible changes are not made to address these problems? What if key governmental departments orchestrating Chennai's urban development continue on their current trajectories? This chapter provides a scenario wherein the city's unchecked urban growth continues to engulf its natural resources.

LAND USE

Current land use conditions are defined as follows: a) encroachment challenges are generally addressed by resettling encroachers and/or using EIA mechanisms and b) pressures are likely to increase as a result of population growth projections (rural-to-urban migration) and economic trends (jobs growth that does not match the skills of the increasing urban populace). These current land use conditions are likely to worsen if the status quo is maintained. Water body areas in Chennai city and its suburbs are already estimated to have shrunk from nearly 12.6 sq. km in 1893 to around 3.2 sq. km in 2017 (Lakshmi, 2018). Continued loss of these water body areas will aggravate floods risk while also jeopardizing many lives and livelihoods. Increasing numbers of families migrating into the city will continue to encroach on cheap but unsafe river and water body banks, in the absence of better, affordable options. Periodically, government agencies such as the TNHB and TNSCB will relocate encroachers to alternate sites within their limited means based on the resources available to them. Lower income citizens who are resettled or evicted will continue to face the same challenges and drawbacks they currently face, ranging from poor quality tenements, lack of facilities, distance of new settlements from the city, poor law and order situations, loss of livelihoods, etc. In the absence of a comprehensive and well-coordinated plan, the very cycle of encroachment will be perpetuated as one group is moved out while another moves in. Similarly, the number of cases of non-compliance with the EIA mandate by public and private developments alike indicates the inherent ineffectiveness of that process. The "as-is" scenario here involves continued encroachments on environmentally vulnerable and associated so-called natural disasters such as the 2015 floods which are in fact largely human-instigated.

Residential tower construction encroaching on Pallikaranai Marsh © Dhruv Malhotra / Circle of Blue / Wilson Center

WATER

Most environmental experts define CMWSSB's emphasis on desalination plants over water body restoration as unsustainable in the long run. The planned plants will take more than 10 years to reach full operation, by which time city water demand will have increased considerably. The CMA expansion will give the CMWSSB jurisdiction to tap into agricultural lands in the expanded area, which will further deplete groundwater levels and affect water availability for agriculture. In the absence of water metering or solving NRW problems, the CMWSSB will experience a severe financial crunch, crippling their O&M and RWH efforts. The unregulated and unmonitored informal private water supply ecosystem will become mainstream and residents will have no option but pay for expensive water tankers as a primary water source. This will further diminish poor people's capacity to meet their basic water requirements. Furthermore, without CMWSSB's support to restore and better manage existing water bodies, these are likely to meet a fate already experienced by several affected and polluted water bodies in the CMA that have already been categorised as unrestorable.

Pallikaranai dump yard, 2013 © Mukherjeeo0606

WASTE

Chennai is a leading generator of waste in the country, with the total amount having increased exponentially over the years. This number doubled from 2,616 tonnes in 2000 to 5,400 tonnes in 2018. With a persistence of the status quo, Chennai's two landfills will go far beyond their saturation point and small land parcels inside the city or in the envisaged expanded CMA will be used for waste dumping. As evidenced in the existing dump yards, unscientific waste disposal into open land parcels will have a severe impact on groundwater quality. The health hazards associated with waste incineration and dumping close to human settlements will only intensify.

Recent estimates by Waste to Energy Research and Technology Council (WTERT) place the quantity of waste ending up in drains at 30 percent of the total amount generated. This leads to widespread storm water drain clogging and water body pollution, which in turn causes extensive inundation as a result of even moderate rainfall. Further, efforts to restore water bodies will prove unsustainable due to inevitable pollution, thus crippling the city's water supply situation. Thus, if the status quo persists, it will have far-reaching and long-term impacts on the city's ecology, water supply and quality of life.

While these as-is scenarios spell despair for the city, many might argue they are not actually possible, given current government's efforts to ensure water security and sustainable development. However, those efforts, while laudable and very much welcomed, are at best fragmented and at worst counter-productive, exacerbating the very problems they aim to address.

An existing example of an as-is scenario is Cape Town's race to postpone "Day Zero". City officials there predicted in 2017 that city piped water supply run dry by early 2018. The city was in the midst of a three-year drought and facing an unprecedented water supply crisis to feed its four million citizens. In the months leading up to the crisis, hydrological poverty crippled public life with severe impacts on health, emergency response, vulnerable populations, business and tourism. But "Day Zero" has now been postponed multiple times; it is currently predicted for the end of 2019, and is still a looming threat.

Though 2018 monsoons helped address the problem, a coordinated government campaign, combined with water consumption behavioural change among consumers, helped the city significantly. Efforts like introducing water limits per person, investing in water supply infrastructure and penalties for over-utilization helped to minimize demand and conserve water effectively.

Lessons from Cape Town echo around the world in cities facing similar water crises. In India, Bengaluru, once referred to as the "city of lakes" but now debilitated by egregious planning decisions, features on the list of possible "Day Zero" cities. If development in Chennai continues without regard for the associated ecological consequences, "Day Zero" in Chennai is an increasingly likely possibility.

Puzhal lake running dry, June 2019 © Palani Kumar/PEP Collective

CHAPTER 5: OVERVIEW OF THE SIMULOGUE AGENT-BASED SIMULATION TOOL

The Napier Bridge at night | © Arvind Balaraman

CHAPTER 5:
OVERVIEW OF THE SIMULOGUE AGENT-BASED SIMULATION TOOL

As part of this project an Agent-based simulation (ABM) tool (or Simulogue) was developed to support integrated planning. This chapter outlines the basic method used to set up the simulation run on this ABM, Simulogue.

The simulation tool uses about 170 parameters to tune different aspects of Chennai, its infrastructure and, specifically, Chennai's planning institutional structure. Simulogue is developed with the use of Agent-based Simulation techniques. Agent-based simulation models are used to simulate decision-making and overall system operation. Individual decision-making entities are modelled as autonomous agents in a simulation software. Simulogue is implemented using Repast Symphony which is an open-source agent-based simulation platform. In order to aid and promulgate integrated planning, the ABMs developed over the course of this project can effectively support policymakers to better understand the interdependencies of multiple agencies and work together towards specific planning goals.

Simulogue models wards (or any chosen geographical area unit) as cellular automata. The land-use classification used in the model follows the Chennai master plans to classify the various ways in which land is being used. Different institutions in Chennai are the individual autonomous agents that act on the Chennai area and influence a variety of parameters through their plans. Thus, each plan consists of aspects of new infrastructure or capacity being added and maintenance operations. Based on the plans, specific resources such as amount of water available, the amount of solid waste produced, etc. can vary in the model.

The simulation tool also models the interactions between agencies. For example, if a new reservoir is to be developed, the specific agency, i.e. the CMWSSB agent in this case, will start the process by first requesting a clearance from the Revenue Department (RD) agent. It then requests clearance from the Tamil Nadu Pollution Control Board (TNPCB) and finally checks if it has the appropriate capital. The infrastructure is added only when all the criteria are met. The following sections provide an overview for setting up a simulation run.

STEP 1: SETTING UP THE GEOGRAPHICAL CONTEXT

The first group of parameters set would be the area under study. We consider the Chennai wards for this study due to the availably of datasets. The geographical context includes the following:

Land-use according to the Chennai master plans includes the percentage of land that is classified as:

1. Primary residential
2. Commercial
3. Industrial
4. Mixed residential
5. Land that can be urbanised
6. Land that cannot be urbanised
7. Coastal regulation zone

Figure 18. Setting up a simulation on Simulogue

8. Institutional land
9. Red Hills catchment area
10. Special industrial land
11. Wetlands and forests

Land-use for encroachments is set to a certain percentage. The assumption is that, for every increase in standard land-use, a certain percentage of land is lost to encroachments. The encroachments land-use parameter is used only as a guide and does not model the specific locations or nature of encroachments.

With regard to land-use for informal settlements, we assume that, due to inequality and lack of affordable housing, there can be informal settlements when there is an increase in population or migration. Similar to the encroachment parameter, this informal settlement land-use parameter is used only as a guide and does not model the specific locations or is not linked to social parameters in the study area.

Each year, there can be an increase or decrease in the different land-use types. Land that can be urbanised, for example, will reduce constantly due to increasing urbanisation.

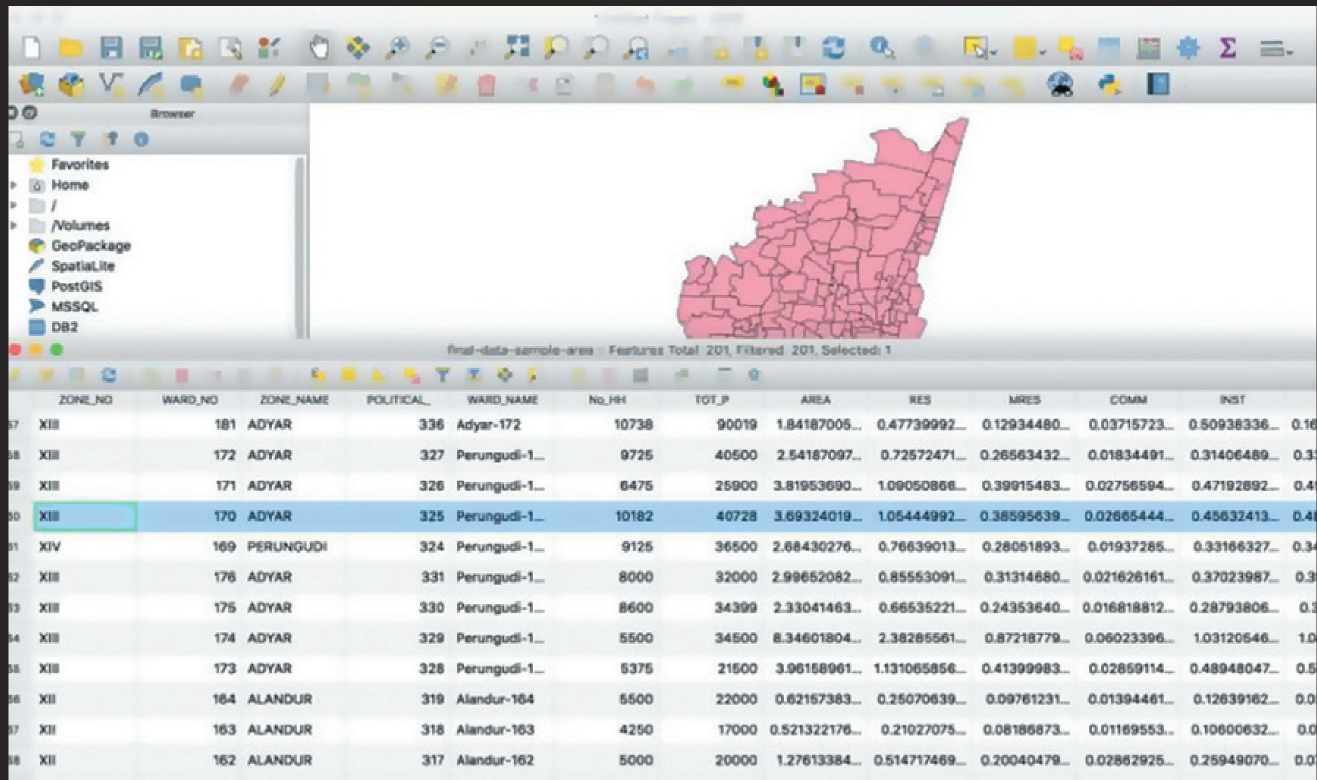

Figure 19. Chennai SHP file with ward and land-use data

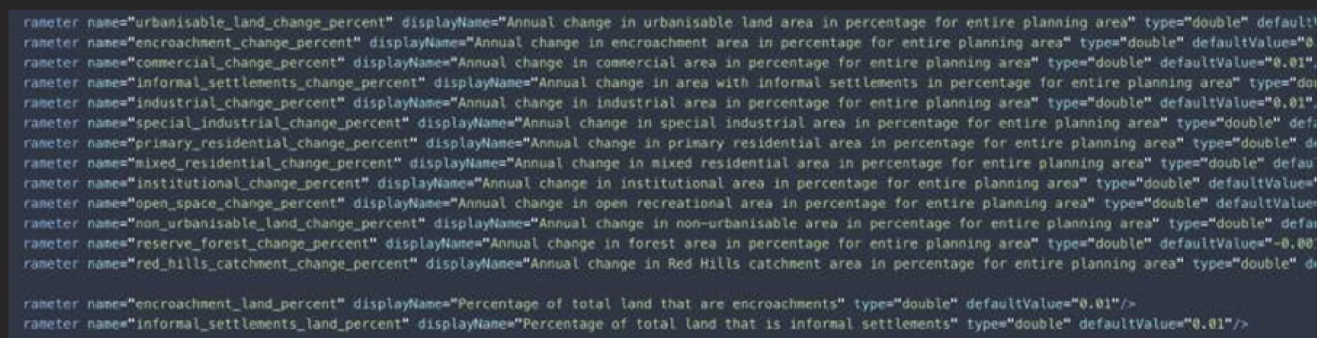

Figure 20. Section in file parameters.xml in the simulation tool

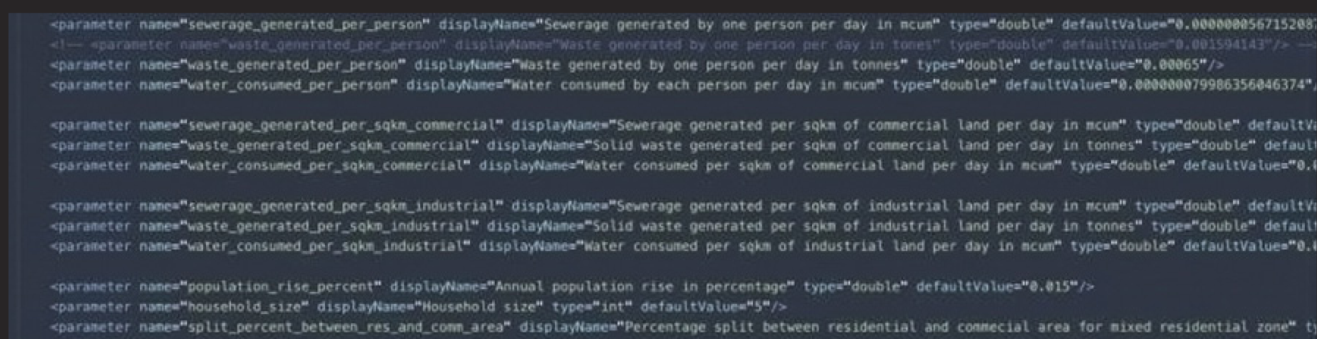

Figure 21. Parameters for setting planning context

However, the amount of primary residential, commercial and industrial areas usually increases. As such increases are observed over decades, the actual rate of increase is kept lower than 1% as per the observations in master plan documents.

The parameters are usually geo-coded; thus, the data is loaded in the form of a shape file. *Figure 19* shows the type of data points embedded in a shape file, such as the size of each type of land-use for a given ward in Chennai. *Figure 20* shows the input file parameters.xml with the expansion levels.

STEP 2: SETTING INSTITUTIONAL PARAMETERS

The various institutions involved in planning and operations of different infrastructure in Chennai related to water, land-use, solid waste management and sewerage management are modelled in the tool. These agencies are chosen based on the social network analysis (SNA) of different institutions as outlined in *Chapter 3*. The current simulation models the following agencies as autonomous agents:

1. Greater Chennai Corporation (GCC)
2. Chennai Metropolitan Development Authority (CMDA)
3. Chennai Metropolitan Water Supply and Sewerage Management Board (CMWSSB)
4. Revenue Department (RD)
5. Chennai River Restoration Trust (CRRT)
6. Tamil Nadu Pollution Control Board (TNPCB)
7. Tamil Nadu Slum Clearance Board (TNSCB)
8. Tamil Nadu Industrial Development authority (TNID)
9. Public Works Department (PWD)
10. Tamil Nadu Housing Board (TNHB)

The simulation models the institutional structure based on the SNA analysis. For example, Revenue Department is in charge of allocating land for housing, infrastructure development, etc. Thus, when TNHB needs to develop housing on a new primary residential area, it will need to contact the RD for approval. Only based on this approval would the TNHB proceed to the next step, i.e. identifying capital to develop such a housing project.

Key parameters and decision variables for each agency comprises of the capital costs and revenue for each agency, the quantity and capacity of assets planned such as new wells, reservoirs, sewerage treatment plants, etc. *Appendix 2* provides a list of all parameters for the simulation.

STEP 3: PLANNING CONTEXT

In the final step, the planning context is set using a number of parameters that make assumptions regarding the consumption of resources, population growth and rainfall forecasts. The list of all current infrastructure is also defined in this step. In other words, this step involves the definition of the ‘current state’ of infrastructure as well as trajectories of phenomena beyond the control of the selected actors that constitute a scenario. The following represents some of the main parameters that describe a context:

1. Population rise rate
2. Current available water capacity
3. Current installed capacity for solid waste management and sewerage management.
4. Consumption pattern per person, per household, household size and solid waste and sewerage generated.
5. Level of rainfall expected as estimates of water available in a given year.

Figure 21 shows setting some of the planning context parameters.

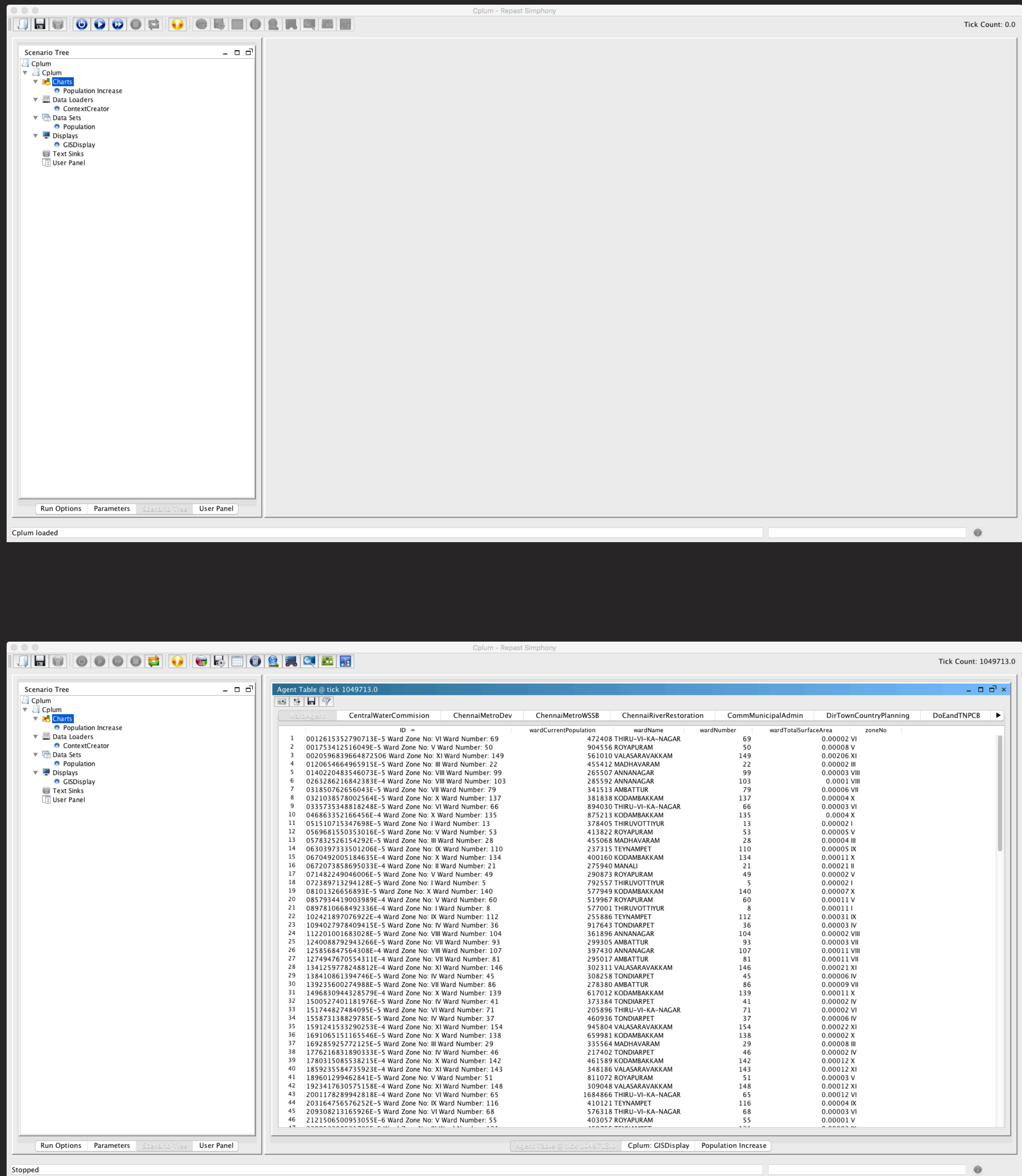

Figure 22. Repast Symphony ready to run a simulation

RUNNING THE SIMULATION

After the input to the simulation is set through populating the parameters, the simulation can be run using the Repast Symphony GUI provided. ***Figure 22*** shows the Repast Symphony GUI ready to begin a simulation run. The "scenario tree" describes the simulation run with the list of data being collected to run the simulation. The figure also shows the list of Chennai's institutional agents initialised and ready to begin the simulation.

Once the simulation begins, each agent enacts decisions based on a series of decision rules. For example, as explained earlier, as the amount of water supplied per capita reduces, an actor such as the CMWSSB initiates the decision to augment capacity through the development of, say, a desalination plant of a certain capacity. This then initiates actions that other agencies need to enact, such as determining the location of the plant and approving funding. As the simulation progresses, each institutional actor performs both routine work as well as non-routine decisions based on the state of the simulation or the actions of other actors. Consequently, this results in changes in land-use, water availability, etc., over the course of the simulation, leading to a final state roughly 20 years after the initiation of the simulation. All of these decisions and actions are governed by behaviour-rules that have been developed through an extensive study on the actions of and interactions between these agencies, as well as the contextual parameters that characterize each scenario.

CHAPTER 6: USING AN ABM TO ASSESS BUSINESS-AS-USUAL SCENARIO

The IT Corridor | © Balu Velachery

CHAPTER 6:
USING AN ABM TO ASSESS BUSINESS-AS-USUAL SCENARIO

Developing a scenario involves changing or planning for new policies and infrastructure to respond to changes in population or land-use patterns in Chennai. A scenario can be created by identifying a set of decisions and choices. In case of the Simulogue simulation, scenarios can be formed by identifying values for different input parameters. ***Appendix 2*** describes all such parameters (including population, land-use, policies, etc.) that are being used as inputs to the simulation tool. The default values describe the observed numbers in 2018.

As described in ***Appendix 2***, the set of input parameters to the simulation tool can be classified based on the specific agents, in this case, public agencies it configures. For example, all parameters configuring the Chennai River Restoration Trust agent are prefixed with "CRRT_". Apart from parameters for specific agents there are a number of parameters that are set for the Chennai urban context to describe the state of the population, zonal areas, encroachments, etc. These parameters do not have a prefix.

Figure 23 provides an overview of the simulation system. The starting condition consists of the various input parameters. These may be broadly divided into:

1. Land-use input parameters, which consist of the land area that are reserved for residential, commercial and industrial activities, as well as other areas such as those that can be urbanised, coastal regulation zones, etc.
2. Water data, such as the number of water sources, wells, reservoirs and their respective capacities. The seasonal effects of rainfall and evaporation are also modelled to determine the amount of water available in each of the water source.
3. Waste data, or the current capability to collect and manage solid waste.
4. Sewerage management information: the current installed capacity for managing the sewerage generated.
5. Other parameters, such as encroachments, informal settlements, clearances for infrastructure development, etc., that affect daily urban local body operations. These are also modelled with some input parameters for the same.

The output scenarios consist of the end-state values for the parameters of population, land-use, water availability, waste management and sewerage management. The scenarios will contain temporal values to indicate how the parameters change over time, given the simulation of daily operations in the Greater Chennai Corporation area.

To go from the inputs to the outputs, the agent-based simulation works in a series of time-steps. At each time-step, each 'agent' – public agencies in this case – carry out actions that are coherent with their overall goals.

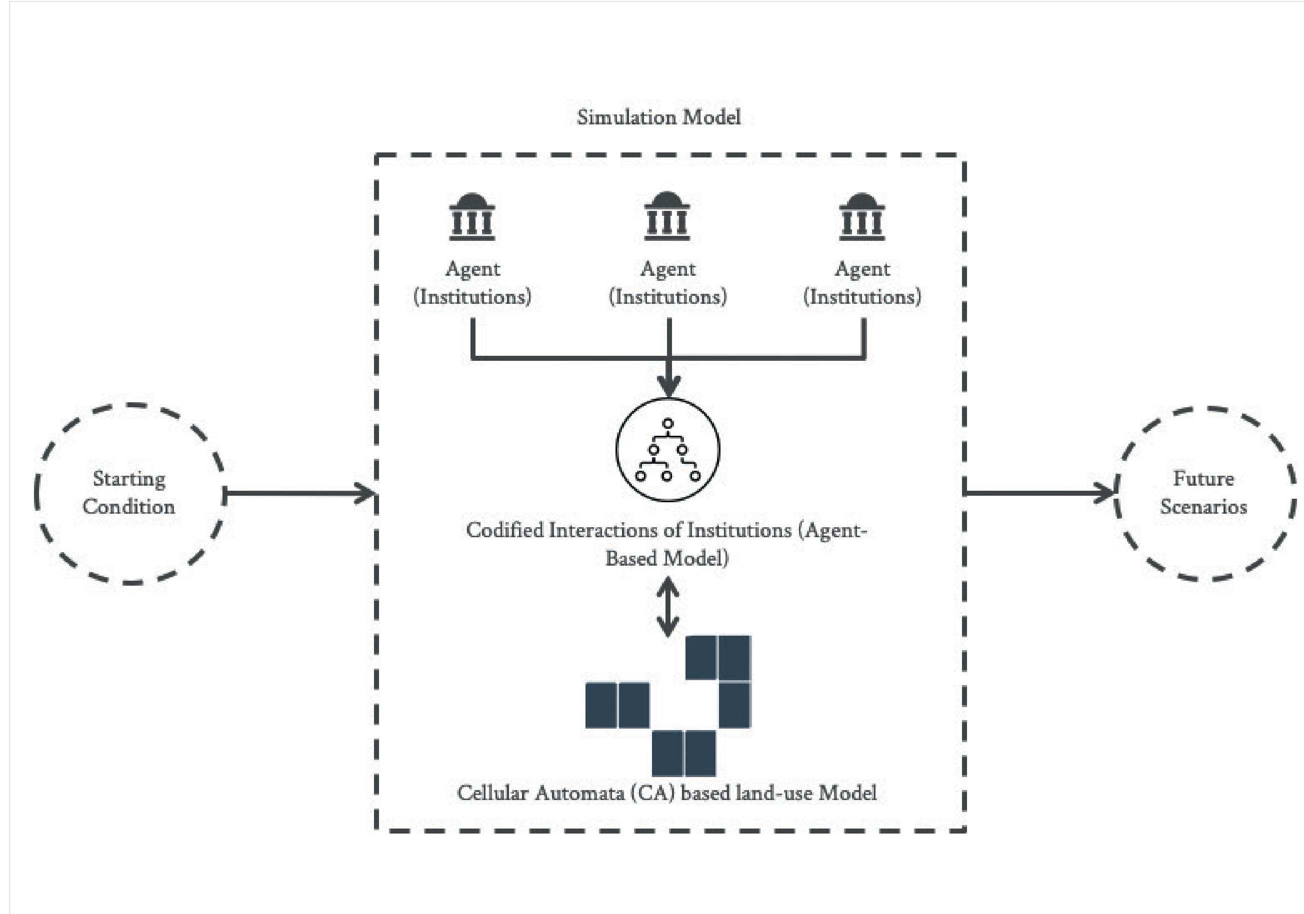

Figure 23. Overview of Simulogue simulation

Take, for instance, the case of CMWSSB deciding to build a new desalination plant. To undertake this project, CMWSSB may initiate actions such as requesting for land from the Revenue Department and obtaining clearances from other agencies (the TNPCB, for instance). In the next time-step, these requests manifest themselves in the 'inboxes' of these other actors who then make decisions on these requests. The average duration for resolution of these requests, as well as the workflows for each decision, have been modelled based on the primary and secondary data collected through workshops and interviews with stakeholders from these agencies. In subsequent time-steps, these decisions may manifest themselves as completed infrastructure projects in the Simulogue environment – in the case of desalination plants this will contribute to an augmentation of water supply capacity from a future time-step. Simultaneously, however, populations will have increased, rainfall patterns will have changed (based on climate models) and the impact of this new desalination plant will be dynamically represented in the outputs. The agent-based simulation thus simultaneously models multiple dynamics to arrive at outcomes at a future state.

The simulation itself consists of the essential operations for each agency that pertains to the development or maintenance of infrastructure, specifically related to water, waste or sewerage. For example, operations that augment water availability capacity, dredge reservoirs and rivers, develop storm water drains, etc. The interactions between agencies to achieve their goals are also modelled as operations between agents. For example, developing a reservoir requires land to be acquired first. This would mean the agent has to request and obtain the required land before the reservoir is built.

Finally, each operation and behaviour in the simulation model influences Chennai growth by influencing the population density, water availability or capacity to handle waste. With increases in population, additional capacity for water and waste needs to be added in order to provide for the new population. In the simulation, by varying the starting conditions or the goals of these actors, such capacities can be planned and added to account for this growth. In other words, the simulation allows us to build 'what-if' scenarios by varying input conditions and ascertaining which set of inputs might lead to the most desirable outcomes space that we envisaged. An exhaustive list of all the initial conditions is provided in *Appendix 2*.

THE BUSINESS-AS-USUAL SCENARIO (BAU)

The business-as-usual scenario refers to a situation where no new interventions are added. Thus, no new infrastructure will be planned. Instead, everyday operations and maintenance are continued.

The objective of the BAU scenario is to provide an insight into the extent of the planning challenge and the amount of resources that may be required to tackle it. The outcome is also indicative of the amount of negotiations that are required among multiple agencies to ensure that they have access to the required resources and are able to meet their mandates.

The business-as-usual scenario assumes that there is no change in operations in Chennai. The population growth is set to the current estimated level of 1.15% as per India's National Sample Survey Office (NSSO) numbers.

The zonal pattern or land-use pattern changes based on economic activities or demand for housing. In case of the BAU scenario, the current trends will continue, i.e., the zoning or land-use will not be allowed to change. Thus, the supply levels will continue to be maintained at the current levels. Land-use patterns will not show significant changes as they have very slow decadal growth rates.

Under this scenario, water, waste and sewerage infrastructure is not planned to be expanded. Thus, they will remain at current capacity and no new infrastructure is built.

POPULATION GROWTH

Figure 24 depicts the population growth at 1.15% as per the NSSO estimate. Simulogue assumes an exponential growth model for population increase. The graph depicts the output from the population generation algorithm. Population data for each ward in Chennai is obtained from the NSSO survey. The population for Chennai is aggregated from each ward for a given year. In the current model, the population increases uniformly across all wards.

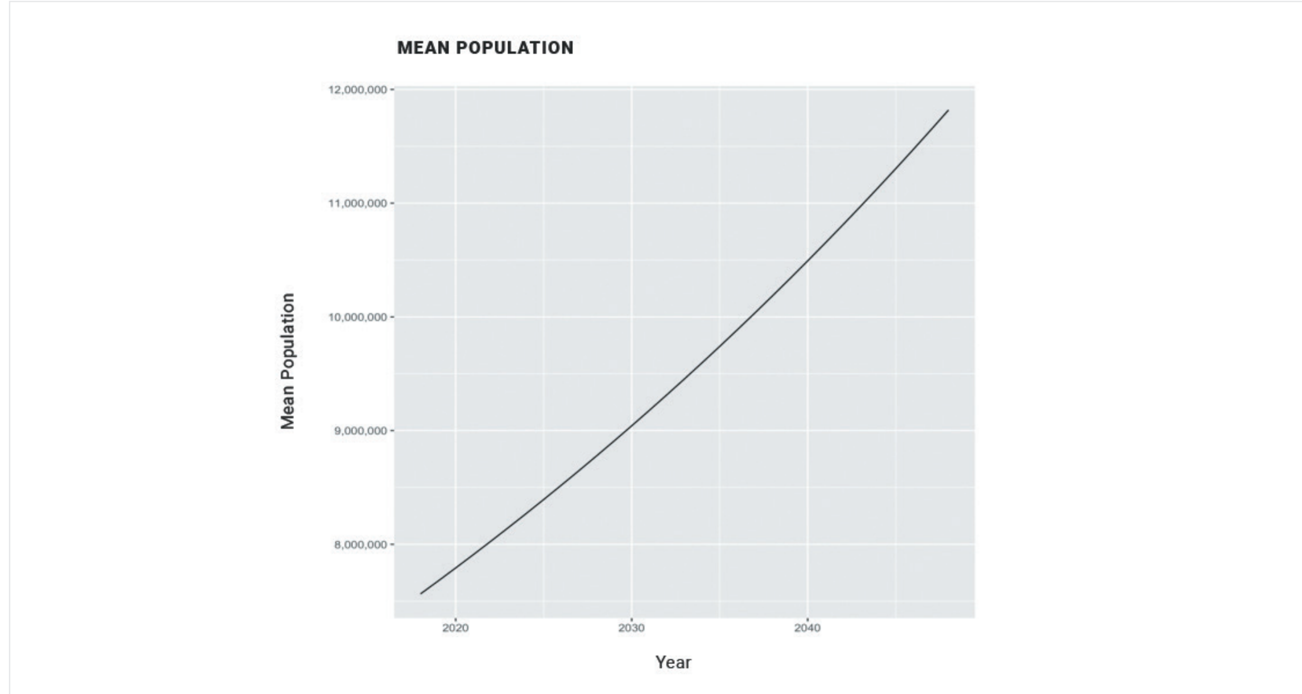

Figure 24. Population rise in the Greater Chennai Corporation from 2018 at 1.15% per year

LAND-USE HOLDING PATTERN

Zone/land-use in Chennai is divided into the following categories as per CMDA planning processes:

1. Residential: area with people living in household units. Each household is assumed to contain a group of 4 people. Water demand, waste generated and sewerage generated data is calculated per housing unit or per person.

2. Commercial: area designated for commercial activities, such as hotels, stores, markets, offices blocks, etc. As these units are not uniform in size, data on water demand, waste generated and sewerage is calculated per square unit of land.

3. Mixed residential: area with a mixture of commercial and residential units. Water demand, waste generation and sewerage generation is the sum of both types of activities.

4. Industrial: area that is designated for industrial activities. Data on water demand, waste generated and sewerage is calculated per unit square of land.

5. Special industrial: area that is designated for certain large industries or industries that are potentially water intensive and/or produce high levels of pollution.

6. Institutional: area that is designated for institutions such as government buildings.

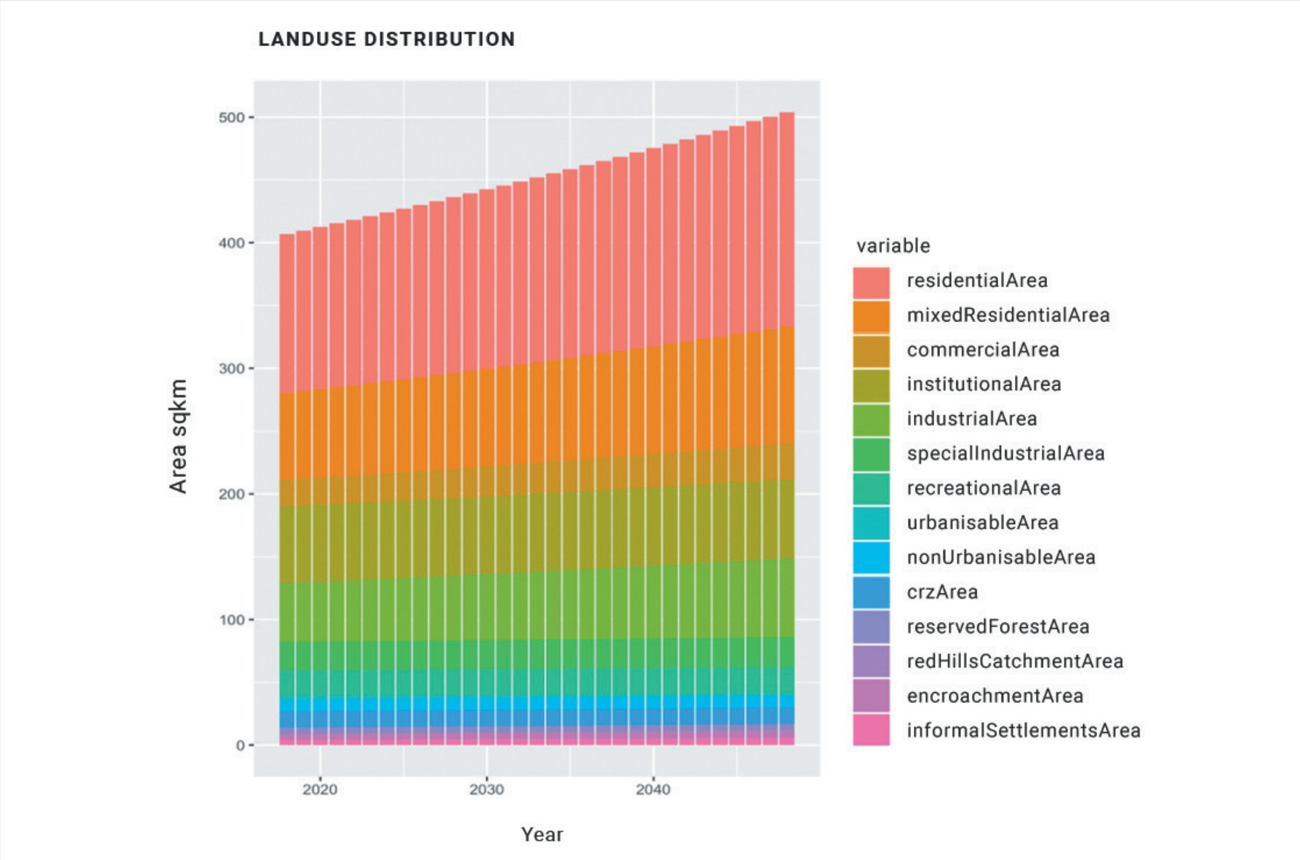

Figure 25. Zone/land-use distribution in the Greater Chennai corporation wards and their annual growth

7. Open space and recreational: parks, playgrounds, etc.

8. Land that can be urbanised: area that is considered as free land, where new infrastructure such as housing, markets, offices, industries, etc., can be developed. The amount of this area is assumed to be reducing as a result of increasing population and the development of new infrastructure.

9. Non-urban: area where no urban activities are allowed.

10. Coastal regulation zone: restricted area along the coast.

11. The Red Hills catchment: area around the Red Hills reservoir, a major source of water supply, has been declared as a catchment in order to restrict urbanisation here.

12. Reserve forest: area around the Chennai that is recognised as reserved and hence restricted from urbanisation activities.

Traditionally, changes in land-use patterns are slow and insignificant, even over decadal observations. However, due to migrations and urbanisation, there is an increasing demand for housing, commercial and industrial activities. Thus, a sudden increase in the trend indicates a growth pattern which has to be considered for planning. Each zone places a demand on water, housing, waste management and sewerage management.

The graph above demonstrates the current zoning change trends and the corresponding change in water demand, waste and sewerage.

Figure 25 demonstrates a constant increase in the area for different land-use types. The last two types, encroachments and informal settlements, are not under the control of any agency. They are commonly-observed phenomena in rapidly urbanising cities that have high demand for affordable housing which is in short supply.

The overall land use distribution data is obtained from Chennai Master Plans for each ward. A simple exponential growth rate was used to model the individual types of area. We observe that, in each case for given decadal increase, the residential area is the largest chunk of available land. Based on data availability, the growth model can be modified to include a full-fledged cellular-automata model that can account for neighbourhood effects, thus providing a more accurate representation of land-use based on changes to surrounding units of land.

Missing data for certain zones and wards was calculated based on the distribution patterns observed in wards by modelling the ratio of population to the type of land-use. For example, high population areas were assumed to be residential or mixed residential in nature; it was assumed that there is very low probability of zoning industries around such area.

WATER SUPPLY, CONSUMPTION AND AVAILABILITY

Water availability was calculated based on data published by CMWSSB on their official website. The lists of wells, reservoirs, rivers, desalination plants and waste water recycling plants were collected. Based on these, the capacity of each water source was calculated. For instance, groundwater wells are able to supply an average of 26 MLD. During times of drought the pumping is increased to get 100 MLD[10].

Water capacity in each water source (except in desalination plants) will depend on the natural watercycle.

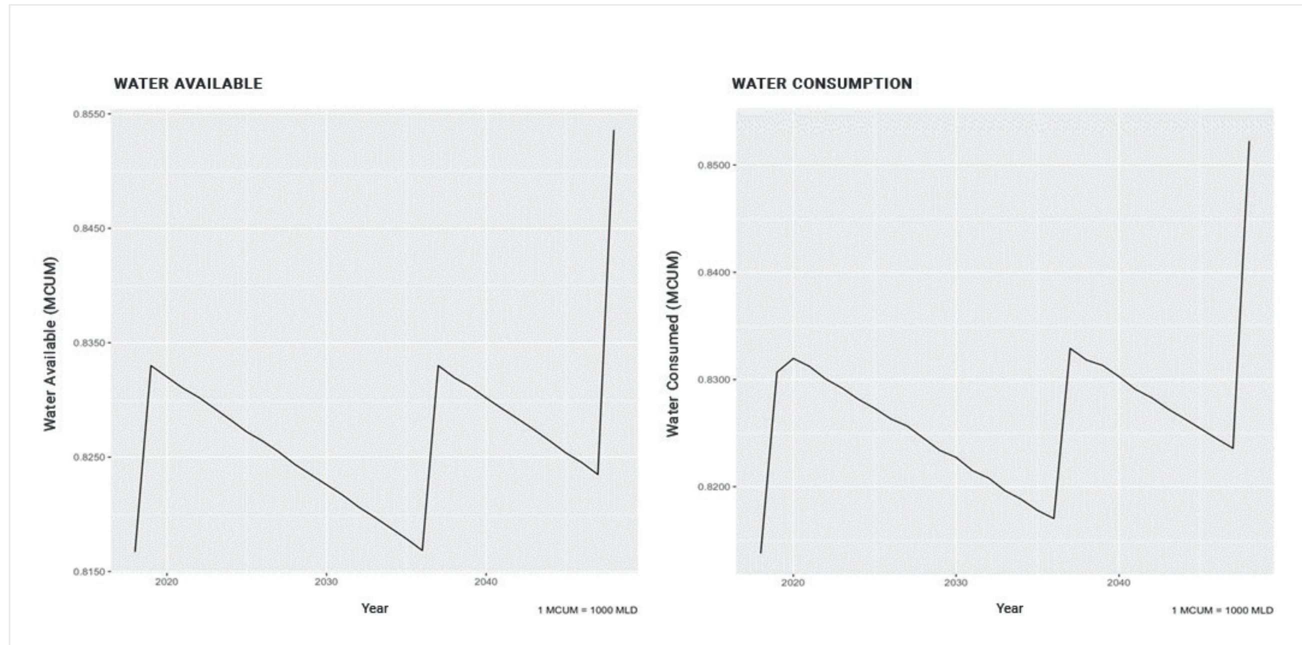

Figure 26. Water available and consumption in Greater Chennai Corporation area

10 Data from CMWSSB as of 2018

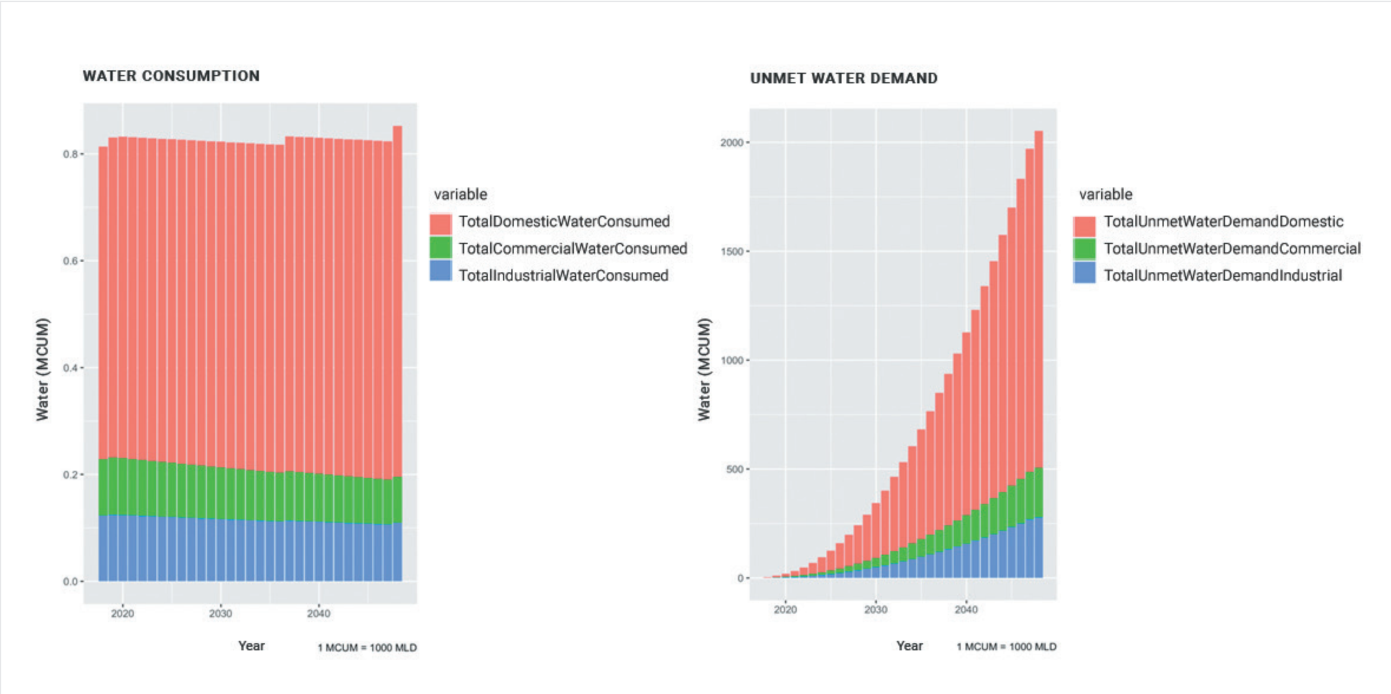

Figure 27. Water consumption based on land-use in Greater Chennai Corporation area annually

Based on the level of rainfall, the amount of water available in each source can reduce or increase, and this is modelled as a factor of its previous water level. For example, in times of drought or low rainfall, the water capacity can reduce by 1% from the previous year's capacity. The reduction can be controlled by the "water_replenish_percent" parameter in the simulation. Please refer to ***Appendix 2***: "water_replenish_percent" for further information.

Figure 26 (preceding page) represents changes in water availability and water consumption in the Greater Chennai Corporation area. We can observe that the total water availability oscillates between different levels (0.8150 MCUM - 0.848 MCUM). Variations in the water availability are due to changes in water levels in different water sources due to rainfall, maintenance and water demand. The quantum of rainfall in a particular year is predicted based on past data and climate models. The capacity improves based on maintenance and returns back to its original levels.

Maintenance operations can include operations such as finding and fixing leaks, removing silt and dredging of reservoirs, cleaning wells, etc.

The average water consumption in Chennai's wards, including commercial and industrial consumption, is also observed in ***Figure 27***. The general trend is to consume the total available capacity of all water sources modelled. As per the CMWSSB data, there is a deficit of approximately 200 MLD.

Figure 27 demonstrates water consumption for domestic purposes and the deficit in water supply. The domestic water demand is the highest demand type - higher than commercial and industrial demand combined. It should be noted that, as the scope of the work is for all Chennai wards, agricultural use and special industrial use, which still actually make up the highest amounts of individual demand, are not included. In the urban context, domestic water demand forms the majority of the water consumption share.

We also observe an increase in water deficit. Without new water sources or source augmentation, the combined (domestic, industrial, commercial) deficit can raise to as high as 250 MCUM with increasing population.

WASTE GENERATION AND MANAGEMENT

Waste generation is modelled similarly to water demand. Each domestic household generates a certain amount of waste. GCC reports that this value is around 650 grams per household per day. The total waste generated is a sum of all the waste generated in all areas of Chennai. Commercial and industrial areas tend to produce more waste and sewage per unit area than residential zones.

Figure 28 displays the amount of solid waste generated. The graph demonstrates that the increase in waste generation will exceed the current capacity to process waste by 2025. The current capacity is estimated at 5400 metric tonne per day, represented by the blue horizontal line. Augmenting or developing new waste processing facilities is out of scope of the current version of Simulogue.

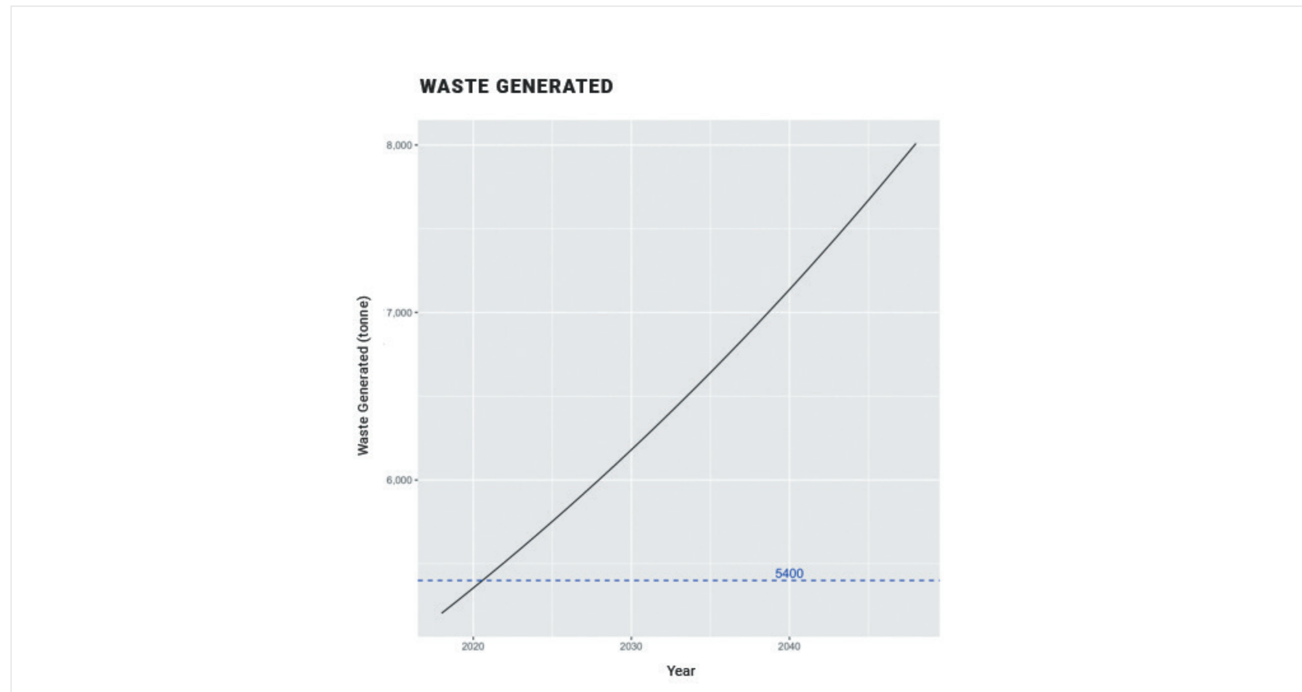

Figure 28. Waste generated from Greater Chennai Corporation area annually

SEWERAGE GENERATION AND MANAGEMENT

Figure 29 shows the sewerage generated by the Greater Chennai Corporation area. As with waste management, sewerage generation increases in step with the increase in population over time. The current installed sewerage management capacity is able to manage the generated sewerage but additional capacity is needed as the current rate of increase would exceed installed capacity in early 2035.

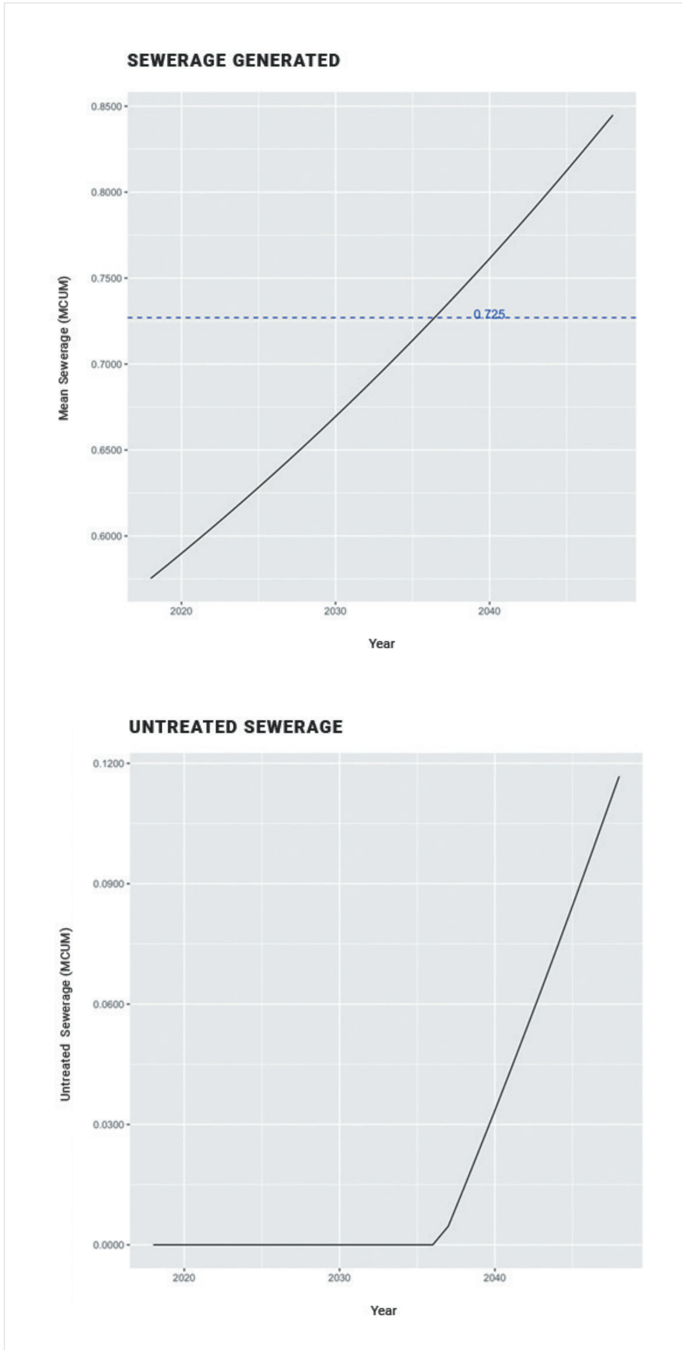

Figure 29. Sewerage generated and untreated sewerage from Greater Chennai Corporation wards annually

CHAPTER SUMMARY

In a situation where the population is increasing at a normal rate and the business-as-usual scenario applies:

- *Water availability will fluctuate within a narrow band unless new water sources are tapped. This scenario also assumes rainfall will remain normal and all water sources are regularly maintained.*
- *Water demand increases in step with the increase in population. The current deficit will increase to 250 MCUM by 2030 without new sources or source augmentation.*
- *Domestic water consumption is the primary type of water demand in the Greater Chennai Corporation area.*
- *Sewerage generated also follows the population increase trend and will exceed the installed capacity of 725 MLD between 2020 and 2035. The amount of untreated sewerage will rise exponentially from 2035 if no new capacity is added.*
- *The waste management capacity of 5400 tons will be exceeded by 2020.*

CHAPTER 7: USING AN ABM TO ASSESS FUTURE SCENARIOS

View from the Marina Light House | © Naufal MQ

CHAPTER 7:
USING AN ABM TO ASSESS FUTURE SCENARIOS

In this chapter, a set of future scenarios will be presented and compared using the Simulogue agent-based model (ABM) to show how this tool can help decision-makers compare and contrast different options. The overall goal or planning objective driving the set of future scenarios developed and presented here include:

a. *Coping with the current deficit in terms of infrastructure and resources (for water, waste and sewerage)*

b. *Planning for the increase in population and urbanisation i.e., the new demand on water, waste infrastructure and sewerage management.*

These points were prioritized by all public agencies participating in the project workshops as important planning objectives. New scenarios are generated by translating these planning objectives in terms of inputs to Simulogue. The list of all possible input values is provided in ***Appendix 2***. For example, the planning objective of "drinking water for all" would require setting up a simulation run with input values for a given population rise percentage and setting the goal for CMWSSB minimum water supply to residential area to reach 100% and then performing the simulation run.

In this chapter, we identify three future scenarios based on the workshops that we conducted with participants from different Chennai agencies. Each scenario attempts to capture the overall planning challenges for future growth of Chennai. The future scenarios for Chennai can be conceptualised based on the following matrix:

TABLE 3. SCENARIO GENERATION MATRIX

Scenario	Rainfall	New Infrastructure Planned	Population Increase	Sustainability Initiatives	Water Supply Goal	Sewerage Management Goal
No sustainability initiatives	Average	Yes	Yes	No	100%	Add 10 % capacity
Low Rainfall	Below Average	Yes	Yes	Yes	At least 90 %	Add 10 % capacity
Low Rainfall with no new infrastructure	Average	No	Yes	Yes	At least 90 %	No change

FUTURE SCENARIO 1:
NO SUSTAINABILITY INITIATIVES

In order to draw focus on the importance of different sustainability initiatives, we simulated a scenario where we plan for an increasingly urbanised Chennai with new infrastructure but no additional sustainability initiatives, while trying to meet 100% of water demand. This scenario can be translated to the simulation parameters based on the following objectives:

SCENARIO OBJECTIVES

1. *Meeting drinking water supply for all residents, commercial establishments at 100%.*
2. *Population increases at a rate of 2%.*
3. *Increased commercial and industrial activities due to increasing urbanisation and hence demand to change the land-use pattern for higher commercial and industrial area.*
4. *Normal levels of rainfall and current levels of water are maintained in reservoirs and wells.*
5. *No sustainability initiatives are undertaken. Thus, no water conservation programs conducted, i.e. no programs are undertaken to reduce water demand, rain-water harvesting or ground water recharge.*
6. *New water sources are planned to meet the increase in demand corresponding to the ongoing urbanisation.*
7. *Increase sewerage management capacity by 10%.*

The simulation was run with following changes to input parameters:

TABLE 4. MAIN INPUT PARAMETERS FOR NO SUSTAINABILITY INITIATIVES SCENARIO

PARAMETER NAME	VALUE
Population Rise Percent	2% as rate or rise in population
CRRT Target Number of Wetland Maintenance	No wetland maintenance programs
CRRT River Restoration Effort	No river restoration efforts
CMDA Residential Change	1.5% as rate of increase in residential area
CMDA Commercial Change	1.5% as rate of increase in commercial area
CMDA Mixed Residential Change	1.5% as rate of increase in mixed residential area
CMDA Industrial Change	1.5% as rate of increase in industrial area
CMWSSB Number of new wells, reservoirs and desalination plants for an additional capacity of	20% increase in water capacity, storage and supply
CMWSSB Number of new STP is increased to 2	Increase 10% in sewerage management capacity

OUTCOMES FROM THE SIMULATION

In order to simulate the effect of no sustainability programs, improvements to the existing water sources and their capacity was set to 0.

The current installed capacity for water is approximately 0.86 million cubic meters (MCUM) from wells, desalination plants and reservoirs. A 20% increase in the water capacity would require an addition of 0.17 MCUM.

There can be different combinations of different water sources to achieve the increase in terms of the types of water sources. For example, one possibility would be to build an additional desalination plant with the capability of 100-150 MLD. The following table demonstrates what needs to happen, if a single water source was used to achieve a 20% increase in water availability. For this scenario, we use one reservoir and two desalination plants to achieve 150 MLD.

TABLE 5. TYPICAL TYPES OF WATER SOURCES AVAILABLE IN SIMULOGUE

SOURCE TYPE	CAPACITY (MCUM)	NO. TO BUILD TO ACHIEVE 0.17 (MCUM)
Reservoirs	0.2	1
Wastewater Recycling	0.01	17
Desalination Plant	0.1	2

Figure 30 shows the rise in the total population at a rate of 2% (higher than the base simulation run). The increase in the corresponding land-use is shown in *Figure 31* (see following page). The expansion can be as large as an additional 200 sq.km. The increase in overall area is due to the additional demand for land for commercial, residential and industrial activities beyond the as-is scenario levels

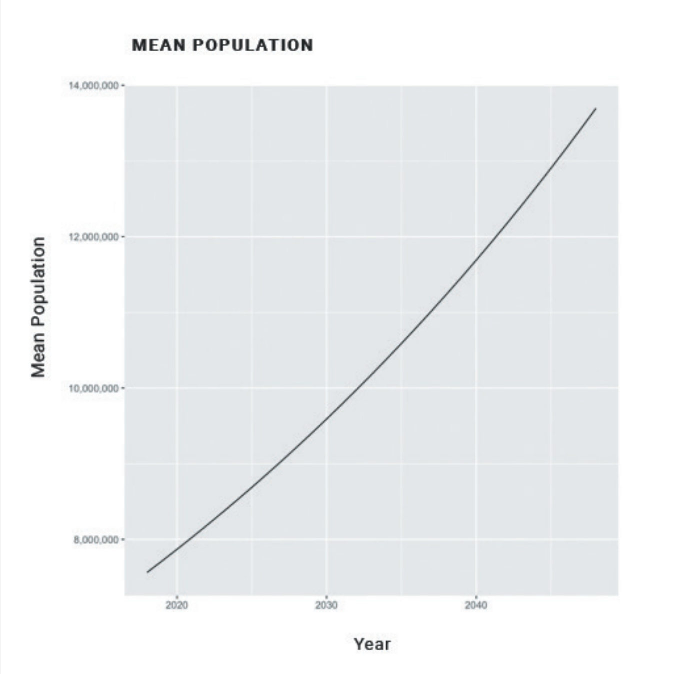

Figure 30. Population rise in the Greater Chennai Corporation from 2018 at 2% per year

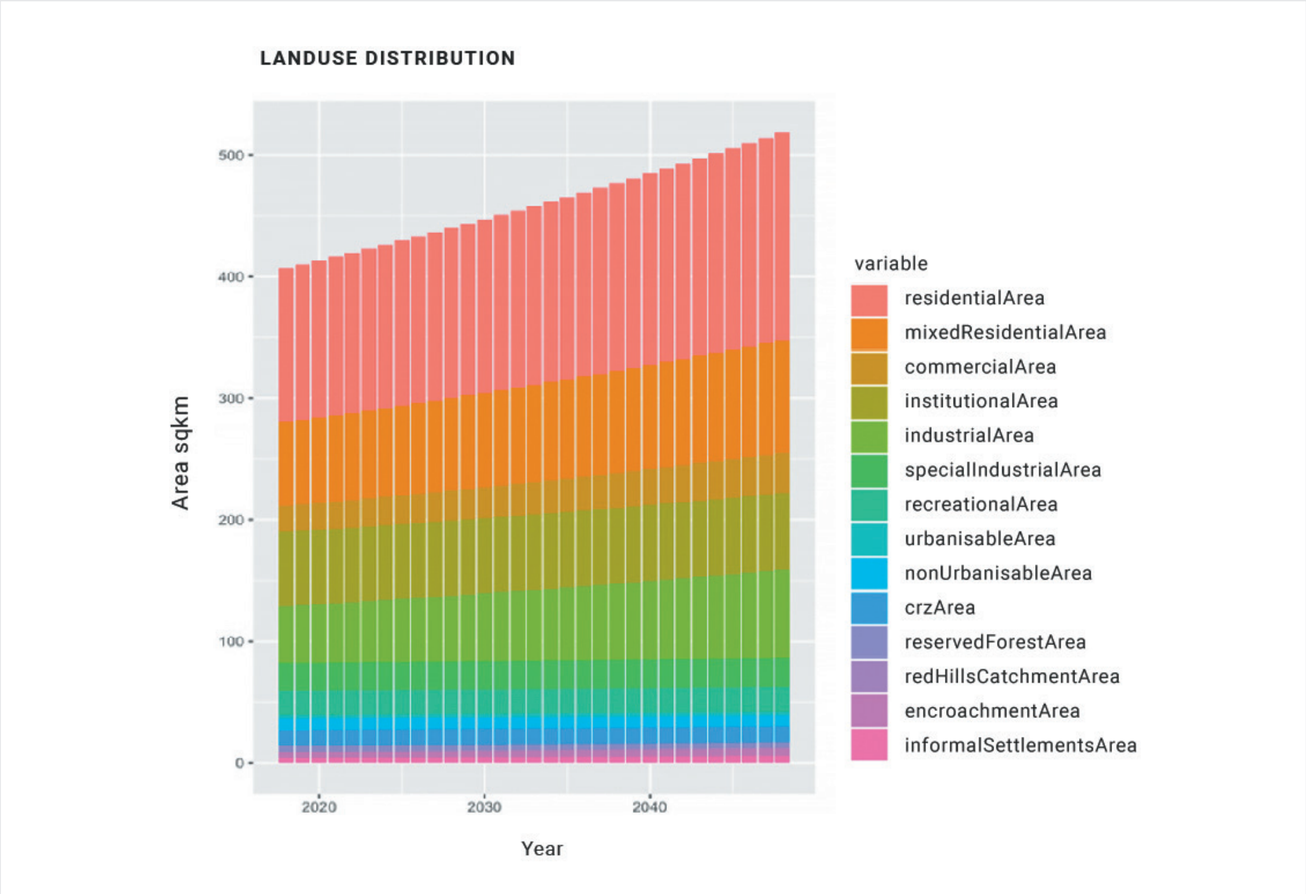

Figure 31. Zone/land-use distribution in Greater Chennai Corporation wards and their annual growth

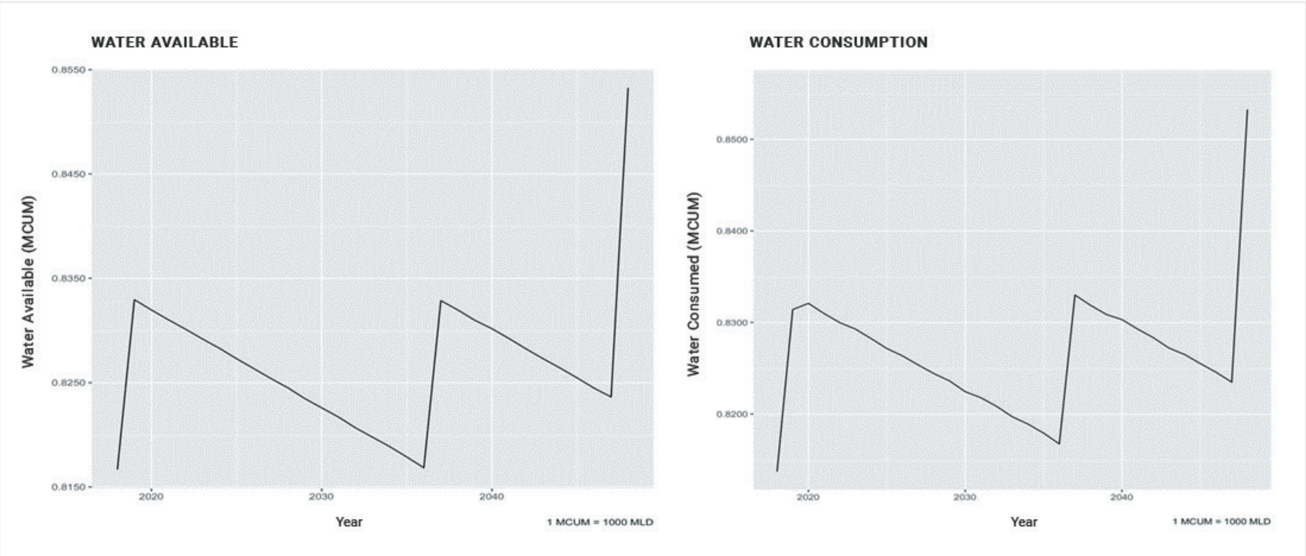

Figure 32. Water available and consumption from Greater Chennai Corporation wards annually

Figure 32 demonstrates that under this scenario all of the water available is consumed by the city.

Figure 33 shows the profile of all the water consumed in Chennai's wards as well as the forecasted water demand at the current level of population growth and increase in land-use.

We see that additional capacity added to increase water capacity does not increase the residual water availability as the amount of population increase has resulted in a corresponding increase in unmet water demand, approximately 500 MCUM by 2030. Thus, any additional capacity is being used to service the increased population.

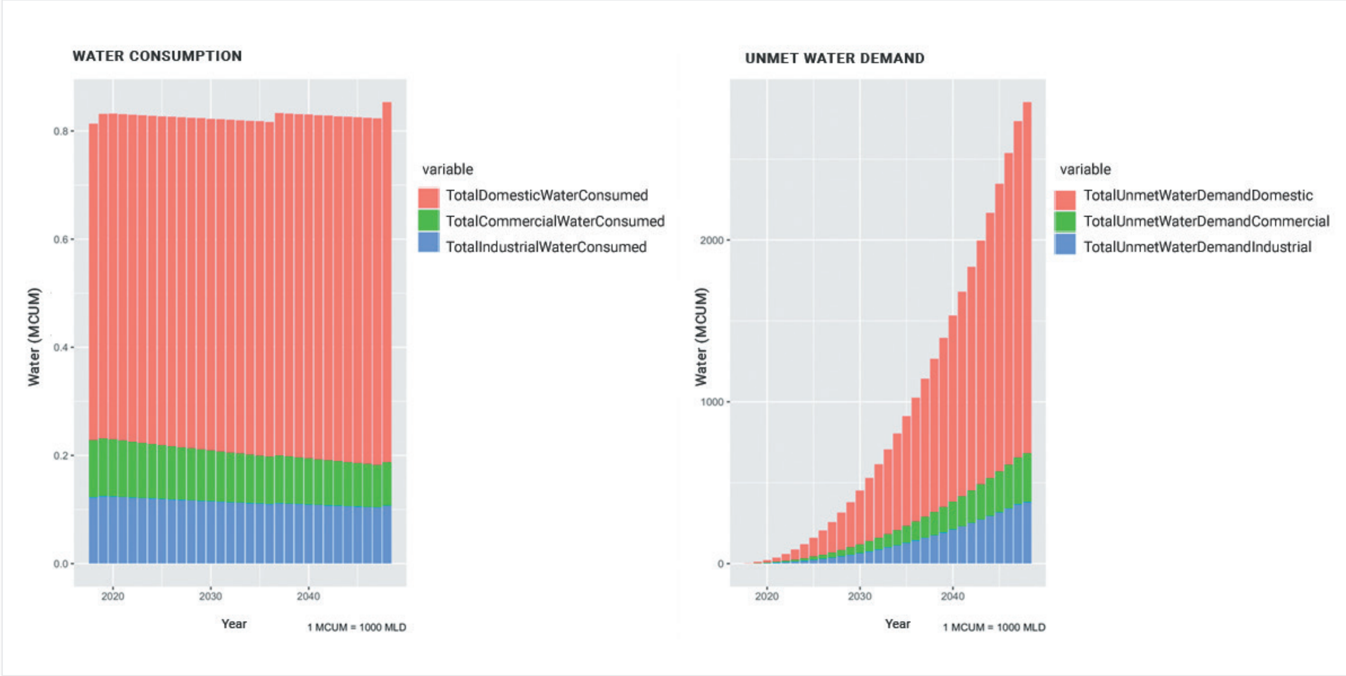

Figure 33. Water consumed and Unmet water demand in Greater Chennai Corporation wards

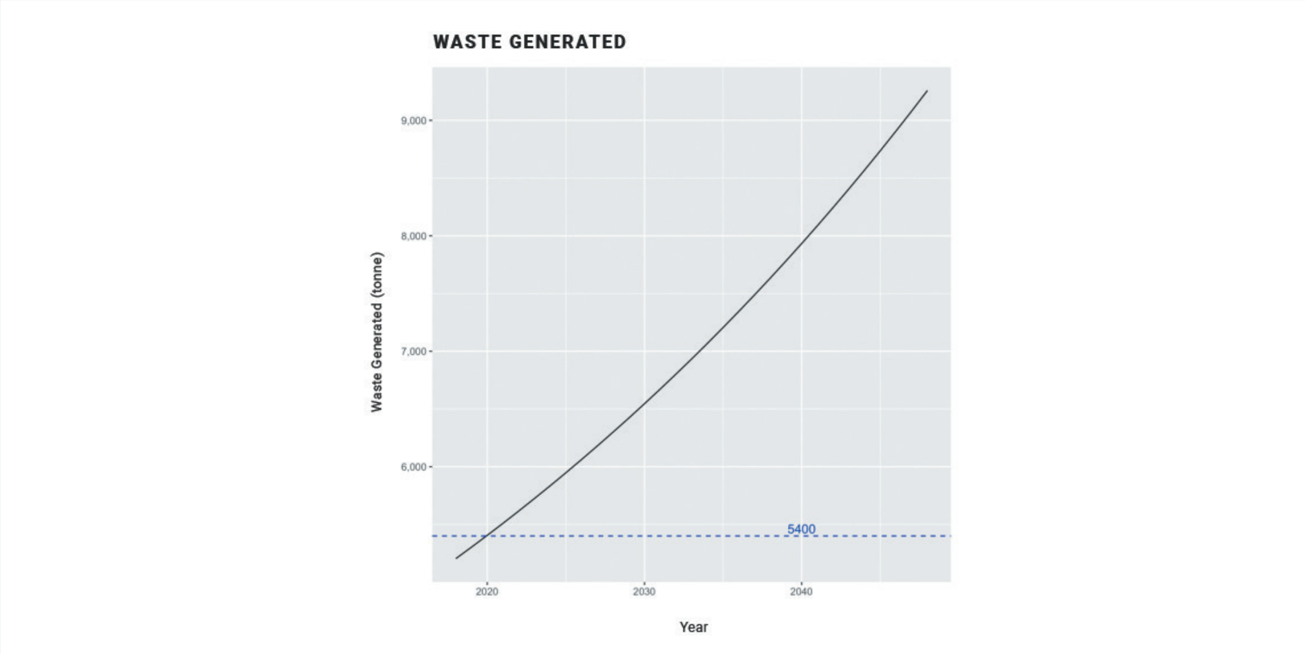

Figure 34. Solid waste generated from Greater Chennai Corporation area annually

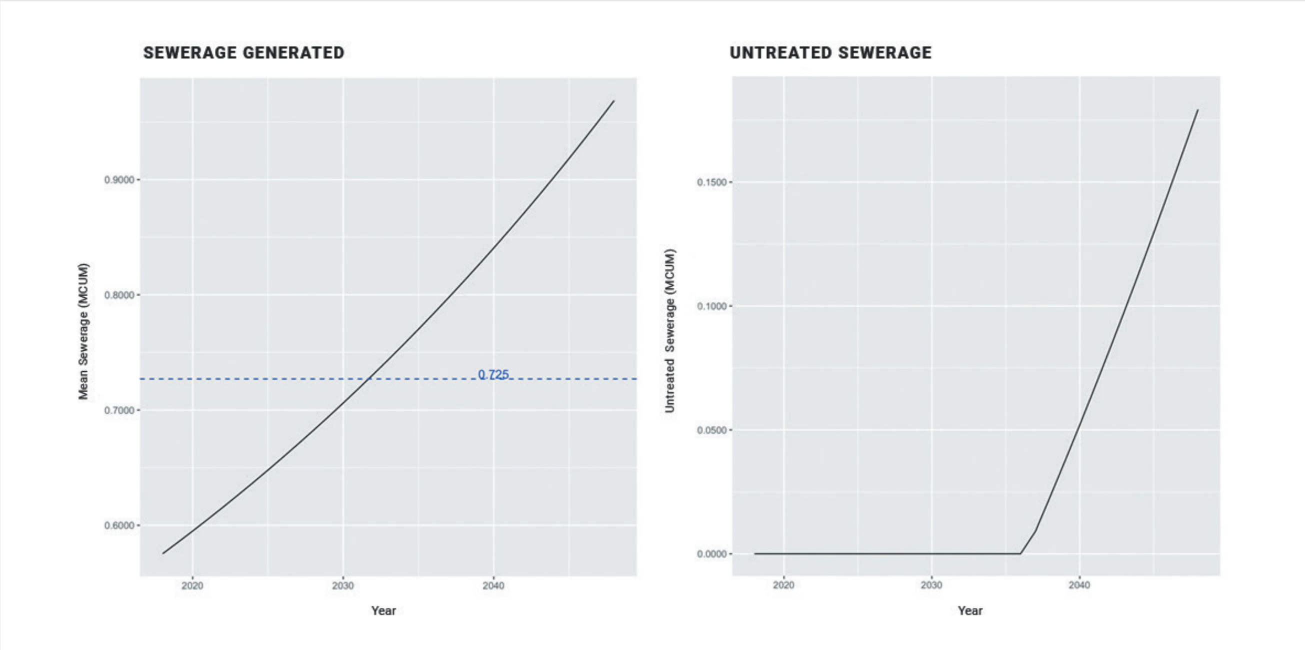

Figure 35. Average sewerage generated and untreated sewerage in Greater Chennai Corporation wards annually

Figure 34 demonstrates the average annual solid waste generated in Chennai. This follows a similar trend to population rise. The solid waste generated is similar to that of the business-as-usual scenario, ***i.e.*** the existing capacity will be exceeded around 2020.

Figure 35 depicts the increase in sewerage due to the increase in population and the corresponding management required. While the existing STP capacity can treat this sewerage for a period of time, post 2030, the quantity of sewerage exceeds capacity resulting in untreated sewerage in this scenario. It is noted that the capacity has exceeded much earlier than in the as-is scenario due to the increase in population.

SCENARIO SUMMARY

Without sustainability initiatives, water demand will rise more rapidly. In this scenario, the unmet water demand by 2030 will be at 500 MCUM – compared to 250 MCUM in the as-is scenario. The capacity for waste management will be reached by 2020 at 5400 tonnes and capacity of sewerage management will be reached by 2030 at 725 MLD respectively. Despite the increase in sewerage management capacity, the increase in population has caused a rise in untreated sewerage. The sewerage management capacity has exceeded much earlier i.e. by 2030, earlier than the as-is scenario due to the increase in population. The increase in population and the lack of conservation programs places a higher demand on water.

FUTURE SCENARIO 2: LOW RAINFALL

With our focus on sustainability initiatives, we simulated a scenario where Chennai and the surrounding area would experience less than normal rainfall. We then estimated the reduction in the amount of water available for distribution, given that low rainfall becomes the norm.

Increasingly urbanised Chennai will plan for new infrastructure to meet the increase in water demand but will also have to adopt water conservation initiatives to mitigate the water demand. This scenario can be translated to the simulation parameters based on the following objectives:

SCENARIO OBJECTIVES

1. *Meeting drinking water supply for all residents and commercial establishments at 90%.*
2. *Population increases at a rate of 1.15%.*
3. *Increased commercial and industrial activities due to increasing urbanisation and hence demand to change the land-use pattern for higher commercial and industrial areas.*
4. *Below average rainfall with lower levels of water in reservoirs and wells.*
5. *Sustainability initiatives are undertaken to conserve water and reduce demand.*
6. *New infrastructure for water, sewage and waste management is planned to meet the increase in urbanisation.*
7. *Increase sewerage management capacity by 10%.*

The simulation was run with following changes to input parameters:

TABLE 6.MAIN INPUT PARAMETERS FOR LOW RAINFALL WITH NEW INFRASTRUCTURE SCENARIO

PARAMETER NAME	VALUE
Population Rise Percent	1.15% as rate or rise in population
CRRT Target Number of Wetland Maintenance	10 programs for wetland maintenance planned
CRRT River Restoration Effort	10 river restoration programs planned
CMDA Residential Change	1.5% as rate of increase in residential area
CMDA Commercial Change	1.5% as rate of increase in commercial area
CMDA Mixed Residential Change	1.5% as rate of increase in mixed residential area
CMDA Industrial Change	1.5% as rate of increase in industrial area
CMWSSB Number of new wells and reservoirs for an additional capacity of	10% increase in water capacity, storage and supply
CMWSSB Number of new STPs is increased	Increase 10% in sewerage management capacity

In order to achieve the 10% increase in water capacity i.e. 0.086 MCUM, 1 new reservoir with capacity of 0.0125 MLD is planned, along with 1 new well with a capacity of 0.07 MCUM. Furthermore, due to a reduction in rainfall, the water sources will not be able to reset themselves to full capacity with reference to 2018 levels. Thus, the replenish percentage parameter was reduced to 50%.

OUTCOMES FROM THE SIMULATION

Figure 36 shows the rise in total population at a rate of 1.15% will mean an overall increase in the total Chennai ward area as shown in *Figure 37*. As in the case of the previous scenario, the increase in overall area is also due to the additional requirement for land for commercial, residential and industrial land beyond the business-as-usual (BAU) levels.

Figure 38 demonstrates the increase in water capacity with additional reservoirs and a well.

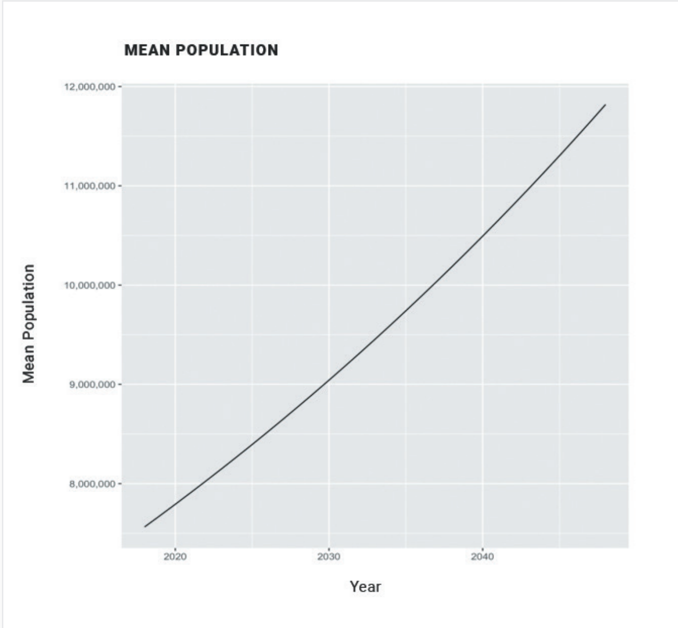

Figure 36. Population rise in Greater Chennai Corporation wards from 2018 at rate of 1.15% per year

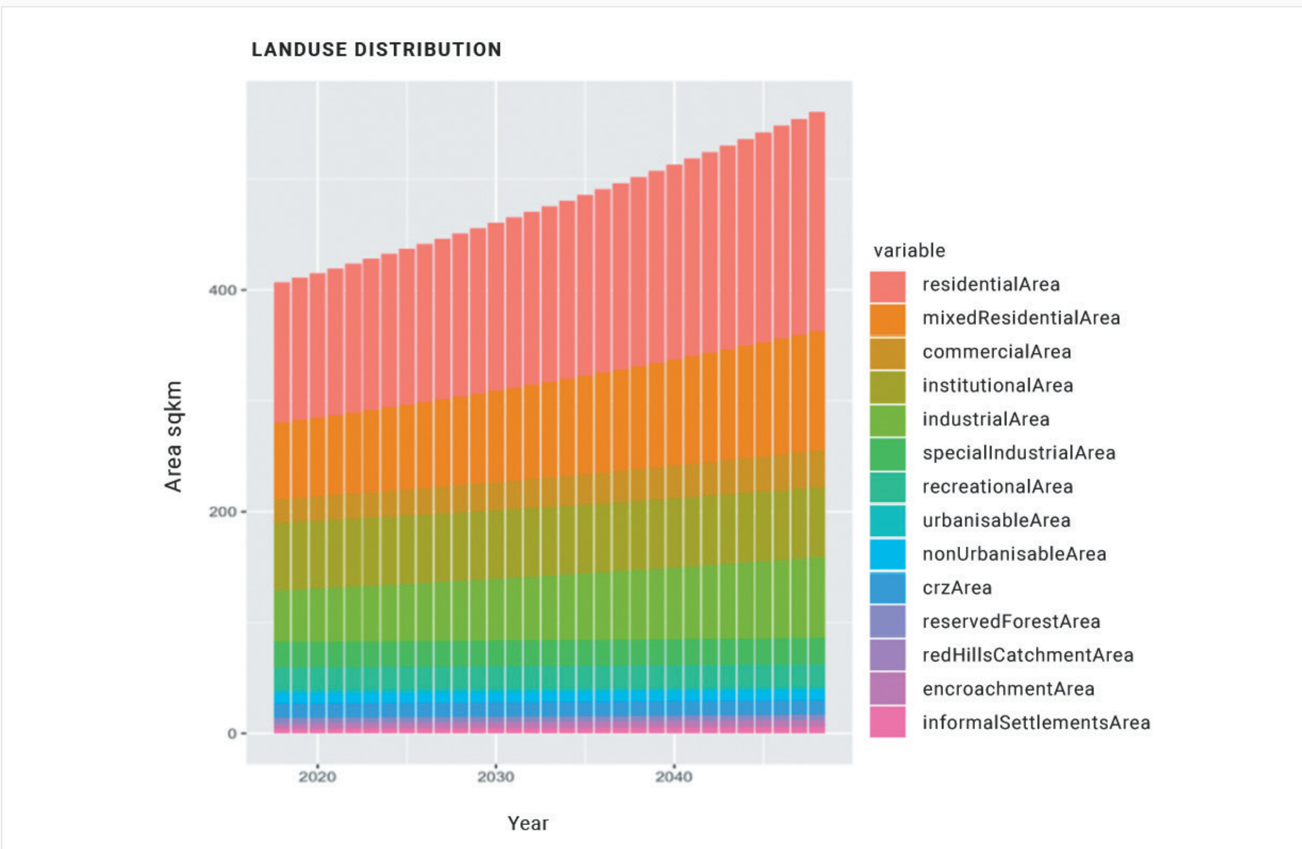

Figure 37. Land-use distribution in Greater Chennai Corporation wards

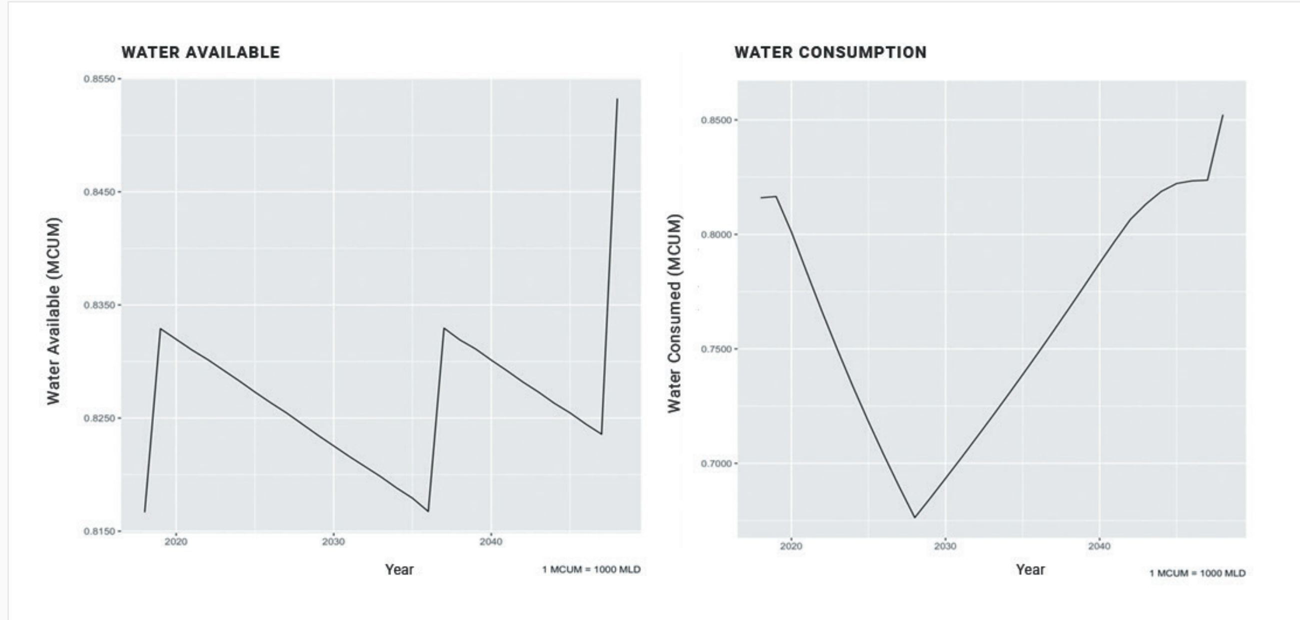

Figure 38. Water available and water demand in Greater Chennai Corporation wards annually

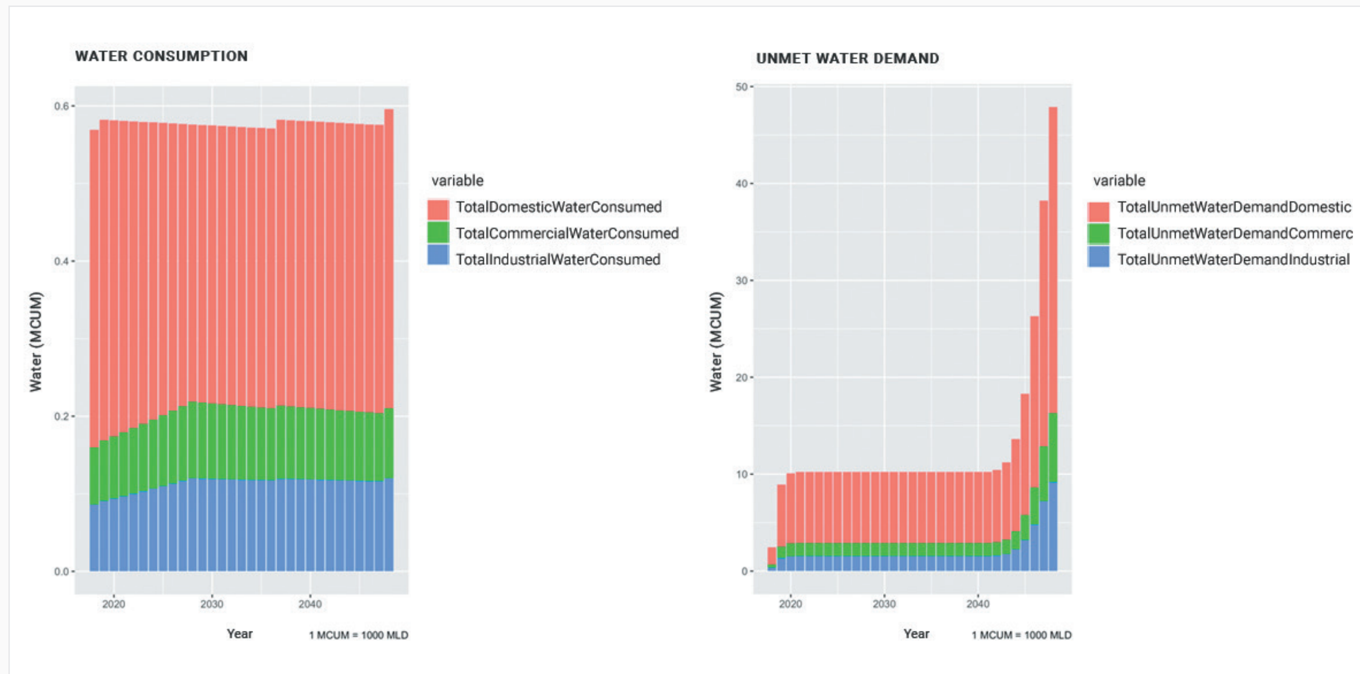

Figure 39. Water consumed and unmet water demand in Greater Chennai Corporation wards

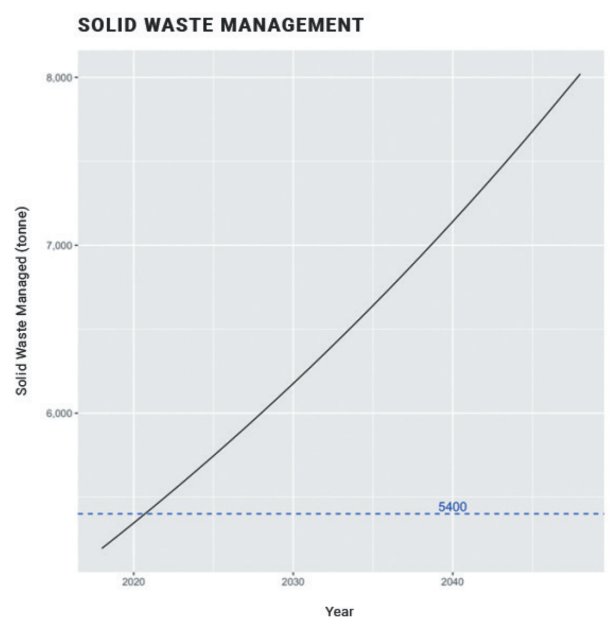

Figure 40. Solid waste generated annually in Greater Chennai Corporation wards

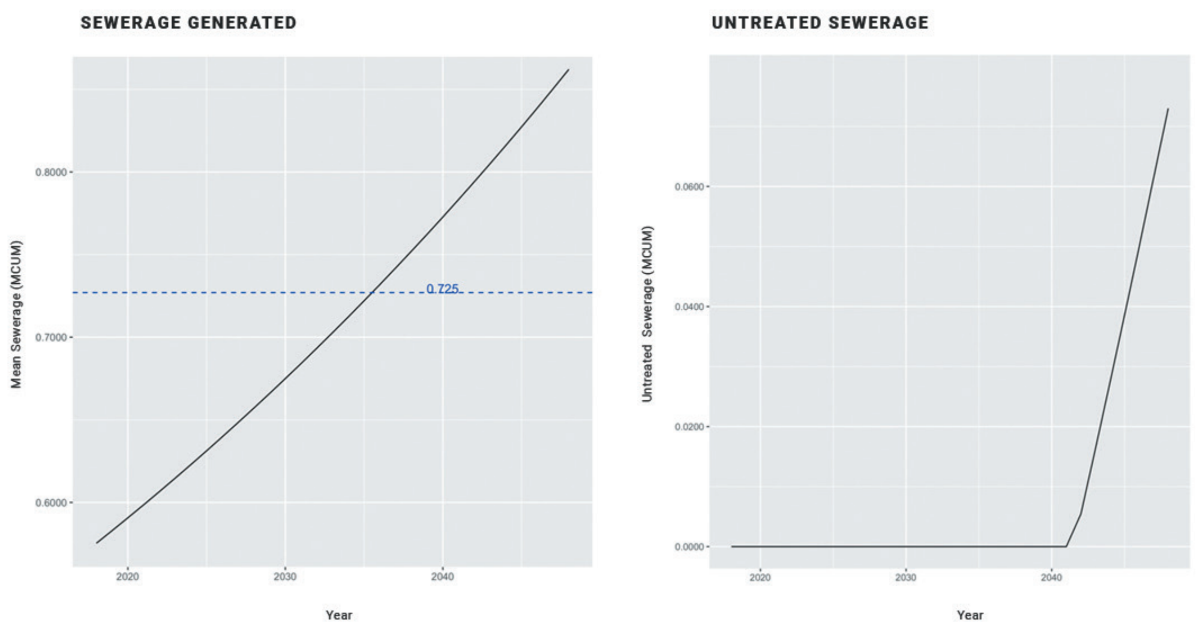

Figure 41. Average sewerage generated annually in Greater Chennai Corporation wards

Figure 39 (see preceding spread) demonstrates water consumption and unmet water demand. In this scenario, CRRT would implement 10 hypothetical water conservation programs. This could be programs such as rain water harvesting, reuse of treated water, water conservation programs, water recharge wells, etc. Each such program has different implementation mechanisms. In order to overcome this, the simulation models the effect in the form of a reduction in water demand. Each such program can reduce the water demand by a set percentage as per the input parameters. Thus, we observe an immediate drop in the water demand, i.e. water consumed. The amount of unmet water demand remains arrested till 2040 to just 10 MCUM. Further, the increase in population and water demand catches up and thus the unmet water demand starts climbing beyond 2040.

Finally, ***Figure 40*** and ***Figure 41*** demonstrate the increase in solid waste and sewage generated and to be managed due to the increase in population. The untreated sewerage does not rise till 2040. This is due to the reduced rate of population rise.

SCENARIO SUMMARY

- *Water conservation programs implemented under this scenario were able to bring down the water demand significantly.*
- *The additional reservoir and one well counter the effects of low rainfall. These measures reduce the unmet water demand to 10 MCUM. Population effects take over only beyond 2040.*
- *The capacity for waste management will be exceeded before 2025.*
- *The additional sewerage management capacity delays the unmet sewerage generation till the end of 2040.*

FUTURE SCENARIO 3:
AVERAGE RAINFALL WITH NO NEW INFRASTRUCTURE

In this scenario we simulate whereby Chennai meets all its waste, water and sewerage services demands entirely by relying on water conservation strategies.

This scenario is designed to look uniquely at existing infrastructure and its maintenance, while we just pursue water conservation initiatives. This scenario can be translated to the simulation parameters based on the following objectives:

SCENARIO OBJECTIVES

1. *Meeting drinking water supply for all residents, commercial and industrial establishments at 90%.*
2. *Population increases at a rate of 1.15%.*
3. *Increased commercial and industrial activities due to increasing urbanisation and hence demand to change land-use patterns for higher commercial and industrial areas.*
4. *Current rainfall levels and current water levels are maintained in reservoirs and wells.*
5. *Sustainability initiatives are undertaken: water conservation projects are implemented.*
6. *No new infrastructure planned for water, solid waste or sewage.*
7. *No additional sewerage management capacity is planned.*

The simulation was run with following changes to input parameters:

TABLE 7. MAIN INPUT PARAMETERS FOR AVERAGE RAINFALL WITH NO NEW INFRASTRUCTURE SCENARIO

PARAMETER NAME	VALUE
Population Rise Percent	1.15% as rate or rise in population
CRRT Target Number of Wetland Maintenance	20 programs for wetland maintenance planned
CRRT River Restoration Effort	20 river restoration programs planned
CMDA Residential Change	1.5% as rate of increase in residential area
CMDA Commercial Change	1.5% as rate of increase in commercial area
CMDA Mixed Residential Change	1.5% as rate of increase in mixed residential area
CMDA Industrial Change	1.5% as rate of increase in industrial area
CMWSSB Number of new wells, reservoirs and Desalination plants for an additional capacity of	0% *i.e.* no additional capacity planned
CMWSSB Number of new STP is same	Sewerage management capacity remains constant

OUTCOMES FROM THE SIMULATION

Figure 42 and *Figure 43* demonstrate the increases in population and area, along with annual land-use patterns.

In this scenario, additional water conservation programs are undertaken to improve the capacity of existing water sources and to promote a reduction in water demand. It is noted that, in this scenario, no new sources of water are developed. The water availability is at the same levels as in Scenario 1.

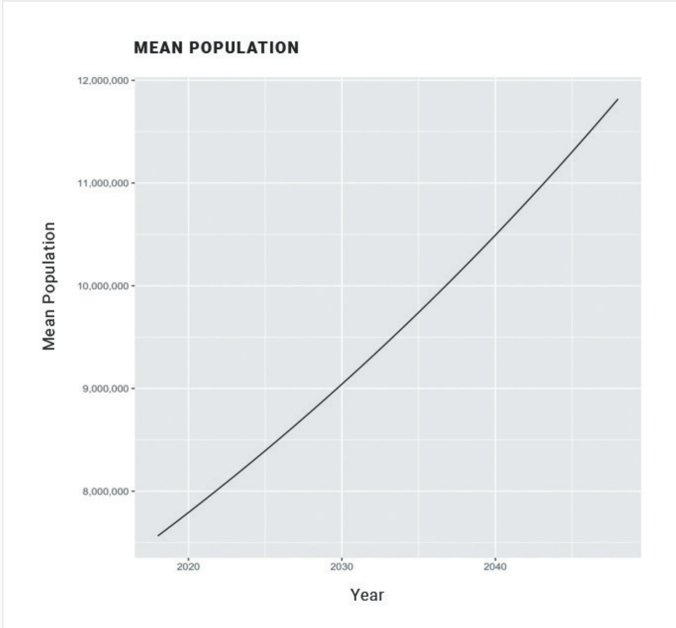

Figure 42. Population rise in Greater Chennai Corporation wards from 2018 at 1.15% annually

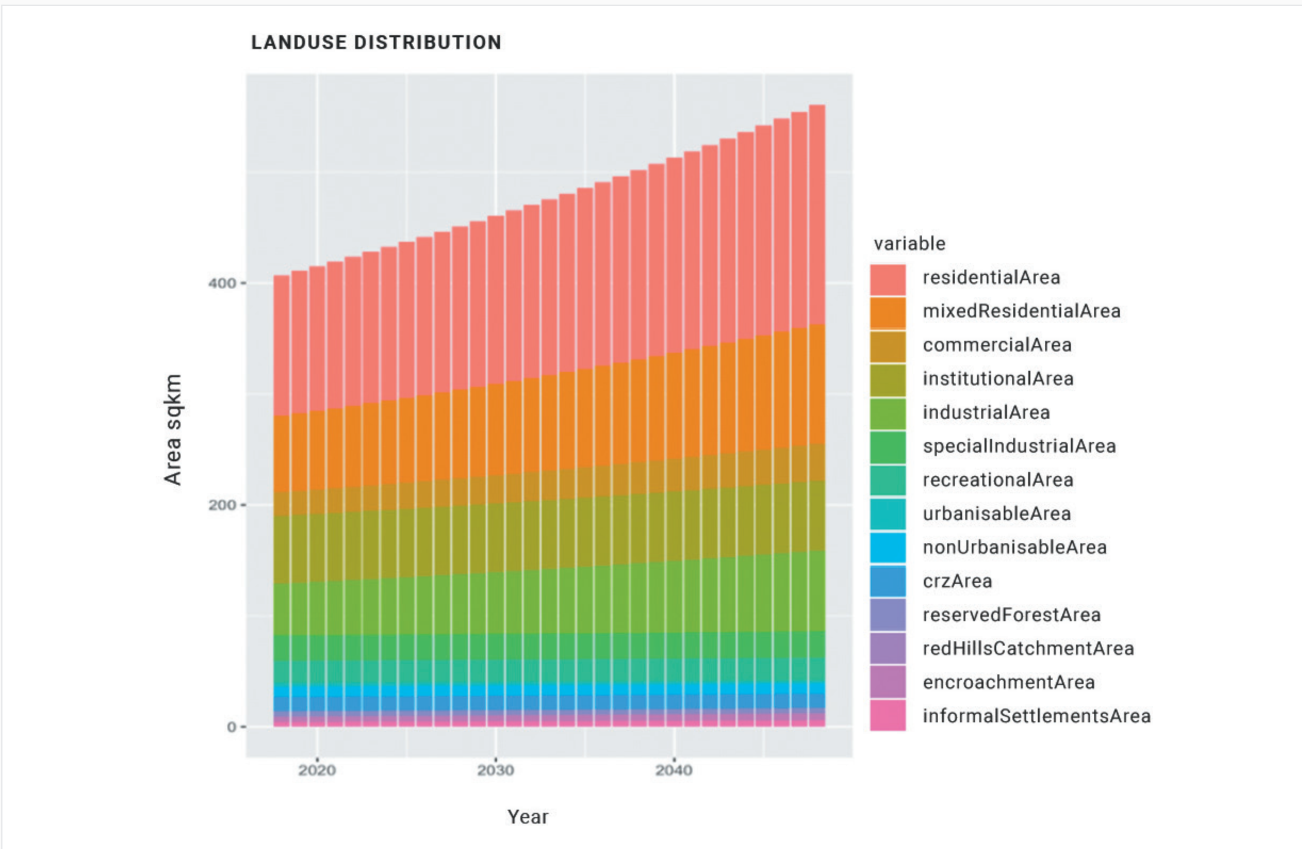

Figure 43. Land-use distribution in Greater Chennai Corporation wards

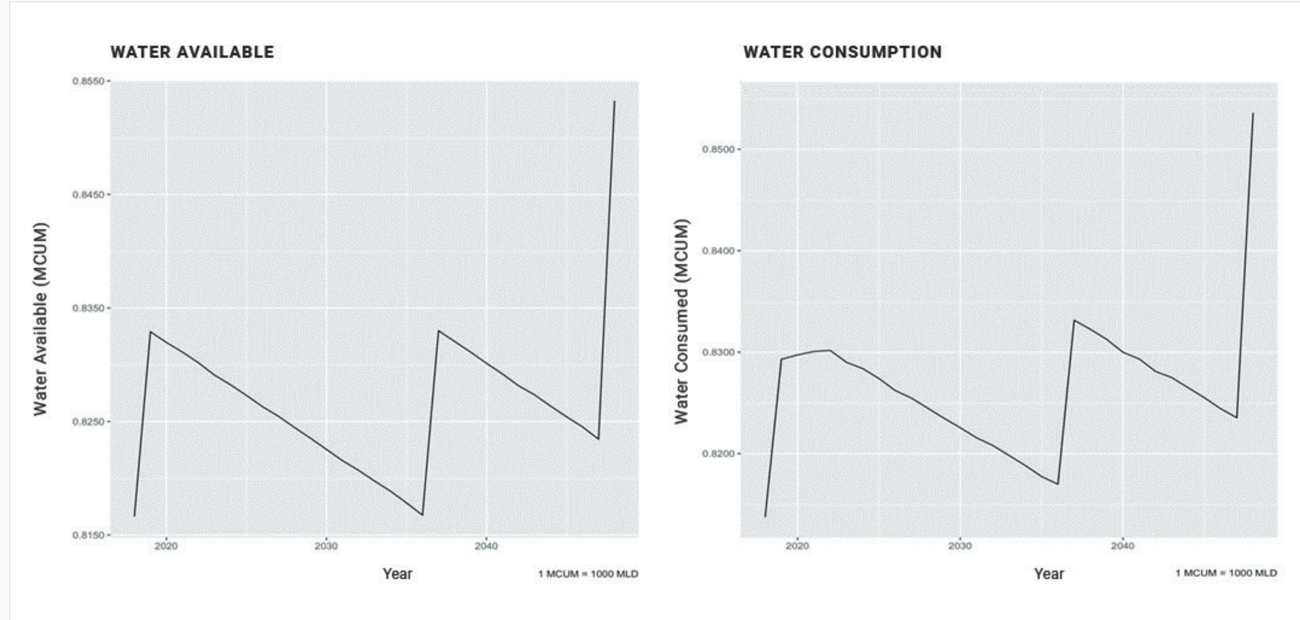

Figure 44. Water availability and water demand in Greater Chennai Corporation wards annually

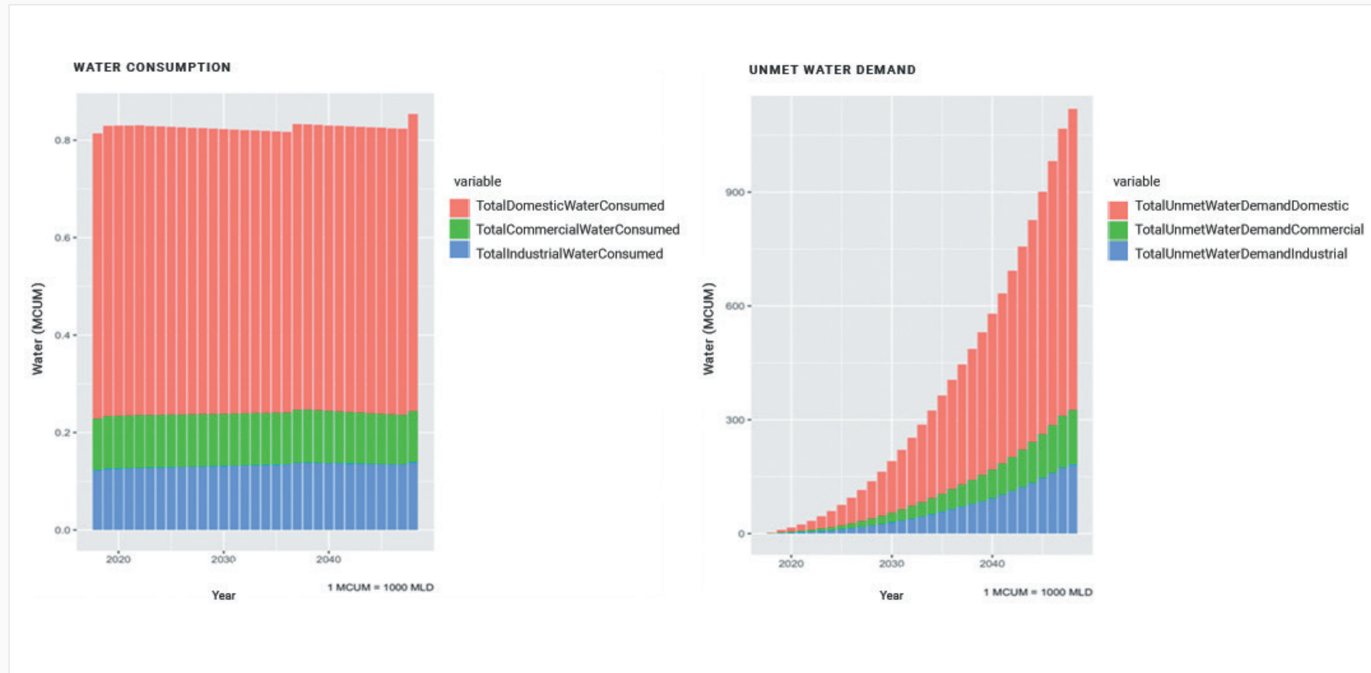

Figure 45. Water consumption and unmet water demand in Greater Chennai Corporation wards

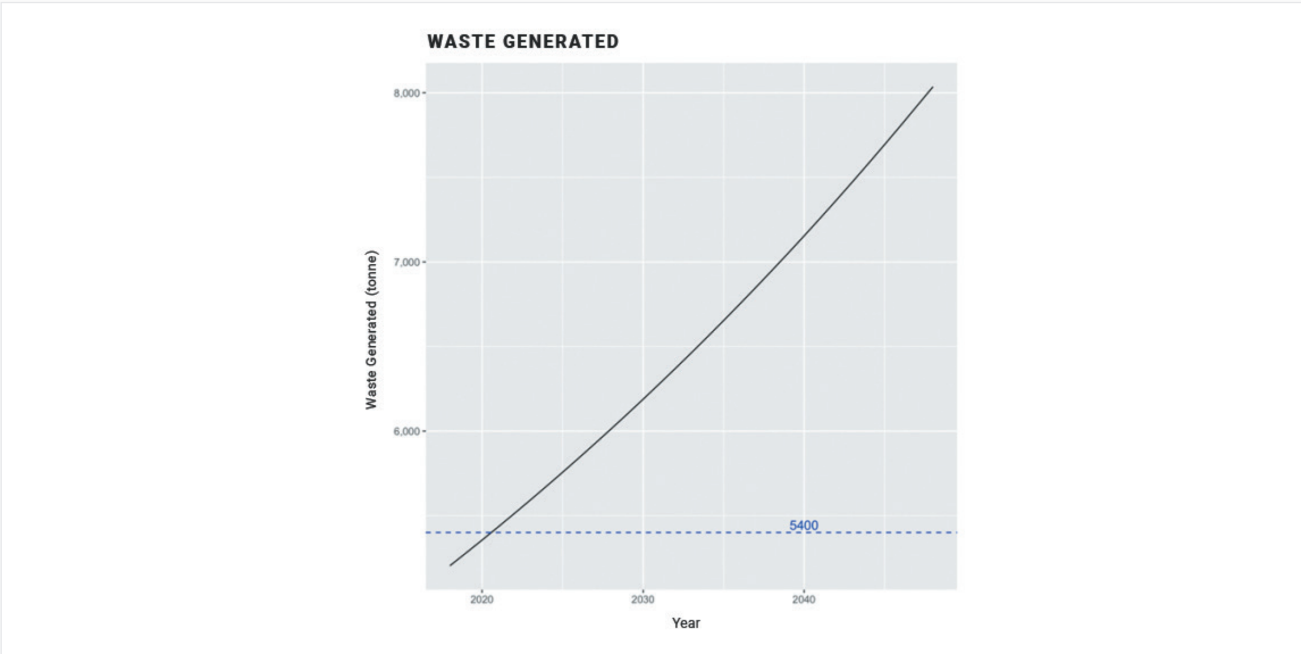

Figure 46. Average solid waste generated in greater Chennai Corporation wards annually

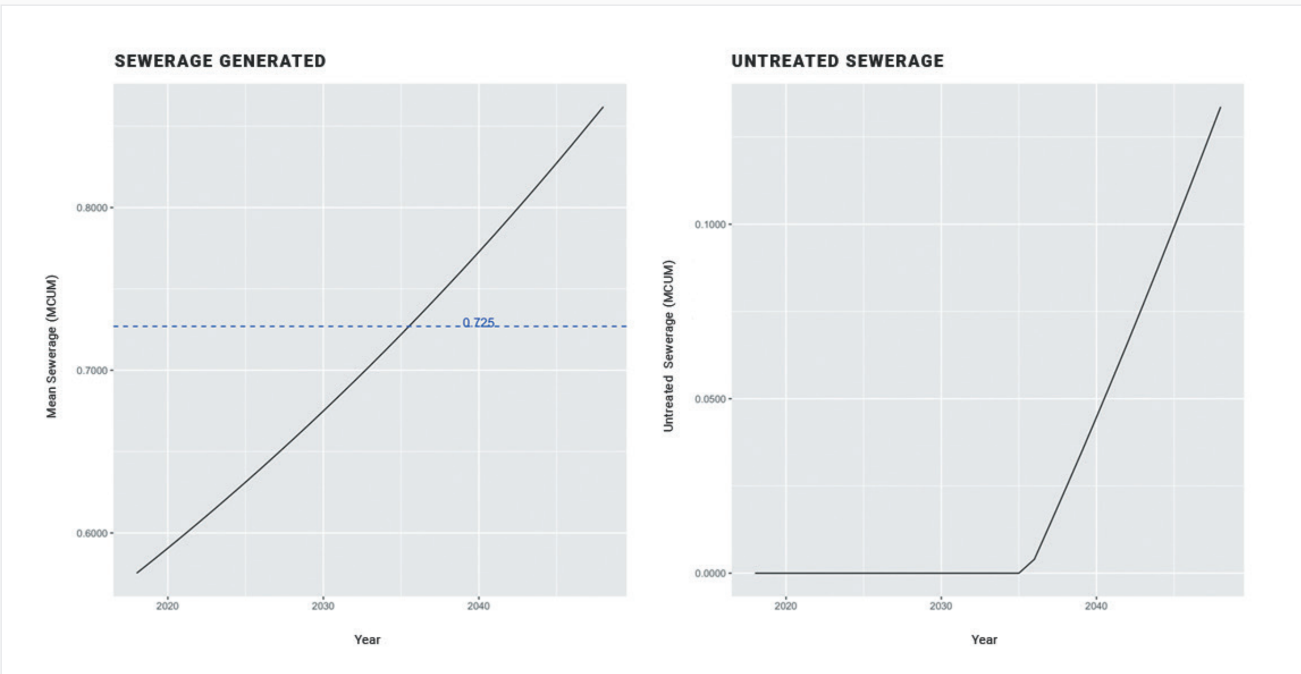

Figure 47. Average sewerage generated annually in Greater Chennai Corporation wards

We observe a reduction in water demand due to water conservation programs as seen in ***Figure 45*** (see preceding spread). The unmet water demand is 150 MCUM in 2030 which is lower than BAU scenario (250 MCUM in 2030), despite no new infrastructure for water. The water conservation programs are similar to those described for Scenario 2

Figure 46 and ***Figure 47*** demonstrate the increase in solid waste management and sewerage due to the increase in population. The trend is similar to Scenario 1, with solid waste exceeding the installed capacity at the end of 2020 and sewerage capacity exceeded by 2035.

SCENARIO SUMMARY

- *Water conservation programs can reduce water demand. The reduction can achieve similar levels of water availability as when new water sources are added, albeit with lower capital expenditure. Low rainfall affects the amount of unmet water demand. It can rise to 150 MCUM by 2030 if no new water sources are created.*
- *The capacity for waste management will be reached at the end of 2020.*
- *The capacity for sewerage management will be reached by 2035.*

OBSERVATIONS FROM ALL SCENARIOS

This section combines some of the observations from all the scenario runs to compare and discuss their outcomes. A few indicative points of comparison between the scenarios are discussed. ***Figure 48*** demonstrates the population rise and the corresponding waste generated in Chennai wards. Each scenario, including Business-as-usual (BAU), Scenario 1, Scenario 2 and Scenario 3, vary certain resource type parameters (such as number of STPs, parks, etc.) while keeping operational parameters (such as maintenance costs) constant. In case of population, the rise rate was kept at 2% rate of increase for Scenario 1 while it was kept at 1.15% for the BAU, Scenario 2 and Scenario 3. The solid waste generated too follows this trend. In ***Figure 48***, the curves for BAU, Scenario 2 and Scenario 3 overlap each other due to the same population growth rate of 1.15% while the population for Scenario 1 grows at 2%. We see a similar effect for the waste generated curves, with BAU, Scenario 2 and Scenario 3 curves almost overlapping.

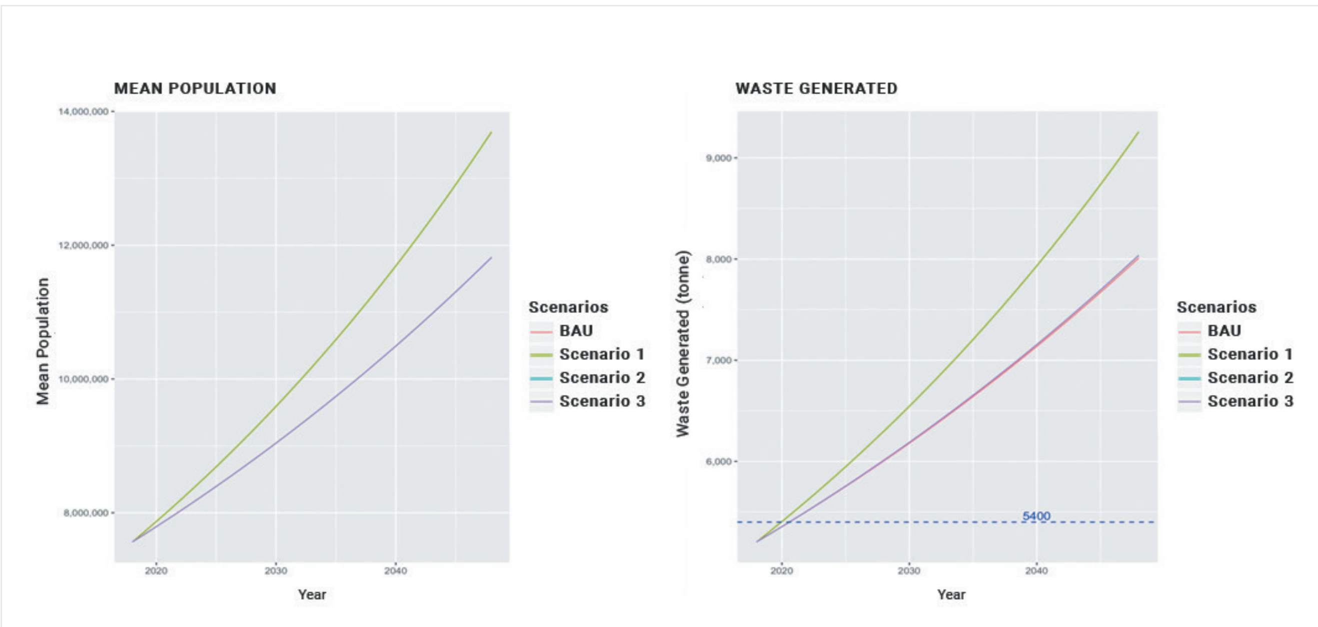

Figure 48. Population and solid waste generated

In case of sewerage generated, Scenario 1 generated the highest amount of sewerage due to a higher rate of population growth. However, Scenario 3 shows an increase in the population without any additional capacity for sewerage management. Scenario 1 and Scenario 2 add additional capacity. We see in ***Figure 49*** that Scenario 2 manages to process sewerage for the longest duration before the installed capacity is overwhelmed.

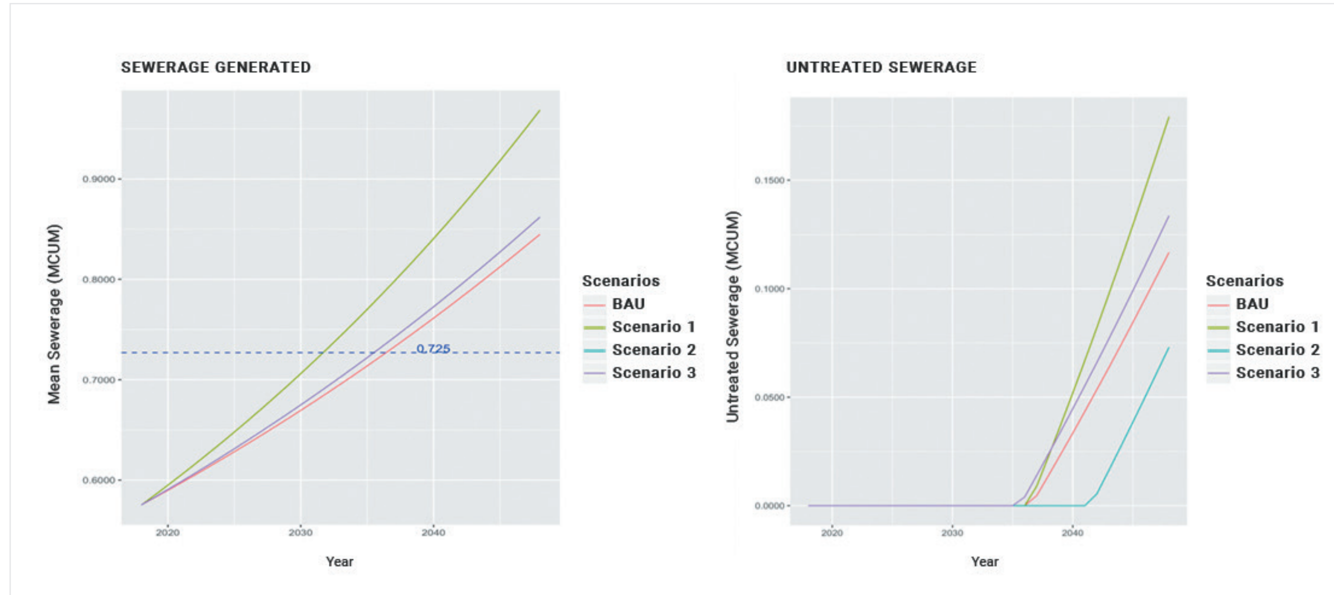

Figure 49. Sewerage generated and unmet capacities

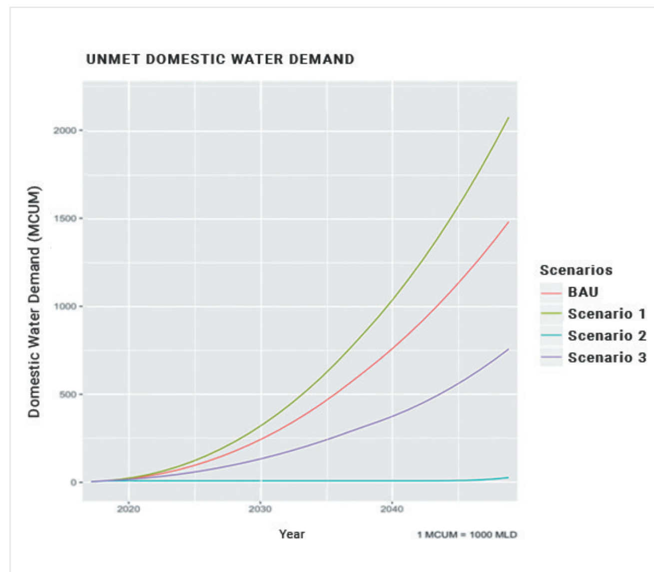

Figure 50. Unmet domestic water demand

In case of water demand, ***Figure 50***, we observe that the lack of any additional water sources creates the deficit in domestic water supplied to rise faster than the business-as-usual scenario.

CHAPTER SUMMARY

A number of potential scenarios can be simulated using this tool. Only a few have been discussed here to demonstrate the capability of the tool and to indicate that it can be used for policy and planning purposes. The simulated scenarios here indicate that, unless they are augmented, the solid waste management capacity and sewerage management capacity will be reached within the next decade as populations increase. This is separate from any new additional capacity that may be planned. Water conservation and water source maintenance is as important as developing new water sources. It is observed that they are able to produce similar levels of water availability with less infrastructure investment. Thus, future strategies for water security will need to consider both water conservation measures as well as new infrastructure.

The table alongside summarizes the scenarios modelled and their outcomes.

TABLE 8. SUMMARY OF ALL SCENARIOS

SCENARIO	OBJECTIVES	KEY LEARNINGS
NO SUSTAINABILITY INITIATIVES	*Testing the effect of no sustainability initiatives on the overall water demand and ability of current resources to develop new sources and cope with water demand*	Without sustainability initiatives, water demand will rise more rapidly. In this scenario, the unmet water demand will be at 500 MCUM by 2030, compared to 250 MCUM in the as-is scenario.
		The capacity for waste management will be reached by 2020 at 5400 tonnes and capacity of sewerage management will be reached by 2030 at 725 MLD. Despite increases in sewerage management capacity, the increase in population causes the rise in untreated sewerage before 2035.
		The population increases combined with no conservation programs places higher demand on water.
		The sewerage management capacity is exceeded much earlier by 2030, compared with the as-is scenario. This is due to the increase in population.
LOW RAINFALL	*Testing the effect of low rainfall (and hence low capacity of reservoirs and other rain-fed water sources) on the ability to meet water demand with new water sources*	The additional reservoir and one well counter the effects of low rainfall. They reduce the unmet water demand to 10 MCUM. The effects of population increase take over only beyond 2040.
		The additional sewerage management capacity delays the onset of unmet sewerage generation till the end of 2040.
AVERAGE RAINFALL WITH NO NEW INFRASTRUCTURE	*Testing the effect of low rainfall on ability to meet water demand by making use of existing water sources only*	Water conservation programs can reduce water demand substantially, thus reducing the unmet water demand compared to BAU or Scenario 1. While scenario 2 seem to achieve maximum reduction in unmet water demand, similar results can be achieved with less capital expenditure by increasing the number of sustainability programs.

CHAPTER 8: COMPARISON OF TRADE-OFFS IN SCENARIOS

Egmore Railway Station | © M Shyam

CHAPTER 8:
COMPARISON OF TRADE-OFFS IN SCENARIOS

Planning exercises are long processes with multiple stages and domain experts preparing Detailed Project Reports (DPRs). An integrated approach to planning requires all agencies to collaborate closely. Furthermore, due to the increasing speed of urbanisation, a more rapid and responsive approach to planning is required, where it is possible to discuss broad parameters before beginning to prepare the DPRs.

In the previous chapter we discussed how to generate different scenarios and then translate them into specific input parameters. Simulogue is built to be a collaborative tool. Each scenario demonstrated in the previous chapter is an overall vision for Chennai which combines individual agency mandates and objectives.

The simulation tries to identify different "paths" to achieve all the objectives for a given agency. Each such path is a range for different planning parameters for each agency.

The agencies can then negotiate with each other to arrive at a holistic set of planning objectives for Chennai. Such a plan would not be as granular as DPRs but would provide a common frame for every agency in Chennai involved with water, waste and sewerage to work with.

In this chapter we employ Simulogue to run a global scenario. A global scenario would allow us to tweak all possible parameters to create a plan, i.e. all infrastructure is under control. Thus, when creating a global scenario, we can tweak the data for water resources, sewerage management and waste management together as a single plan. (In normal cases, just the parameters under the control of a given agency using the tool are available for planning. For example, only water supply and sewerage infrastructure is available if CMWSSB is the agency using the tool).

We then discuss the output from the scenario and provide broad recommendations. For this exercise we ran Simulogue with the objective of maintain basic services, i.e. provision of drinking water and building enough capacity to manage a population growth of 1.15% as per the NSSO estimates. As part of the development of the tool and the research exercise, we conducted multiple stakeholder workshops with different agencies in Chennai. Based on the discussions and feedback from the stakeholders we estimated the range of different parameters. The complete list of all parameters that were varied along with their range of variations is presented in ***Appendix 3***.

We estimate modest increases in infrastructure while continuing to stress conservation programs for water and ecologically sensitive areas. We analyse the various paths and then provide some recommendations.

In ***Chapter 6*** we described the BAU scenario. In ***Chapter 7***, we described and demonstrated various scenarios towards the use of developing new infrastructure and running conservation programs in the backdrop of increasing population and water demand. It must be noted that these scenarios were undertaken for demonstration purposes and the simulation allows for the development of a number of alternative scenarios based on variations in input parameters. Agencies can change their goals and objectives and re-run a series of 'what-if' scenarios based on this platform.

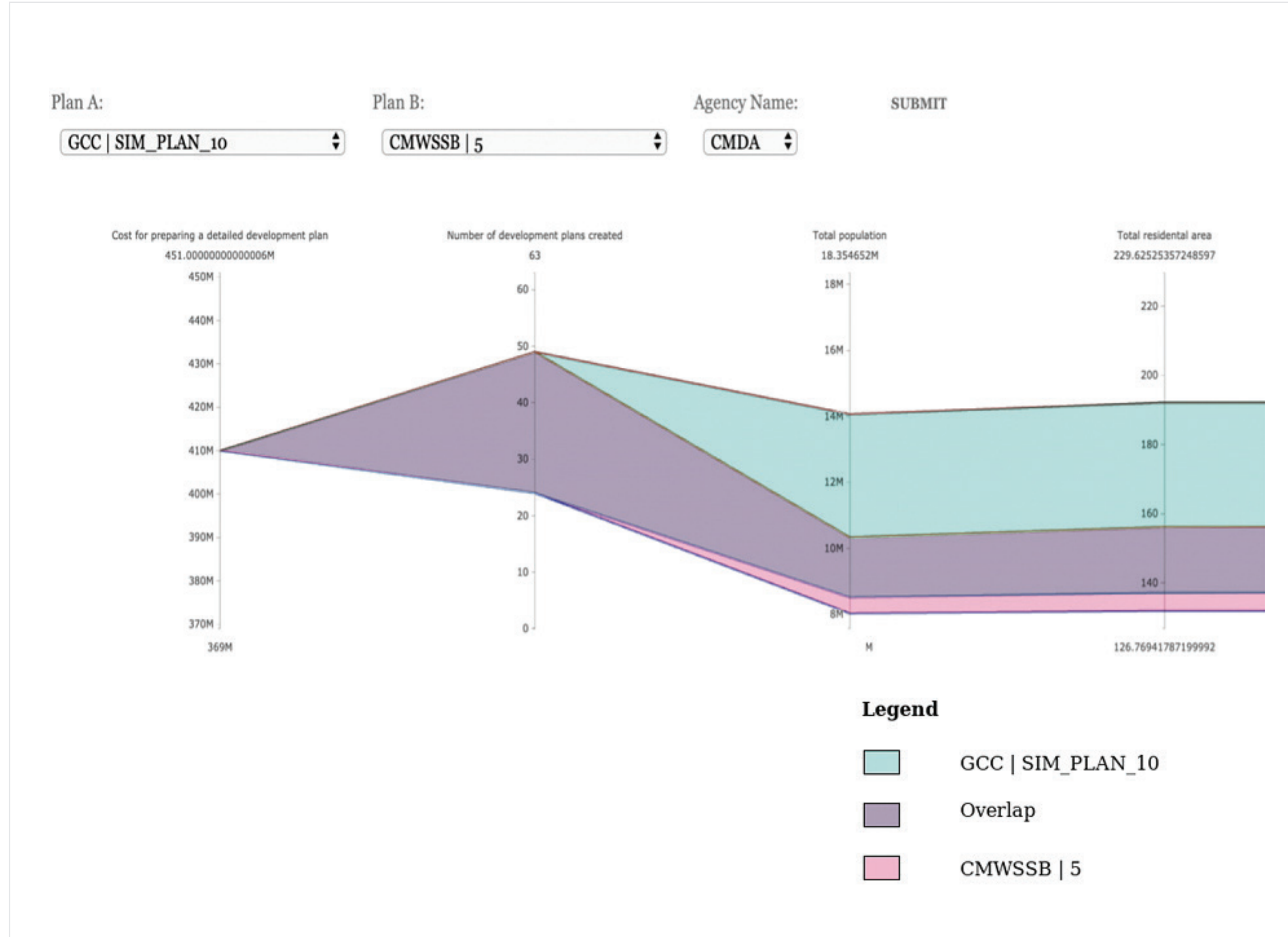

Figure 51. Interface to generate parallel coordinate graphs

By studying multiple strategies for development at once, we will be able to identify trade-offs between the strategies to achieve the scenario in terms of specific parameters. For example, ***Scenario 2*** and ***Scenario 3*** in ***Chapter 7*** described the increase in water availability through two approaches. In one approach, there was a lot of new infrastructure built while in the second approach, water conservation programs and maintenance operations were undertaken. In both cases it was possible to increase the water availability. However, each approach came with its own advantages and constraints. New infrastructure requires capital spending in the short term but can achieve more water availability. Conservation programs do not require capital investment and can efficiently use the available infrastructure, freeing up the capital for future development, but may be more challenging to implement and regulate.

In order to visualise the trade-offs, Simulogue was run by varying individual parameters within a given range. For example, the population increase rate was varied between 1.5% and 3%, in steps of 0.5%. This will produce three runs, in which, while all the other parameters are constant, the state of Chennai's development can be observed with three levels of population increase.

By repeating this process for all relevant parameters, we are able to study the simulation runs and observe the range of possible values that each parameter can take. Different parameters for each such run can be represented using parallel coordinate graphs.

We choose this method as:

1. The parameters are at different scales.
2. Parameters belong to the same simulation run but are not related to each other. For example, the number of wells and the amount of area zoned under industrial may not have any relation with each other but are part of the same scenario.
3. It is convenient to display the range of possible values for each parameter and how they would affect other parameters.

The outcome from the simulations is displayed with the use of parallel coordinate graphs[11].

Each of the scenario (or planning) parameters can be assumed to be a dimension along which we would like to compare different plans. Thus, a plan can be considered a multi-dimensional line. Multiple plans can then be compared with each other using a parallel coordinate graph which is used to visualise multi-dimensional parameters.

Figure 51 (preceding page) shows the Simulogue's interface that is used to generate parallel coordinate graphs to compare between different plans. As the number of parameters is large and not all parameters may be of interest for all agencies, there is a means to filter out the parameters of interest for each agency. The figure represents all possible values that are valid to achieve Plan A and Plan B.

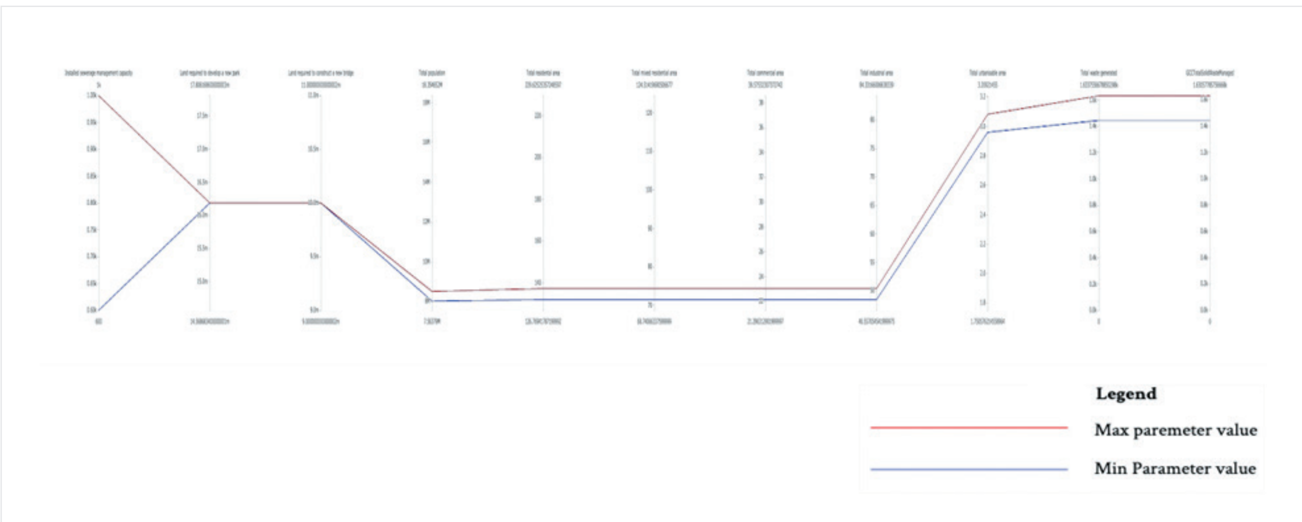

Figure 52. Waste management aspects for the Greater Chennai Corporation area simulation context

11 Alfred Inselberg. 2000. Visualizing high dimensional datasets and multivariate relations (tutorial AM-2). In Tutorial notes of the sixth ACM SIGKDD international conference on Knowledge discovery and data

The area which overlaps all along the parameter axes are valid values which indicate the desirable values of parameters for all agencies. Thus, by using values within the overlapping range, agencies can mutually agree on plans.

The diagrams below and alongside demonstrate the scenarios generated for a different planning objective.

Figure 52, ***Figure 53*** and ***Figure 54*** demonstrate the different scenarios for the entire simulation context i.e. for studying the Greater Chennai Corporation area for water, sewerage and solid waste management, given rise in population and land-use. The simulation accounts for all the parameters that are identified and modelled.

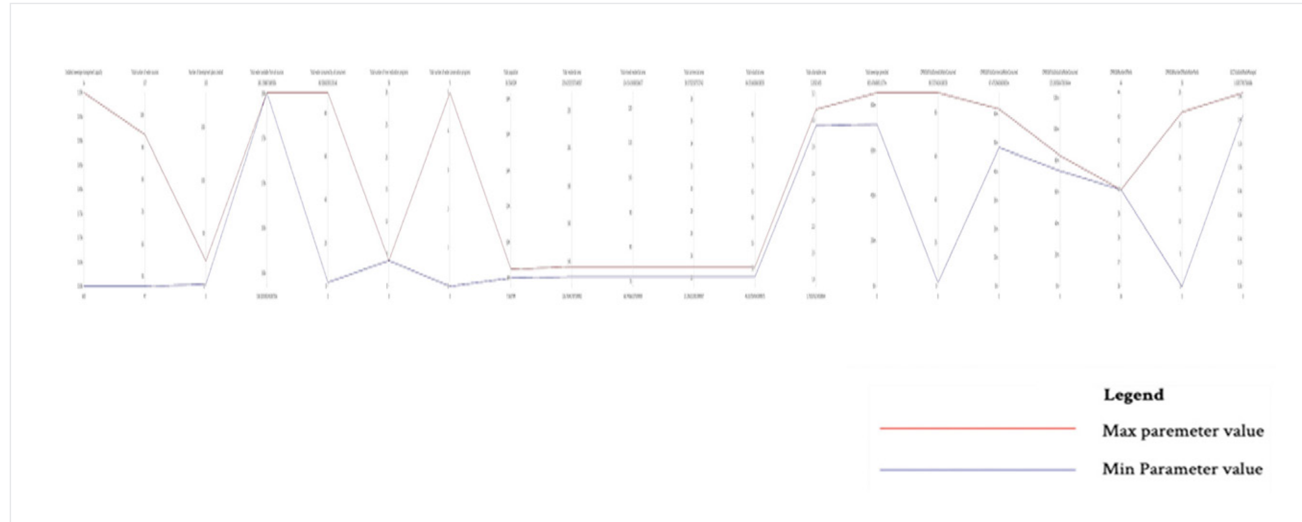

Figure 53. Water source development aspects for the Chennai metropolitan simulation context

Figure 54. Land-use/Zone development aspects for the Greater Chennai Corporation simulation context

The outcomes are represented on a parallel coordinate system with maximum and minimum values that can be assigned to each parameter represented by red and blue lines respectively. Thus, unless there is an overlapping straight line, values between the red and blue lines for each parameter are valid to achieve the final scenario objective. Each value can then be chosen based on each agency's preferences and trade-offs.

For example, consider the section represented for water source infrastructure development as shown in ***Figure 55***.

For the given scenario, one can build anywhere between 0 - 28 waste-water recycling plants while maintaining the solid waste management levels between 1400 tonne – 1600 tonne. Any value beyond these would not lead to a valid scenario.

Similarly, ***Figure 56*** co-represents the water consumption levels to be maintained and number of water conservation programs that need to be carried out to complete the current development scenario as described in ***Appendix 3***. In a similar vein, ***Figure 57*** co-represents waste and sewerage generation.

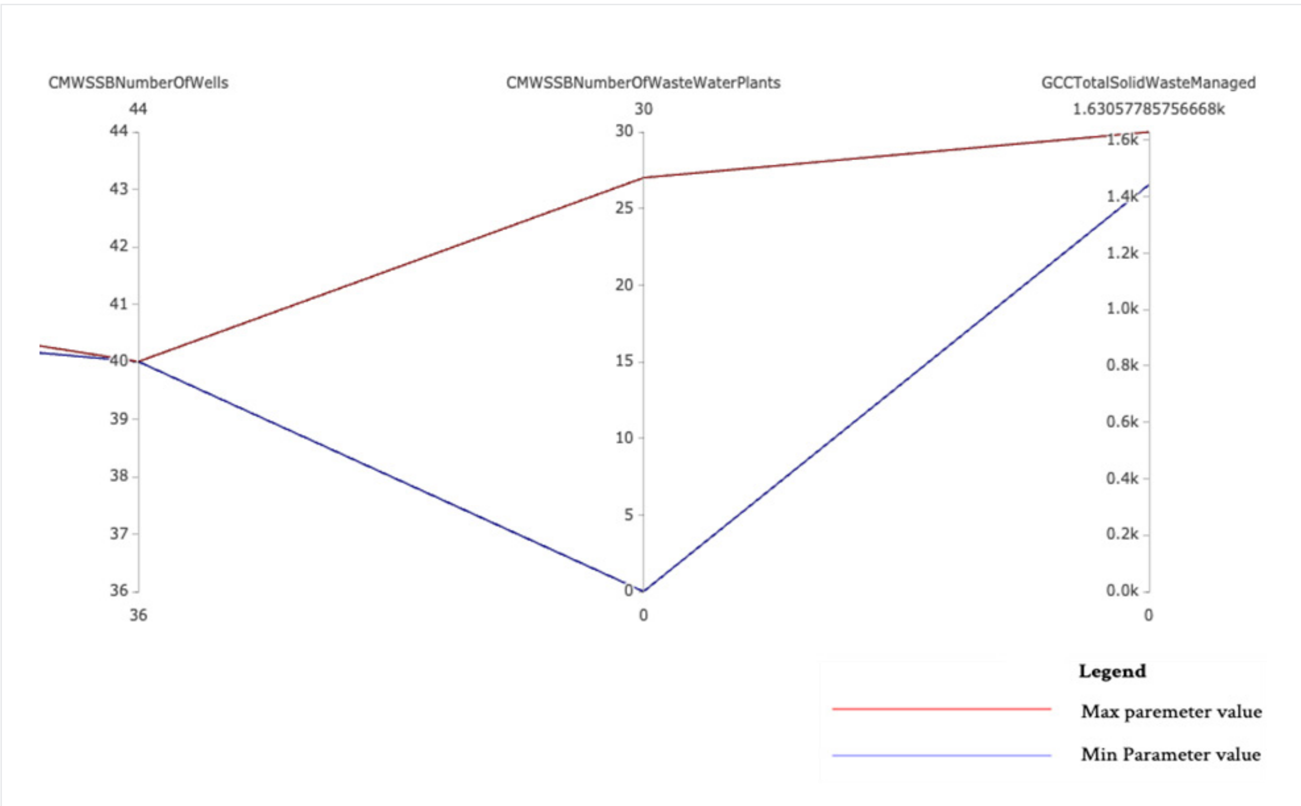

Figure 55. Section from outcomes plot representing water source infrastructure development

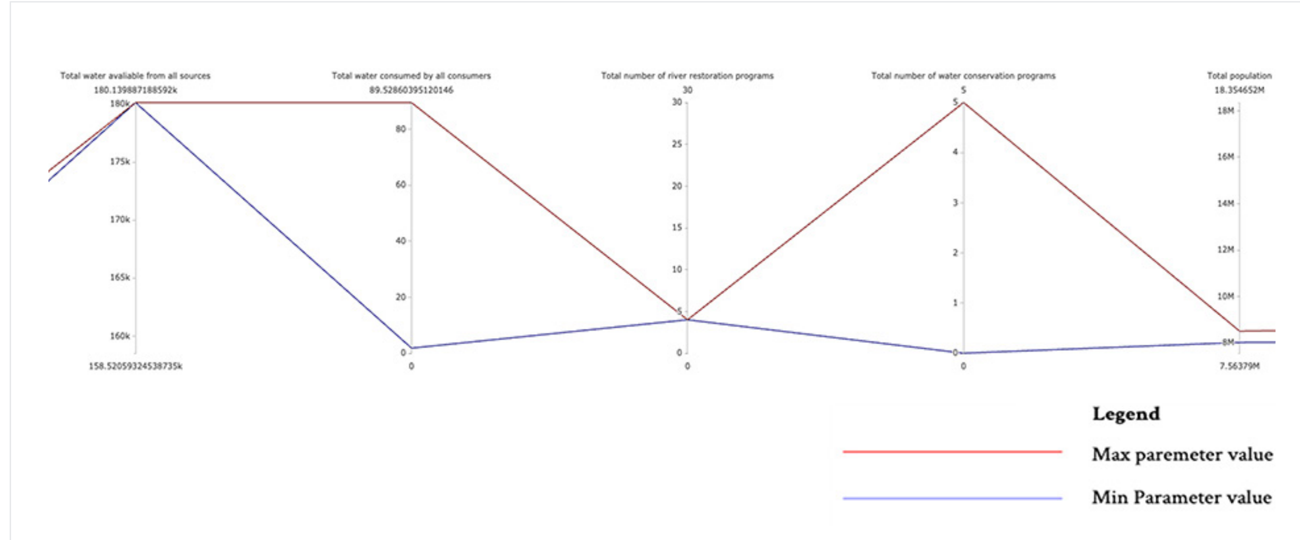

Figure 56. Section from outcomes plot representing water consumption and conservation programs

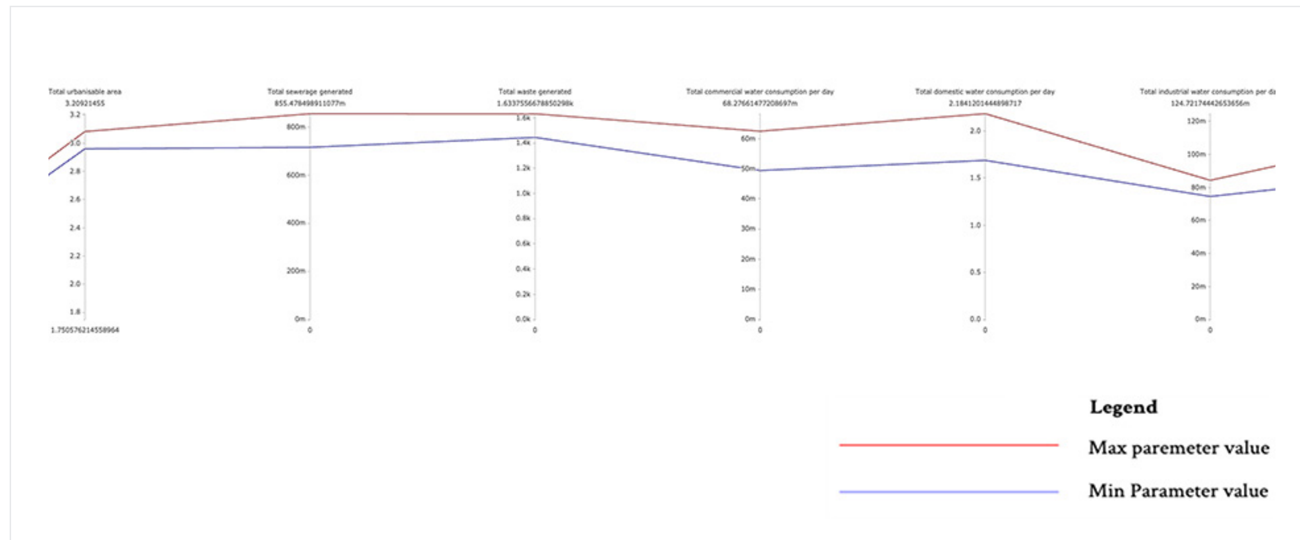

Figure 57. Section from outcomes plot representing waste and sewerage generation

FUTURE MODIFICATIONS TO SIMULOGUE

The simulation tool has a number of new features being implemented for the first time.

1. ***The simulation tool combines quantitative data and qualitative data in a single tool:*** The Simulogue simulation tool was developed with different stakeholders along with traditional data modelling. The project employed multiple structured stakeholder workshops to map interactions between Chennai's urban agencies involved with urban planning, specifically those involved in planning for water, sewerage management and solid waste management.

2. ***The simulation accounts for Chennai's governance structure:*** Traditional land-use based simulation, while using cellular automata-based models or ABMs, use very similar planning parameters that measure the types of land-use, population resources, etc. In this simulation tool we incorporate Chennai's governance structure, which ultimately affects the year-on-year changes in these parameters as well as the implementation of plans generated. This is done because:

    a. The speed and the scale of urbanisation in the Indian context affect planning requirements more rapidly than in cities in other parts of the world. For example, master plans are prepared for five to ten years in the future. However, by the second or third year, the rate of population rise in many Indian cities (resulting both from births and migration) is high enough to distort the targets that were set during the master plan process. This compels planning organisations to update and change their planning and implementation strategies.

    b. The speed of response to urbanisation is considered to be slow in most Indian cities. In this simulation we intended to study not only the plans but the constraints under which the plans will be implemented. This would allow us to understand the limitation of certain plans by considering the rate of urbanisation as a parameter for planning.

The simulation tool also employs the use of cloud-based resources in order to create an interface that is designed based on usability requirements for the stakeholders, i.e. the interface attempts to filter the details and improves the speed of computation in order to be usable by the agencies. This tool is also designed to be used while collaborating for better communication using simulations as an artefact to help them achieve this.

The current simulation focuses on water, solid-waste and sewerage management. The tool is designed to be modular and can be extended to include new infrastructure, agencies and planning methods. The following are some new ways it can be extended immediately:

i. ***Adding transport planning parameters.*** The land-use models can be modified to estimate requirements for transport planning parameters. This would be able to model demand for public transport, current levels of service and future demand. This model can be eventually extended to plan for the transition to Electric Vehicles in Chennai for public transportation.

ii. ***Adding the ability to model energy requirements.*** Given that urbanisation will continue in Chennai, city energy requirements and plans for improving capability can also be added to the model. Tamil Nadu is a leading state in renewable energy generation. The simulation tool can be modified to include energy demand models based on land-use and urbanisation patterns. Such a model can understand India's plans to open access to buy power generated in the open market and to estimate if the current grid can manage future demands with higher renewables in the mixture.

iii. Finally, one of the main problems in Indian cities is the issue of ***affordable housing supply.*** This tool can be modified to focus deeper on this.

LIMITATIONS DUE TO GAPS IN DATA

Up-to-date information on land-use in each ward within the CMDA area.

Information with respect to land-use at the level of wards and neighbourhood will provide a more accurate estimate for water demand, sewerage and waste. Chennai city is modelled as a cellular automaton in Simulogue. However, due to lack of data the simulation is able to work at the level of wards. Improving zoning information with respect to neighbourhoods will allow for a much better representation of growth of Chennai city.

Lack of data with respect to CMA area

The Chennai metropolitan Area encompasses the Greater Chennai Corporation area along with towns and peri-urban regions around Chennai. There is a lack of GIS data with respect to the towns in the CMA area as it is not publicly available. Thus, the effect of agencies' decisions on the overall Chennai region cannot be captured in the current version despite the agencies being modelled in the simulation.

Clearances for developing various infrastructures

The simulation can be further improved by including data around clearance procedures and criteria for approval of different infrastructure by various agencies. Simulogue currently models simple clearance procedures and has the capability to include further details of the approval procedure. The modelling of clearance procedures is unique to Simulogue as it attempts to improve the planning parameters for infrastructure at the negotiation stage. Our hypothesis is that this would identify bottlenecks in current implementation procedures which can be identified and handled during the negotiation process.

CHAPTER 9: CONCLUSION – STRATEGIC RECOMMENDATIONS

Sembakkam Lake Restoration | © Ram Keshav/TNC

CHAPTER 9:
CONCLUSION – STRATEGIC RECOMMENDATIONS

This concluding chapter presents targeted recommendations for managing Chennai's land, water and waste in a more sustainable way that will also help mitigate the tensions that arise across these sectors as they interact.

Our recommendations are based on this report's analysis and findings, and reflect a set of potential strategies which aim to facilitate better collaboration, greater convergence between planning and action and concurrence between multiple stakeholder visions for future city development along a more socio-environmentally and economically sustainable path.

These recommendations are varied in nature. Some relate to financial sources and arrangements, some to institutional relations and processes, while others are regulatory or technological in nature. Some relate to short term interventions, while others require longer term efforts. Similarly, some recommendations can readily be implemented, while others may need significant political heavy lifting. In the end, collectively, these recommendations present strategic ideas for achieving a more resilient CMA with regard to the governance of its water, waste and land.

The recommendations are categorised as follows:

1. Participatory and data-driven planning
2. Holistic/integrated and well-coordinated planning
3. Stringent enforcement of existing rules and regulations
4. Formulating comprehensive policies
5. Awareness campaigns
6. Enhancing resource support and capacity building

PARTICIPATORY AND DATA-DRIVEN PLANNING

While economic development policies/investments that support mega-projects are often prioritized as a result of the pressures of increasing population and associated infrastructure needs, the IT corridor development and its subsequent consequences discussed in this report reiterate the importance of more participatory planning processes that accommodate diverse social, economic and ecological concerns. A system of broad participation by local residents, non-profit organizations, industries and government bodies are more likely to protect multiple interests and visions than simply caving to economic growth pressures (particularly when doing so comes at the cost of local livelihoods and the environment). Furthermore, a narrow focus on immediate economic growth jeopardises sustainable city development.

Thus, we recommend that multi-stakeholder participation is fostered by making public consultation processes more inviting and accommodating, involving the public in budgetary processes and mandating citizen representation in ward committees. Doing so will improve citizen trust, which is important because citizens today are typically disenchanted with government actions. It will also increase transparency and ensure that government policies and investments are in line with civic priorities. In addition, empowering ULBs in the formal governance space is key to ensuring that local needs are well recognized among decision-making processes.

In addition, planning can be strengthened by leveraging available data. Cities across India are saturated with data but struggle to analyse or make sense of it. It is imperative that data be leveraged to improve operational efficiencies, productivity and service delivery, which in turn will improve citizens' quality of life. Procuring and using quality data to drive policy and planning decisions will be crucial to assessing the long-term feasibility of government interventions.

For instance, future budget allocations for disaster responses should be based on the vulnerability mapping included in Chennai's official Disaster Management Plan. This would mean expenditures more effectively target higher-risk-prone areas. Similarly, it would mean other expenses around storm water drains are data-driven.

Another extremely important aspect of data-driven policy is the need to accommodate alternative forms of knowledge (for instance, community-based knowledge) in planning and decision-making. Local communities are repositories of information that experts and experienced officers often do not have access to. Therefore, community knowledge should be an integral part of planning. Data-driven approaches to governance should also include spatial mapping and simulation tools such as ABMs, which test the outcomes and projection of new policies and projects. Data-driven governance can be supported by establishing a state-of-the-art data centre in partnership with reputed academic institutions for procuring and analysing quality data to make informed decisions.

HOLISTIC/ INTEGRATED AND WELL-COORDINATED PLANNING

In light of the many master plans that have been drawn up by multiple agencies and a general non-compliance with the legally-binding Second Master Plan and the CMDA's development regulations, an argument can be made for better integrating all planning functions within a single nodal agency. For example, while the CMDA's Second Master Plan was prepared for a time period of 20 years, the CMWSSB's master plan was prepared for a time period of 30 years; and each plan had different starting dates. A nodal agency could potentially mean improved coordination, with all existing departments functioning as implementing and monitoring agencies. However, as public agencies point out, this system will work effectively only if the level of coordination between the planning agency and the implementing and monitoring agencies is substantial. If it isn't, the effort would be counterproductive to any effort to building more inclusive and participatory planning processes. Hence, the master planning exercises should be prepared simultaneously and in conjunction with all relevant agencies.

The problem mapping exercise conducted during workshops made it clear that there is a need in Chennai for greater coordination among key government departments and a better understanding of how operations are interlinked. For example, it was evident that a holistic approach will best address issues of encroachment (by informal settlements) in Chennai – an ongoing challenge in terms of protecting both city water bodies and vulnerable communities in the event of disasters.

Given the relatively low levels of income and education among resettled/affected communities, there is a clear need to ensure these populations maintain their relevance in the economy and current market trends. Resettlement processes, which often relocate families at great distances from their original city residence, must address the resulting effects on employment and livelihoods. Thus, greater emphasis should be placed on TNSCB skills training programmes and their efforts should be coordinated to a higher degree with other departments such as the TNHB and the Ministry of Labour and Skills Development in order to yield a greater impact. Creating additional links with potential employers and NGOs involved in this space will also help catalyse the impact.

Better connectivity to the city at affordable prices is also essential for resettled families, in light of their new resettlement tenements being located on city outskirts, several kilometres away from where they work or send their children to school. Without this, many are forced to remain in the city during weekdays, finding cheap, often illegal, accommodation options close to vulnerable areas such as flood plains or waterbodies, thereby further aggravating encroachment issues. Hence it is crucial to develop an integrated and holistic approach to addressing this problem.

Further, integrated planning will also ensure that we recognize the interlinkages between multiple challenges and design creative solutions that address them simultaneously. For example, in order to improve groundwater levels and mitigate the impacts of floods, developing public spaces and private infrastructure can be judiciously used by introducing innovative elements such as porous pavements and rain gardens that have water conservation in the forefront. Ongoing efforts by the GCC to build recharge wells in select stretches inside the Integrated Storm Water Drain network is a relevant move that should be scaled up to the extent possible across the city so as to ensure maximum impact.

STRINGENT ENFORCEMENT OF EXISTING RULES AND REGULATIONS

To ensure the protection and conservation of ecologically vulnerable areas including water bodies, marshlands and groundwater sources, existing rules and regulations designed to guard against the exploitation of these resources need to be more effectively enforced. For example, in the area of land-use governance, land-use reclassification should be made more institutionally rigorous, involving multiple stakeholders and agencies. This is important as a means to checking land-use reclassification, particularly in cases where previously undeveloped or ecologically vulnerable lands are reclassified for construction or development.

While current reclassification processes involve a technical working group that includes representatives from organizations such as the CMWSSB, PWD, GCC and the TNPCB, reclassification decisions are in fact carried out unopposed, despite reservations from various government departments. Further, the reclassification process does not consider existing master plans or visioning exercises carried out by various other government departments. During our interviews, the CMWSSB pointed out that infrastructure projects conforming to their master plan had to be put on hold to accommodate infrastructure requirements in newly classified areas. In addition to the need for increasing the stringency of land reclassification processes, there is a particular need to rigorously restrict the conversion of waterbodies or land in close proximity to waterbodies, especially if they are to be converted for industrial or hazardous land-use purposes. This is of particular importance in the case of peri-urban areas that are likely to be affected by the planned expansion of the CMA.

In terms of water governance, measures to protect Chennai's groundwater resources must be implemented in order to address over-exploitation and pollution. These threats are compounded by that of saline intrusion, the result of Chennai's geographic situation on the coast. Saline intrusion is both the result of over-exploitation and a factor contributing to pollution. While the 1987 Chennai Metropolitan Area Groundwater (Regulation) Act clearly requires that approvals and compliances are followed for extracting groundwater, it is poorly enforced and ineffectively monitored, and this has led to a rampant increase in the exploitation and pollution of groundwater. In some cases, this has resulted in the complete depletion of crucial aquifers, such as that in Thiruvanmiyur. Therefore, a dedicated enforcement agency with sufficient manpower needs to be established within the CMWSSB to strictly enforce existing laws, collect quality data around domestic, commercial and industrial borewells and to monitor groundwater extraction.

In the area of waste governance, enforcing source segregation will be a crucial step to decreasing the quantity of waste that goes to landfills. Experts estimate effective source segregation can reduce the quantity of waste being landfilled to 1000 tonnes per day (totalling an 80% reduction) (Merigala, 2017). While clearly defined rules already exist for source segregation, the city has had a hard time implementing them. Further, the private operators in charge of conservancy operations in three zones are not contractually obligated to collect segregated garbage.

In congruence with the recently-rolled out State SWM policy, the GCC must take drastic efforts to implement city-wide source segregation, which also includes individual dwelling units. In order to increase its uptake, the GCC should introduce incentive mechanisms for source segregation and heavy penalties, including non-collection of unsegregated waste, in order to bring about behavioural change in waste management. Incidentally, the recently--drafted GCC solid waste management by-laws give the GCC the authority to collect user fees based from waste generators and to impose fines on waste segregation offenders. User fees will be crucial to addressing existing O&M issues related to financial limitations and investing in the required technology and human resources.

FORMULATING COMPREHENSIVE POLICIES

The gamut of problems that define Chennai's land-use-water-waste nexus cannot be addressed by cosmetic and fragmented interventions but by formulating targeted and comprehensive policies that address the roots of these problems.

Policy for integrated water management:

For example, in order to address the multiple threats plaguing Chennai's water system, the CMWSSB should draft a dedicated water policy that includes the following elements:

1. **Water Metering:** Stakeholder workshop participants identified existing water pricing mechanism as a key deterrent to Chennai water security today. To curb increasing water demand and to better conserve water resources, water meters should be installed at the household level. In addition to affecting behavioural change among water consumers, this capital infusion will be crucial to CMWSSB investments in new water supply and distribution networks, as well as to improving existing networks.

2. **Mapping and restoring water bodies:** Restoring defunct waterbodies is key to improving Chennai's water security and flood management capacity. An elaborate mapping exercise should be undertaken to identify waterbodies and waterways in the CMA. Subsequently, targeted master plans should be developed for restoring them. Holistic and customised plans should be in place to address encroachment along waterbodies. As articulated in an earlier section, relevant government departments should effectively coordinate to ensure humane eviction and resettlement, affordable housing for all and skills training programs to avoid tearing vulnerable populations away from their livelihoods – which in itself ends up contributing to new illegal encroachment in the city.

3. **Mandating industrial and commercial recycled waste water use:** Wastewater reuse can significantly reduce groundwater extraction and dependence on fresh water. Some industries already reuse sewage water. Complete industrial dependence on wastewater would require a substantial increase in STP capacity by setting up new plants near industrial estates. There are currently more than 40 industrial estates in the Chennai, Kanchipuram, and Thiruvallur districts. In terms of commercial establishments, specifically hotels and educational institutions, STPs and grey water recycling plants would provide necessary water for all purposes including drinking. In addition to capacity increases, treatment processes need to be upgraded to tertiary treatment, and extensive awareness campaigns are needed to reassure users about the quality of treated water for drinking and cooking. Further, CMWSSB could make it mandatory for industries to use only treated water and provide necessary support. It would also have to strengthen monitoring mechanisms to ensure industries reuse wastewater.

4. **Use of smart technologies for monitoring:** In order to reduce NRW losses, innovative technologies should be installed across pumping stations, reservoirs, desalination and sewage treatment plants and the water supply network to detect leakages, drops in pressure, and the presence of contaminants in the piping.

5. **Establishing a data repository:** A primary challenge to addressing Chennai's water problems is a lack of data. A dedicated, public access data portal should be created that includes up-to-date datasets indicating total water availability, supply, demand, quality, aquifer status, information about ongoing projects and proposed plans for improving water security.

6. **Promoting wastewater reuse for domestic users – decentralized water treatment plants:** In addition to increasing the capacity of existing sewage treatment plants, CMWSSB should actively support the construction of decentralized water treatment plants at a neighbourhood/ward scale. The support should include knowledge transfer, capacity building, training, and incentive mechanisms to generate uptake. While a similar directive mandating wastewater recycling and reuse theoretically exists with CMWSSB, the rule is restricted to special and multi-storey buildings constructed after April, 2017.

7. **Flood mapping tool:** CMWSSB should develop a mapping tool to monitor and forecast floods at a basin level using new weather forecasting technologies, real-time hydro-meteorological information and modelling tools based on new scientific knowledge. Based on the analysis, funds should be appropriated to improve flood management and response in vulnerable areas.

Policy for humane resettlement and rehabilitation:

1. **Affordable housing:** A primary cause behind Chennai's illegal encroachment problem is insufficient affordable housing options. Hence, we recommend that existing policies are enforced and public-private partnerships encouraged to ensure adequate and affordable rental housing is provided for the urban poor, thereby helping to minimize illegal encroachments.

2. **Integrated resettlement and rehabilitation plans:** The existing eviction and resettlement system needs to be replaced with a well-coordinated process with clearly defined roles and responsibilities for all involved. Various stakeholders (including the TNSCB, the police, the Revenue Department and the Registration Department) should liaise to work together during eviction drives or resettlement processes, and their respective roles and responsibilities should be clearly stated, leaving no room for flexibility in interpretation or ambiguity in enforcement. This would streamline the process of identifying and dealing with encroachments, evictions and resettlement and leave no concerns unaddressed.

Policy for effective solid waste management:

Most SWM issues in Chennai are not so much due to a lack of effective policies as they are to poor implementation. In addition to effectively implementing existing SWM policies, GCC efforts should include the following:

1. **Landfill management:** Stakeholder workshops and interviews highlighted a concern among participants around a shortage of land for storing and disposing garbage. At 485 hectares, Chennai already has the largest parcel of land demarcated for waste disposal in the country. Predicted urbanization trends will only make it harder for the government to make use of contiguous tracts of land for waste disposal in the future. Further, any positive changes resulting from improved source segregation will be muted by an absence of effective landfill management plans.

The GCC should construct waste to energy (WTE) plants inside landfills. These can be used to generate power while also helping to reclaim land. Waste generated in Chennai is estimated to contain the highest calorific value (10.9 MJ/kg) in the country and has a power production potential of 149 MW (Annepu, 2012). However, WTEs only work in conjunction with source segregation, to reduce the quantity of waste present in the two dump yards, and eventually pave the way for their closure. Further, any new landfills should be developed according to Chennai's 2016 SWM Rules, which require that selected areas are more than 100 meters away from waterbodies and 500 meters from human settlements.

2. **Decentralised waste processing and treatment:** In addition to large-scale WTE plants, the GCC should also construct and promote localised waste processing facilities. Biodegradable waste from gated communities and large-scale dwelling units should be processed, treated and disposed of through composting and biomethanation, and this should be done on-site wherever possible. The private sector, especially Special Economic Zones (SEZ), Industrial Estates and Industrial Parks, should earmark space for waste processing inside their premises, as defined in the SWM Rules, 2016.

3. **Enhanced private sector role in SWM:** Chennai's conservancy operations should be privatised in all 15 zones and the contracts should include the rules, regulations and provisions mentioned in SWM Rules 2016 for waste handling and waste processing. Despite mixed reviews on the effectiveness and efficiency of private operators in Chennai, the technology and financial resources available among the private sector do outweigh the GCC's operational capacity. The GCC's weak budget allocation for SWM over the years further illustrates this lack of resources for SWM at the GCC. The private sector, under an effective monitoring set up, should take over conservancy operations in the city. GCC support here can include access to personnel through formalised training of existing informal garbage collectors.

Apart from conservancy operations, the private sector should be encouraged to use compost and fertilizers derived from waste processing and Refuse Derived Fuel (RDF) resulting from WTE plants. Further, this will promulgate private sector innovation and research in manufacturing biodegradable products. For example, the recent state-wide ban on single-use plastics incentivized the private sector to develop eco-friendly and innovative bio-degradable plastics.

AWARENESS CAMPAIGNS

Dedicated programs should be designed to address a lack of awareness or knowledge in Chennai about larger and longer-term impacts of development projects on the environment. Also, about procedures that must be fulfilled to obtain requisite environmental clearances and documents by both public and private developers. Creating training modules and conducting awareness programmes on the rationale of environmental clearance and EIAs could help generate better understanding among project developers (at the conceptualization stage), consultants (at the testing stage) and regulators (at the assessment stage). This could ensure a higher degree of responsibility towards environmental sustainability among these key players.

Improvements to Chennai's water sector appear to focus primarily on increasing water supply, while very little is done to address demand-side management issues. To curb demand, CMWSSB should develop a comprehensive strategy for generating water conservation awareness and should include tools that facilitate it, such as water-efficient showers, toilets and other appliances. Further, the merits in using treated wastewater for domestic purposes should be clearly explained to the public and substantiated with data around quality and reliability.

ENHANCING RESOURCE SUPPORT AND CAPACITY BUILDING

1. **Increase O&M funds:** Stakeholder input highlights the extent to which budget allocations for operations and maintenance of existing infrastructure are low. Depending on the agency, this varies between 20 and 50 percent, according to CMA representatives, the State Finance Commission assigns them only 5 percent for O&M. This presents a major challenge to maintaining existing storm water drains, sewerage systems, roads, etc. A sustainable future seems possible only if agencies dedicate more resources for daily O&M. Without it, all infrastructure, including that which is newly added, will, in time, continue to fall into disrepair.

2. **Improved resource/power allocation to the State Expert Appraisal Committee (SEAC):** Besides incorporating periodic training for SEAC members on their role when evaluating development proposals, small steps can go a long way to ensuring the sanctity of the EIA process, including the provision of adequate notice to SEAC members prior to meetings and allowing them the time and capacity to individually or as groups verify the assessments conducted by consultants acting on behalf of developers. Making appropriate financial allocations for this purpose is also necessary. Given that the findings by the SEAC are advisory and not binding in nature, perhaps a method to accord greater recognition to unanimous SEAC findings (for example, a majority of members arriving at the same opinion) could help boost the SEAC's role.

3. **Public outreach:** Involving local NGOs, RWAs and corporate entities in ongoing restoration efforts and environmental conservation programs can direct funds, human resource and know-how towards better city resource maintenance. Further, promoting community ownership models of public spaces such as parks, lakes, ponds, etc. will increase buy-in from the public and ensure their upkeep.

4. **Capacity building:** Existing vacancies in government departments need to be filled and adequate staff strength needs to be maintained in order to improve the efficiency and quality of work. Staff should be trained on new technologies, such as Geographic Information System (GIS), in order develop know-how and improve in-house technical capacity. Further, expert personnel should be appointed on contract or direct basis, to deal with emerging issues in land-use, water and waste.

Additionally, existing inventories of machinery such as excavators, tippers, jet rodding machines, desilting machines, electrical equipment, and ladders that are required for infrastructure maintenance, repair and restoration, need to be increased according to requirement and demand.

These recommendations, along with the agent-based models presented in preceding chapters, can guide key stakeholders to identify short, medium- and long-term interventions along various axes, including financial, technological, personnel and regulatory. They can also help assess implications of specific land, water and waste related decisions on CMA water vulnerability.

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APPENDIX I

List of organizations/groups interviewed	Nature	Number of interviews
Chennai Metropolitan Development Authority	Government	2
Chennai Metropolitan Water Supply and Sewerage Board	Government	1
Greater Chennai Corporation	Government	1
Public Works Department	Government	2
Tamil Nadu Water Investment Company	Private	1
Tamil Nadu Urban Infrastructure Financial Services Ltd	PPP	1
Tamil Nadu Urban Finance and Infrastructure Development Corporation Limited	PPP	1
Urban Workshop	Private	1
Coastal Research Centre	NGO	1
Care Earth	NGO	1
Citizen Consumer and Civic Action Group	NGO	1
Indo-German Centre for Sustainability	Think tank	1
Rain Centre	NGO	1
MIDS	Academia	2
MCCI	Industry	1
IIT Madras	Academia	1
Semmancheri Residents	Vulnerable communities	2 groups (10 in each)

APPENDIX II

DEFAULT PARAMETER DATA

SN	Parameter Name	Parameter Description	Default Value
1	sewage_generated_per_person	Sewerage generated by one person per day in mcum	9.0411E-08
2	waste_generated_per_person	Waste generated by one person per day in tonnes	0.581862
3	water_consumed_per_person	Water consumed by each person per day in mcum	5.35906E-07
4	sewage_generated_per_sqkm_commercial	Sewerage generated per sqkm of commercial land per day in mcum	1.90607E-05
5	waste_generated_per_sqkm_commercial	Solid waste generated per sqkm of commercial land per day in tonnes	0.096503091
6	water_consumed_per_sqkm_commercial	Water consumed per sqkm of commercial land per day in mcum	0.000888756
7	sewage_generated_per_sqkm_industrial	Sewerage generated per sqkm of industrial land per day in mcum	4.76517E-06
8	waste_generated_per_sqkm_industrial	Solid waste generated per sqkm of industrial land per day in tonnes	0.024125773
9	water_consumed_per_sqkm_industrial	Water consumed per sqkm of industrial land per day in mcum	0.00104367
10	population_rise_percent	Annual population rise in percentage	0.015
11	household_size	Household size	4
12	split_percent_between_res_and_comm_area	Percentage split between residential and commercial area for mixed residential zone	0.5
13	urbanisable_land_change_percent	Annual change in urbanisable land area in percentage for entire planning area	-0.01

SN	Parameter Name	Parameter Description	Default Value
14	encroachment_change_percent	Annual change in encroachment area in percentage for entire planning area	0.01
15	commercial_change_percent	Annual change in commercial area in percentage for entire planning area	0.01
16	informal_settlements_change_percent	Annual change in area with informal settlements in percentage for entire planning area	0.01
17	industrial_change_percent	Annual change in industrial area in percentage for entire planning area	0.01
18	special_industrial_change_percent	Annual change in special industrial area in percentage for entire planning area	0.001
19	primary_residential_change_percent	Annual change in primary residential area in percentage for entire planning area	0.01
20	mixed_residential_change_percent	Annual change in mixed residential area in percentage for entire planning area	0.01
21	institutional_change_percent	Annual change in institutional area in percentage for entire planning area	0.001
22	open_space_change_percent	Annual change in open recreational area in percentage for entire planning area	0.01
23	non_urbanisable_land_change_percent	Annual change in non-urbanisable area in percentage for entire planning area	0.001
24	reserve_forest_change_percent	Annual change in forest area in percentage for entire planning area	-0.001
25	red_hills_catchment_change_percent	Annual change in Red Hills catchment area in percentage for entire planning area	-0.001
26	encroachment_land_percent	Percentage of total land that is encroachments	0.01
27	informal_settlements_land_percent	Percentage of total land that is informal settlements	0.01

SN	Parameter Name	Parameter Description	Default Value
28	CMDA_revenue	Revenue per annum for CMDA in INR	576400000
29	CMDA_capital	Capital with CMDA in INR	8892900000
30	CMDA_cost_new_detailed_development_plan	Cost of developing a new detailed development plan in INR	410000000
31	CMDA_initial_planning_knowledge	Planning experience with CMDA measured as a absolute value	500
32	CMDA_knowledge_cost_new_development_plan	Experience cost for developing a new plan by CMDA measured as a absolute value	100
33	CMDA_knowledge_revenue	Experience gained while developing plans measured as a absolute number	2
34	CMWSSB_revenue	Revenue per annum for CMWSSB in INR	2275775000
35	CMWSSB_capital	Capital with CMWSSB in INR	5299300000
36	CMWSSB_cost_new_detailed_development_plan	Cost of developing a new development plan in INR	10000000
37	CMWSSB_initial_planning_knowledge	Planning experience with CMWSSB measured as a absolute value	500
38	CMWSSB_knowledge_cost_new_development_plan	Experience cost for developing a new plan by CMWSSB measured as a absolute value	100
39	CMWSSB_knowledge_revenue	Experience gained while developing plans measured as a absolute number	2
40	CMWSSB_cost_per_mld_sewage_management	Cost of managing sewerage for every million liter per day in INR	164700.4791
41	CMWSSB_istalled_capacity_sewage	Installed capacity for sewerage management in million cubic meters	727
42	CMWSSB_min_domestic_supply_percent	Minimum water supply to domestic consumers as percent of total domestic demand	0.9

SN	Parameter Name	Parameter Description	Default Value
43	CMWSSB_min_commercial_supply_percent	Minimum water supply to commercial consumers as percent of total commercial demand	0.9
44	CMWSSB_min_industrial_supply_percent	Minimum water supply to industrial consumers as percent of total industrial demand	0.9
45	CMWSSB_target_number_wells	Number of wells planned to be built	10
46	CMWSSB_target_number_desalination_plants	Number of desalination plants planned to be built	10
47	CMWSSB_target_number_reservoirs	Number of reservoirs planned to be built	10
48	CMWSSB_target_number_wasteWaterRecycling	Number of waste water recycling plants planned to be built	10
49	CRRT_revenue	Revenue per annum for CRRT in INR	476105482
50	CRRT_capital	Capital with CRRT in INR	310400000
51	CRRT_encroachment_study_cost	Cost for conducting a study of encroachments in planning area in INR	1000000
52	CRRT_forest_wetland_maintenance_cost	Cost for maintenance of forest and wetlands in planning area in INR	1000000
53	CRRT_water_conservation_cost	Cost for conducting a water conservation program in planning area in INR	4900000
54	CRRT_number_conservation_programs	Number of water conservation programs planned	5
55	CRRT_river_restoration_cost	Cost for restoring a river in INR	1000000
56	CRRT_conservation_demand_reduction_percent_ward	Percentage of reduction in water demand due to water conservation programs implemented	0.01

SN	Parameter Name	Parameter Description	Default Value
57	CRRT_river_capacity_improvement_percent	Percentage improvement in capacity of river due to restoration programs implemented	0.05
58	TNPCB_revenue	Revenue per annum for TNPCB in INR	0
59	TNPCB_capital	Capital with TNPCB in INR	0
60	GCC_revenue	Revenue per annum for GCC in INR	33615900000
61	GCC_capital	Capital with GCC in INR	21916100000
62	GCC_number_of_bridges	Number of bridges with GCC	5
63	GCC_number_of_parks	Number of parks with GCC	5
64	GCC_length_of_SWD	Length of storm water drains with GCC	2000000
65	GCC_number_of_bridges_planned	Number of bridges planned to be built	5
66	GCC_number_of_parks_planned	Number of parks planned to be built	5
67	GCC_length_of_SWD_planned	Length of storm water drains planned to be built in planning area	10000
68	GCC_number_of_electrical_work_planned	Number of electrical work programs planned in planning area	5
69	GCC_cost_per_kg_solid_waste_management	Cost for management of 1 ton of solid waste per day in INR	36532.40294
70	GCC_cost_per_bridge	Cost of maintenance for a bridge in INR	5000000
71	GCC_cost_per_park	Cost of maintenance for a park in INR	500000
72	GCC_number_of_electrical_work	Number of electrical work programs completed in planning area	5

SN	Parameter Name	Parameter Description	Default Value
73	GCC_cost_of_electrical_work	Cost for completing one electrical work program in the planning area in INR	200000000
74	GCC_cost_storm_water_drainage_maintenance	Cost for maintenance of 1 storm water drain within planning area in INR	500
75	GCC_new_storm_water_drainage_cost	Cost for developing a new storm water drain in the planning area in INR	5000
76	GCC_new_storm_water_drainage_land	Land required to develop a new storm water drain in the planning area in sqkm	0.000001
77	GCC_new_park_cost	Cost for developing a new park in the planning area in INR	25000000
78	GCC_new_park_land	Land required for developing a new park in the planning area in sqkm	0.016187426
79	GCC_new_park_time	Time taken to develop a new bridge in the planning area in years	2
80	GCC_new_bridge_cost	Cost for developing a new bridge in the planning area in INR	6000000
81	GCC_new_bridge_land	Land required for developing a new bridge in the planning area in sqkm	0.01
82	GCC_new_bridge_time	Time taken to develop a new bridge in the planning area in years	4
83	PWD_revenue	Revenue per annum for PWD in INR	19901538000
84	PWD_capital	Capital with PWD in INR	30824099000
85	PWD_length_of_SWD	Length of storm water drains with SWD	500000
86	PWD_length_of_SWD_planned	Length of storm water drains planned to be built in planning area	5
87	PWD_cost_maintenance_per_water_supply	Cost of maintenance for a the water supply in PWD area in INR	1000000

SN	Parameter Name	Parameter Description	Default Value
88	PWD_cost_new_storm_water_drainage	Cost for developing a new storm water drain in the planning area in INR	500
89	PWD_new_storm_water_drainage_land	Land required for developing a storm water drain in the planning area in sqkm	0.000001
90	RD_revenue	Capital with RD providers in INR	53640448000
91	RD_capital	Revenue per annum for RD in INR	500001000
92	TNHB_revenue	Capital with TNHB providers in INR	194547000
93	TNHB_capital	Revenue per annum for TNHB in INR	2000
94	TNHB_number_of_housing_projects_completed	Number of housing projects completed	5
95	TNHB_number_of_housing_projects_planned	Number of housing projects planned	5
96	TNHB_cost_housing_project	Cost of implementing a housing development project	10000000
97	TNHB_convert_percent	Percentage of open land converted to residential zone in a housing development project for each ward	0.01
98	TNHB_land_cost_housing_project	Land required for developing a housing project from a open area in sqkm	1
99	TNID_revenue	Revenue per annum for TNID in INR	5000000
100	TNID_capital	Capital with TNID providers in INR	50000000
101	TNID_lobbying_cost	Cost for lobbying program to convert open land to industrial area in INR	1000000
102	TNID_cost_land_industry	Land requested in the lobbying program for industrial area in sqkm	0.01

SN	Parameter Name	Parameter Description	Default Value
103	TNID_industry_convert_percent	Percentage of open land converted to industrial zone in a lobbying program	0.03
104	TNID_number_lobby_completed	Number of lobbying programs completed	0
105	TNID_number_lobby_planned	Number of lobbying programs planned	5
106	TNSCB_revenue	Revenue per annum for TNSCB in INR	23022617000
107	TNSCB_capital	Capital with TNSCB providers in INR	13000
108	TNSCB_cost_settlement_rehabilitation	Cost for rehabilitation programs for a slum in INR	366400000
109	TNSCB_cost_land_rehabilitation	Land required for a rehabilitation program in sqkm	25
110	TNSCB_rehabilitation_convert_percent	Percentage of open land converted to residential zone in a rehabilitation program	0.3
111	TNSCB_number_rehab_completed	Number of rehabilitation programs completed	0
112	CMWSSB_target_number_STP	Number of sewerage treatment plants planned	0

APPENDIX III

BATCH PARAMETERS TO GENERATE ALL POSSIBLE DEVELOPMENT STRATEGIES

SN	Parameter Name	Start Value	End Value	Step Value
1	encroachment_land_percent	0.01	0.02	0.005
2	population_rise_percent	0.015	0.03	0.005
3	split_percent_between_res_and_comm_area	0.3	0.6	0.15
4	CMWSSB_istalled_capacity_sewage	600	1000	200
5	open_space_change_percent	0.01	0.02	0.005
6	waste_generated_per_person	0.000398536	0.00043839	1.99E-05
7	sewage_generated_per_sqkm_industrial	4.77E-06	5.24169E-06	2.38E-07
8	waste_generated_per_sqkm_commercial	0.096503091	0.1061534	0.004825155
9	water_consumed_per_sqkm_commercial	0.000888756	0.000977632	4.44E-05
10	PWD_length_of_SWD_planned	1000	5000	1000
11	informal_settlements_change_percent	0.01	0.02	0.005
12	commercial_change_percent	0.01	0.02	0.005
13	waste_generated_per_sqkm_industrial	0.024125773	0.02653835	0.001206289
14	CMWSSB_cost_per_mld_sewage_management	150000	200000	10000

SN	Parameter Name	Start Value	End Value	Step Value
15	water_consumed_per_sqkm_ industrial	0.00104367	0.001148037	5.22E-05
16	CMWSSB_target_number_ wasteWaterRecycling	0	10	2
17	encroachment_change_percent	0.01	0.02	0.005
18	GCC_number_of_bridges_planned	0	5	1
19	industrial_change_percent	0.01	0.02	0.005
20	TNID_number_lobby_planned	0	5	1
21	institutional_change_percent	0.001	0.002	0.0005
22	CMWSSB_target_number_reservoirs	0	10	2
23	special_industrial_change_percent	0.001	0.002	0.0005
24	CMWSSB_min_industrial_supply_ percent	0.5	1	0.1
25	GCC_length_of_SWD_planned	10000	50000	10000
26	TNHB_number_of_housing_ projects_planned	0	5	1
27	GCC_number_of_parks_planned	0	5	1
28	GCC_number_of_electrical_work_ planned	0	5	1
29	sewage_generated_per_sqkm_ commercial	1.90607E-05	2.09667E-05	9.53E-07
30	CMWSSB_min_commercial_supply_ percent	0.5	1	0.1

SN	Parameter Name	Start Value	End Value	Step Value
31	non_urbanisable_land_change_ percent	0.001	0.002	0.0005
32	water_consumed_per_person	1.36E-07	5.36E-07	1.00E-07
33	urbanisable_land_change_percent	-0.01	-0.02	-0.005
34	CRRT_number_conservation_ programs	0	5	1
35	GCC_cost_per_kg_solid_waste_ management	35000	45000	5000
36	CMWSSB_target_number_wells	0	10	2
37	red_hills_catchment_change_ percent	-0.001	-0.002	-0.0005
38	mixed_residential_change_percent	0.01	0.02	0.005
39	reserve_forest_change_percent	-0.001	-0.002	-0.0005
40	CMWSSB_target_number_ desalination_plants	0	10	2
41	informal_settlements_land_percent	0.01	0.02	0.005
42	sewage_generated_per_person	9.04E-08	1.00E-07	1.00E-08
43	CMWSSB_min_domestic_supply_ percent	0.5	1	0.1
44	primary_residential_change_percent	0.01	0.02	0.005
45	CMWSSB_target_number_STP	1	5	1

APPENDIX IV

OUTCOME PLOTS

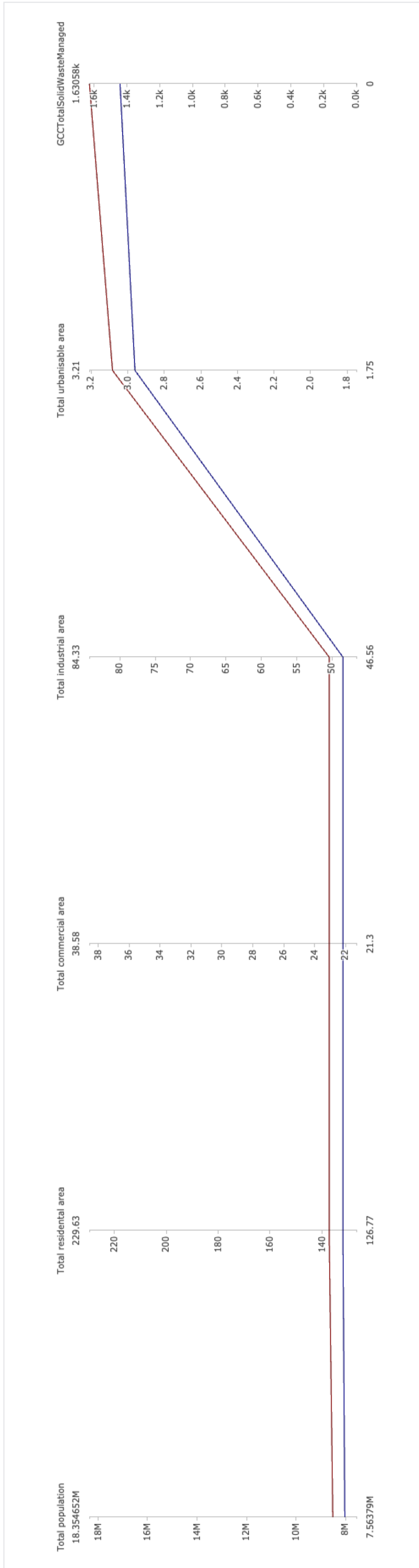

Figure 58. Outcome plot for the solid-waste management

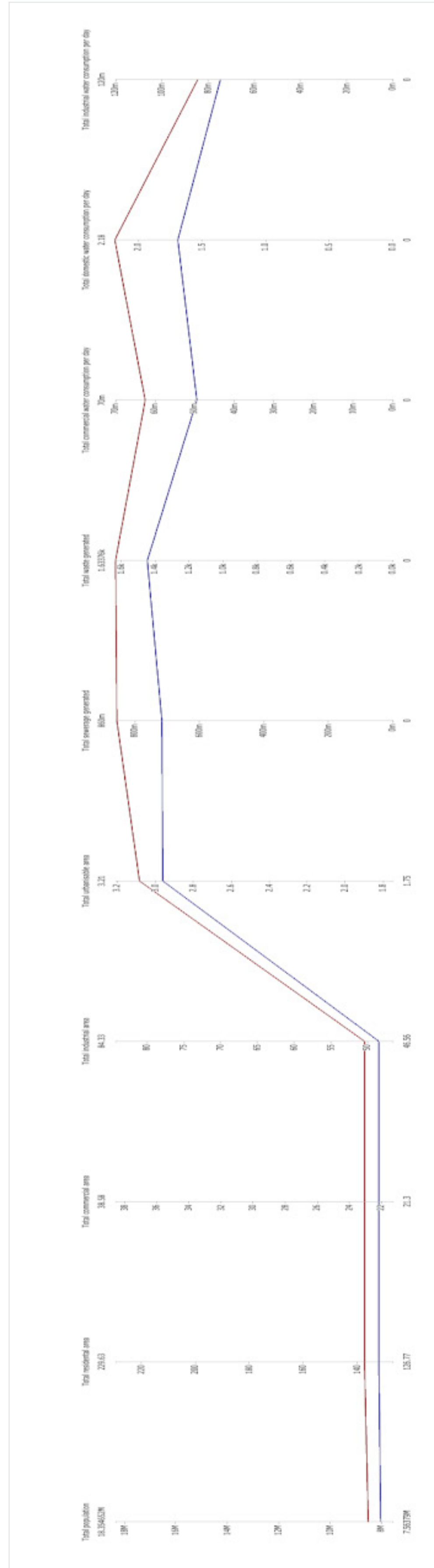

Figure 59. Outcome plot for the land-use/zone

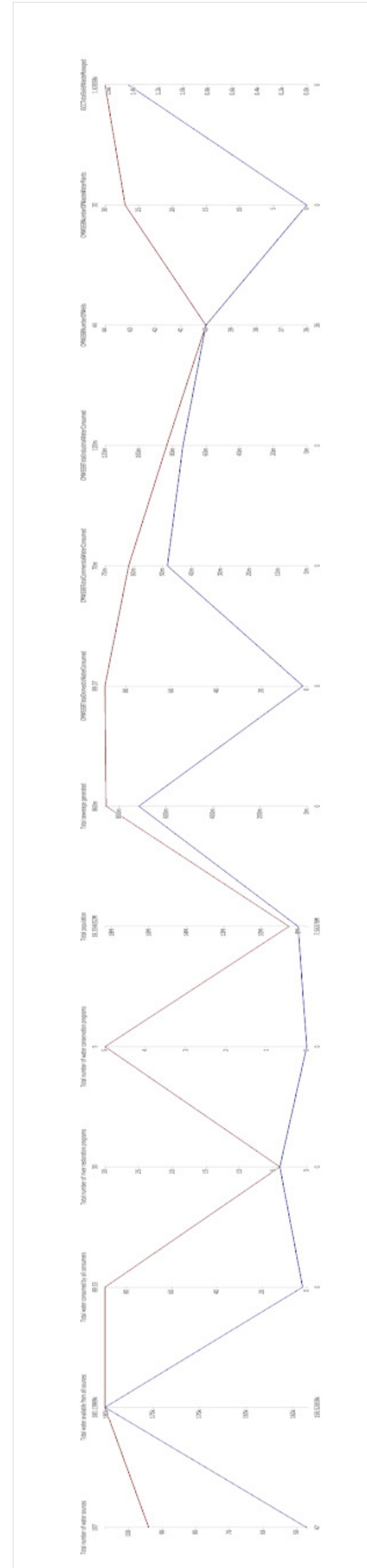

Figure 60. Outcome plot for water consumption and new source development

APPENDIX V

DATA FROM CMWSSB

SN	Variables	Temporality Requirement (in mld)
1	total_water_sources_potential	1642 mld
2	total_gross_demand	1136 mld (for the year of 2015)
3	domestic_water_demand	859 mld (for the year of 2015)
4	industries_water_demand	86 mld
5	water_deficit_in	254 mld
6	sewage	508.35 mld
7	sewage_treatment_cost_in_lakhs	6.86 lakhs/day
8	desalination_cost_in_crores	570(Nemmeli)
9	desalination_capacity_per_facility	200 mld
10	sewage_treatment_installed_capacity	745 mld
11	water_wells_yield_mcm	Appr. 26 mld.During the time of Drought it will be enhanced to approximately 100mld depending upon the availability.
12	water_wells_cost_in_lakhs	Not Available
13	total_subbasin_gross_groundwater_extraction	63 mld
14	groundwater_balance_potential_available_in_ subbasin	285 mld

SN	Variables	Temporality Requirement (in mld)
15	surface_water_potential	375 mld
16	total_subbasin_net_groundwater_potential_mcm	1119.38 mcm
17	livestock_water_demand_mcm	859 mld (for the year of 2015)
18	irrigation_water_demand_mcm	-
19	net_irrigation_demand_mcm	-
20	Cost of laying water supply lines	Rs.2297 (approximately)
21	Cost of laying sewage lines	Rs.7000 (approximately)
22	desalination_power_consumption_cost_in_lakhs	900/months (on an average)
23	water_tankers_capacity	494 nos
24	water_tankers_cost	NA

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THROUGH PARTICIPATORY SIMULATIONS

— 2019 —

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