Imagining Futures – A generative scenario-based methodology to improve planning and decision-support systems for policymakers

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Abstract

This study proposes a generative scenario-based methodology to improve planning and decision support systems that help policymakers in a given urban context, to imagine futures, to advance towards integrating government functions, and to identify pathways to get there. To demonstrate the same, we developed a scenario-based simulation platform, named 'Simulogue'. The tool is set in Chennai, India, and is designed as a platform for integrated governance through a facilitated dialogue between various stakeholders involved with governing Chennai. The dialogue is based on various future scenarios that each stakeholder develops and is able to negotiate with their peers. A futures-based approach helps to improve decision-making by (i) facilitating the integration of diverse public institutions and collaboration between stakeholders by defining specific goals and evaluation parameters by stakeholders themselves and (ii) incorporating intangible data with regards their interaction and decision-making into the decision support system. Scenario-based planning enables stakeholders to explore different situations they would like to plan for. It enables them to articulate their goals and constraints with respect to the functions they perform. As a result, planning outcomes can be designed that stem from policymakers themselves. To be able to do so accurately, we must capture all relevant data such as data on resource-access, control, regulation and use as well as qualitative data on interaction amongst stakeholders. Through a combination of stakeholder-led workshops and developing an agent-based simulation tool, we bring together data, people, processes and constraints, presented in the form of future scenarios that policymakers must identify and work towards.

Keywords – Decision-support; Scenario-based; Integrated-governance; Simulation-platform; Generative

1. Introduction

Coastal cities in India and across the world are being impacted by climate change in the form of heavy rains, cyclones and rising sea levels. The challenges posed by climate change are compounded by the inter-connected and resource-based challenges that governance of urban areas (coastal or otherwise) brings with it, such as the need for drinking water, management of solid and wet waste, and land-use planning for an increasing population. The need to respond to these challenges is clear and policymakers have access to large amounts of data for their planning processes.

There are difficulties of aggregating and making such data actionable as policymakers also operate within existing institutional frameworks that are often fragmented, limiting the interaction across institutions and thereby impacting the nature and efficacy of decisions made. The consequences of policymakers' decisions assume criticality given that they are responsible for performing essential public functions such as the supply of drinking water, maintenance of drainage systems, etc. Combined with specific challenges such as planning for a large and diverse set of stakeholders, the unprecedented speed of urban growth and corresponding effects on climate and the environment, the lack of support can harm lives and livelihoods. Such an ecosystem presents the tell-tale signs of a complex system in operation. Therefore, there is a need to develop tools that help account for challenges that such systems present like the scale of interaction, emergent effects, unintended consequences and cascading failures. Such tools must be able to help policymakers plan and react to on-the-ground challenges in a timely manner.

To help understand different ground-level issues and policy-level challenges, there is a need to grasp the complexity of the governance ecosystem within which agencies define their goals and actions, and make policy. Furthermore, a thorough mapping of a city's institutional network will enable the various institutions to use a common platform for integrated governance and develop coordinated and strategic responses to the challenges they face.

A significant reason as to understanding the institutional structure is our objective to build a simulation tool that will help policymakers envision different future scenarios. For this, it is crucial to build the tool using data we obtained from stakeholders. By relying on quantitative data and stakeholder-provided qualitative data, we can ensure the integrity and usefulness of the tool and thereby enable a practical approach to policymakers' response to changing conditions of land use, waste, and water rather than a theoretical one.

In order to accomplish this, we consider the case of Chennai, a coastal metropolitan city in south-east India. It is a major port to the Bay of Bengal and is one of the largest cities in the country with an increasing population and huge water demands. We have mapped the institutional structure for Chennai along and collected qualitative data from the city to look at its water, waste and solid-waste management as a futures approach.

While the specifics of the agent-based model that will form the simulation tool will be discussed in a separate section, we will discuss how understanding and mapping the institutional structure in Chennai will feed into the final tool that will be used by policymakers. The scenario-based simulation tool incorporates both quantitative models and qualitative inputs based on stakeholder mapping and social-network analysis (SNA).

2. Methodology

The methodology of developing the scenario-based simulation platform involved a combination of quantitative analysis, qualitative analysis, and incorporating outcomes from these analyses to structure the simulation platform. The analysis begins with collection of quantitative data through secondary research and qualitative data through primary sources such as interviews and workshops. In order to accurately model the institutional structure and develop the simulation platform, some qualitative data was also collected through secondary sources where primary data was unavailable.

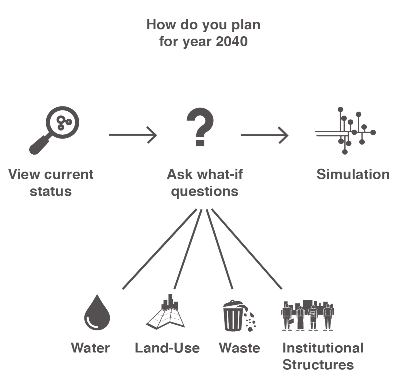

Figure 1: Methodology Framework

Quantitative data was captured using traditional approaches where data published by respective departments and ministries was collected. Qualitative analysis encompasses stakeholder mapping and SNA. The output from quantitative and qualitative analyses then be used to develop the scenario-based simulation platform.

2.1 Quantitative Analysis

The quantitative data analysis involves identification of dependent and independent variables for the statistical model, collection of secondary data, identification of type of quantitative databases – time series or panel data, and data modelling. The methodology includes secondary research to finalise the list of dependent and independent variables. Depending on the availability of secondary data on identified dependent and independent parameters, the study includes time series and panel data analysis to incorporate correlation and regression analysis for different models.

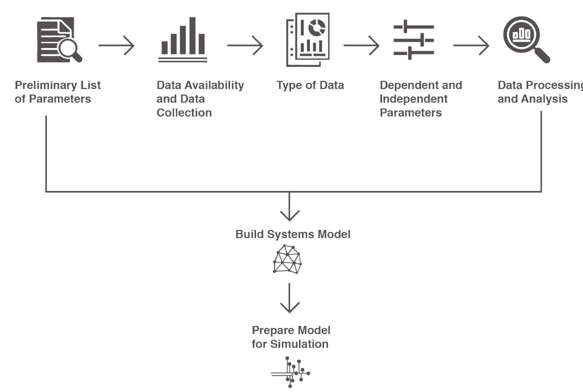

Figure 2: Quantitative Analysis

The set of quantitative data on water, waste, and land-use are collected from Chennai River Basin Report (Public Works Department, Government of Tamil Nadu, 2013), Chennai Metropolitan Water Supply & Sewerage Board (Chennai Metropolitan Water Supply & Sewerage Board, Chennai Metropolitan Water Supply & Sewerage Board, 2018), Municipal Administration and Water Supply Department of Tamil Nadu Government, Tamil Nadu Water Supply and Drainage Board (TWAD), and Water Resources Organisation of Public Works Department (PWD).

The data collection process is followed by the data cleaning process. Collected databases include land-use data; monthly, seasonal, and annual rainfall data; water level data in rain-gauge stations; data on area-wise ground water potentiality and extraction; number of observation wells and water quality; number of water tanks and water capacity; data on domestic and industrial demands for water; data on generation of solid waste, manure, and sewage; and data on gross water supply, demand, and unmet demand. The statistical models were built incorporating identified dependent and independent parameters. These models help to run correlation and regression analysis to understand the trend and relationship between these parameters.

The time series database on reservoirs for Chennai river basin area includes data on the storage capacity of reservoirs (mcft), actual storage of water (mcft) (Chennai Metropolitan Water Supply & Sewerage Board, Storage with Reference to Mean Sea Level, 2018), inflow (cusec), outflow (cusec), and rainfall (mm.) at daily basis for the period 2014-2017. The research considers four reservoirs in the river basin – Poondi, Cholavaram, Redhills, and Chembarambakkam. For the Time Series analysis, we have used quarterly data as a modified version of the actual reservoir-specific daily data. From the graphical representation of the water inflow-outflow quarterly data, we can understand the relationship between inflow and outflow of water for these four major reservoirs. The correlation analysis of the quarterly database shows the interdependencies between rainfall and water inflow to the reservoirs, between rainfall and outflow from reservoirs, and also between water inflow and outflow. The analysis has been done for both annually and quarterly to identify significance of correlation and also to find impact of seasonality.

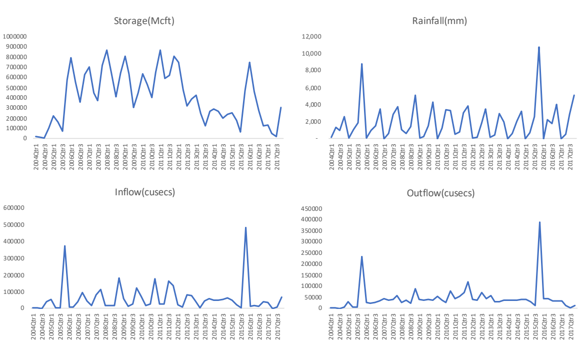

Figure 3: Quarterly Reservoir Water Storage, Inflow, Outflow, and Rainfall

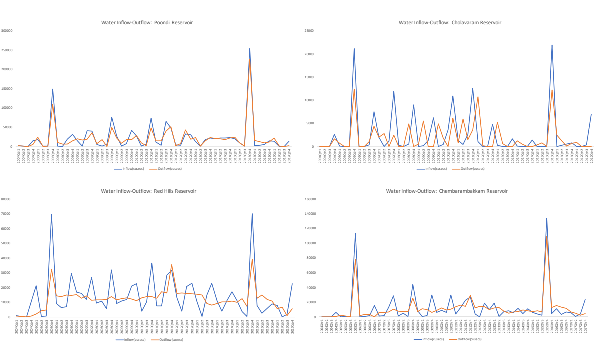

Figure 4: Water Inflow and Outflow Trend of Reservoirs

Apart from the time series analysis, the study also encompasses analysis of panel or categorical data on land-use distribution, ground water potential, surface water potential, ground water extraction, demand for water both household and industrial purposes, and on waste generation within the Chennai river basin area. Data on the above-mentioned parameters are available for all 8 sub-basins of the Chennai river basin at an annual basis for the year 2007, 2010, 2020 (E), and 2045 (E). Through this analysis, the study was able to demonstrate different scenarios for each sub-basin in different time periods. The analysis was done to study the impact of population and area of each sub-basin on ground water and surface water potential, ground water extraction, generation of solid waste, sewage, and manure. The panel data has been done through developing all possible models – pooling linear model, one-way individual effect between model, one-way first-difference model, one-way within model, and one-way random effect model. The coefficients of all independent parameters from each one of the good-fitted time-series and panel data models were further used in the simulation model to forecast different scenarios.

2.2 Qualitative Analysis

Collection of qualitative data posed a challenge. Qualitative data required a space where the stakeholders could provide data about their operations based on their experience and daily interactions. There are delays and differences in decision-making processes due to real-time and on-the-ground changes. Such changes and events need to be accounted for during the planning phase. Decision-making processes are also affected by the influence stakeholders exert and existing institutional relationships and interactions. This data is completely invisible and is not captured by traditional methods. In order to collect qualitative data, we designed a new data-collection methodology administered in a structured workshop format. This method requires representatives from stakeholder organisations (or stakeholders themselves) to participate in a five-stage approach to formulate organisational goals while interacting with their peers. These interactions are carefully documented to create a structured format of institutional interactions while tackling a specific planning or implementation problem. This document then provides us with a cross-sectional view of the specific decision-making process and thus, document intangible and qualitative parameters.

We conducted a set of stakeholder mapping (Lienert, Schnetzer, & Ingold, 2013) workshops to gather qualitative information from decision-making departments' officials involved in this context. Through the stakeholder mapping workshops, we sought to create a map of Chennai's institutional environment with respect to land use, waste, and water. Representatives from relevant agencies articulated and described their interactions with other departments. This information captures the effective interactions between public departments, delays in decision-making, the flow of information, and the practical constraints under which they operate. We sought to understand the jurisdiction and responsibilities of different government institutions by reviewing secondary research material such as department websites and planning documents. To identify all the major stakeholders for this study, we introduced social-network analysis (SNA) (Lienert, Schnetzer, & Ingold, 2013) to our qualitative analysis process. By looking at the organisational structure and the officials in-charge of various institutions, we identified the commonality in management, through overlapping board membership, of different institutions. Using an online open source tool called 'Cytoscape' (Cytoscape, 2019), we have visualised these relationships to be able to represent them in the form of actor maps for individual agencies as well as Chennai's entire institutional structure.

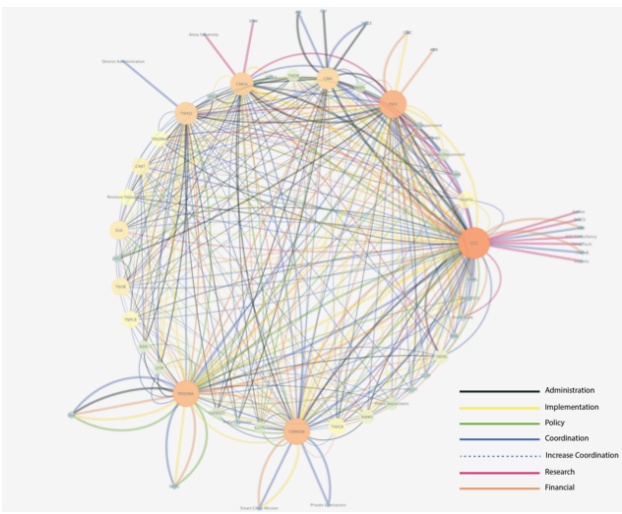

Figure 5: Cytoscape - Social Network Analysis

A follow-up workshop was conducted so that the govt. stakeholders could validate the interactions and maps of their agencies. Through the data collected from all the above-mentioned sources, we classified the interactions between agencies based on the nature of the relationships they shared. These are the relationships between various institutions with respect to their day-to-day operations and the larger planning processes:

- Administrative: The relationship is hierarchical. One institution needs permission from another to carry out their functions.

- Funding: The relationship is financial.

- Policy: One institution frames a policy, and the other institution must implement it.

- Coordination: Institutions cooperate in terms of providing information relevant to the work at hand, and collaborating for a project together.

- Implementation: This relationship is specific to certain projects that two institutions are working on, where one sets out the tasks and the other implements it.

- Research: This relationship applies when two institutions are conducting research together.

In the workshop with policy-level officials, we sought to understand different departmental priorities around the issues of land use, waste and water. Participating officials were encouraged to enumerate key problems from their perspective, list the different actors involved in working on the same, and identify the gaps in coordination between these actors. Based on the outcomes of the previous workshop, we identified the key problems around land use, water, and waste management that were broadly agreed upon by all participating departments. These include encroachment on water sources, maintenance of storm water drains, disposal of solid waste, water supply-demand mismatch and also the lack of coordination amongst government departments. We then classified the identified problems based on where they occur in the policy and implementation cycle, which consists of planning; designing a policy and getting approval; implementation; evaluating the policy; and getting feedback and making modifications. Having characterised the policy-level challenges, the next set of workshops sought to incorporate the localised, context-specific issues by bringing together field-level officials across departments. Participants brought out the micro-level implementation challenges related to water, waste and land use management that they face. They also enumerated crucial issues in terms of personnel, equipment, and govt. and non-govt. actors and discussed approaches for addressing these issues.

2.3 Simulation Model

Both qualitative and quantitative data are then employed to create a simulation model to generate various what-if decision-making scenarios. We make use of an agent-based approach where we model various stakeholders as individual autonomous agents, with their own respective objectives and functions. This simulation tool models the behaviour of public institution stakeholders as separate agents to capture the specifics of their operation.

In the land use modelling community agent-based models (ABM) are used mainly because it offers a way of incorporating the influence of human decision-making on land use in a formal and spatially explicit way, considering social interaction, adaptation and decision-making at different levels (Matthews, Gilbert, Roach, Polhill, & Gotts, 2007). Furthermore, the ability to link social and environmental processes is an additional advantage of ABMs, providing a way of studying human–ecosystem relationships with the ultimate aim of developing principles for managing real coupled human-environment systems (Parker, Manson, Janssen, Hoffmann, & Deadman, 2003).

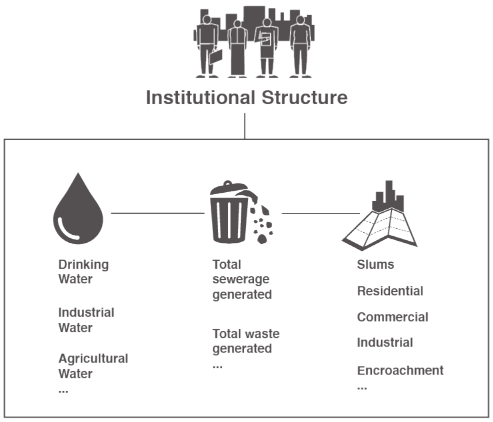

Figure 6: Simulation Platform

Using the data, our simulation generates multiple future scenarios that can be explored by policymakers in order to come up with a multitude of plans for the future. The classification of relationships becomes significant in context of the agent-based model wherein each relevant agency performs the role of a separate 'agent'. In this ABM, each agent is defined to have the following traits:

- Geographical Jurisdiction
- Budgetary Allocation
- Functions and Responsibilities
- Outward and Inward Interactions (with other 'agents')

These traits will determine (a) the range of available actions for every agent; (b) the efficacy of their actions; and (c) the impact of their choices. The extent of impact will be decided based on equations written to represent the relationship between these traits. Consequently, this will imply the kind of inputs (in terms of choice and range) agents will be able to make while planning for Chennai's future through the tool. These choices for range and choices of inputs are based on the qualitative data that we have collected through the interviews, secondary sources, and workshops. Any further information required has been obtained from follow-up interviews with the stakeholders or from secondary sources such as government websites and policy documents. While it is possible to obtain some of data to model an agent entirely from secondary sources, we chose to adopt a stakeholder-driven approach to ensure that the data is representative of the manner in which institutions practically function and interact with one another. By capturing issues and responses from the stakeholders' perspective, we sought to ensure the usefulness and consequent adoption of the simulation tool.

2.3.1 Building an institutional agent

We begin with the data we collected to determine the geographical jurisdiction of each institutional agent. For example, Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) functions within the limits of the Greater Chennai Corporation (GCC) while the Tamil Nadu Water Supply and Drainage Board (TWAD Board) functions within the areas under the Chennai Metropolitan Area (CMA) outside the GCC zones.

We then proceed to the data regarding budgetary allocations for each agent. Data on budget will determine the extent of investment possible by an institutional agent, limits on the projects it can undertake, and further financial flows between agents.

Information was collected and classified as administrative, financial, implementation, policy, and research has been used to determine the various functions for each institutional agent. The frequency (daily, monthly, quarterly, annually) of these activities will be determined to the extent possible from the collected data. This will have an impact on their efficacy as well as the time spent on different activities.

Finally, we determine the inward and outward interactions related for each agent. Coordination refers to interaction between two agencies either for seeking/granting permissions; sharing of information/data; or cooperating for undertaking activities. Where an agency requires permission or data from another, it will form an outward interaction.

For example, if the Tamil Nadu Housing Board (TNHB) seeks to increase the quantum of Economically Weaker Section housing in Chennai, they will need to seek land from Revenue Department, seek permission from Public Works Department (PWD) if the land is close to a waterbody, seek to cooperate with CMWSSB for providing water supply and will need data from Chennai Metropolitan Development Authority (CMDA) (or another agency) to determine the extent of housing required. All of the above interactions will be outward interactions from the perspective of TNHB. The same interactions will form inward interactions for CMDA, PWD, Revenue Department and CMWSSB. In this way, every agency will have a number of inward and outward interactions that will determine the kind of actions they can undertake. The impact of other agents' choices will also decide the efficacy of the agent's activities. For instance, if PWD refuses to grant permission for development near a waterbody, TNHB will have to seek land elsewhere causing delays in the availability of housing. With increasing population year-on-year, this will have an impact on the number of encroachments, no. of housing units, etc.

2.3.2 Modelling the land-use, population and resources in Chennai

Data on infrastructure and resources we have collected from the urban local bodies, are used to create a model for Chennai. The resource data collected can be classified into the following:

1. Land use input parameters which consist of the land area that are reserved for residential, commercial, industrial activities and other area such as urban, coastal regulation zone, etc.,
2. Water data such as the number of water sources, wells, reservoirs and their respective capacities. The seasonal effects of rainfall and evaporation is also modelled on the amount of water available in each of the water source.
3. Waste data, current capability to collect and process solid waste.
4. Sewerage Management, installed capacity for managing sewerage generated and managed.
5. Other parameters, encroachments, informal settlements, clearances for infrastructure development etc., that affect the daily operations for the urban local bodies are also modelled.

The population and thus, the Chennai area is modelled to grow at a certain rate as observed by the Indian Census 2011.

Each operation and behaviour of the institutional agent in the simulation influences the growth of Chennai by influencing the population density, water availability or the capacity to handle waste. With increase in population, additional capacity for water and waste needs to be added in order to provide for the new population. Each institutional agent then has to spend on operations, maintenance or build new infrastructure to meet the additional demands on the city.

3. Conclusion

The user of this scenario-based simulation tool, that is, the policymakers, will be able to see the impact of the qualitative and quantitative data in terms of (a) the actions that are available for them to undertake, (b) the range of inputs for each action, and (c) the outcome of each of their actions. By using 'Simulogue', stakeholders can develop actionable strategies, for the short and long term, that help them achieve their desired futures. Our process of data collection for institutional interactions and processes provides an end-to-end research platform which brings all stakeholders together to make possible what-if scenarios.

Further, an integrated platform to engage both quantitative and qualitative analysis by creating a simulation tool brings more value and novelty to the study. Provided with data on qualitative and quantitative aspects, this model can be extended for other geographical areas and domains.

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References

Lienert, J., Schnetzer, F., & Ingold, K. (2013). Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes. *Elsevier*.

Cytoscape. (2019, May 20). Retrieved from Cytoscape: https://cytoscape.org

Matthews, R., Gilbert, N., Roach, A., Polhill, J., & Gotts, N. (2007). Agent-based land-use models: a review of applications. *Landscape Ecology*, 1447-1459.

Parker, D., Manson, S., Janssen, M., Hoffmann, M., & Deadman, P. (2003). Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers*, 314-337.

Chennai Metropolitan Water Supply & Sewerage Board. (2018). *Storage with Reference to Mean Sea Level*. Retrieved from http://www.chennaimetrowater.tn.nic.in/public/lake.htm

Chennai Metropolitan Water Supply & Sewerage Board. (2018). *Chennai Metropolitan Water Supply & Sewerage Board*. Retrieved from https://chennaimetrowater.tn.gov.in

Public Works Department, Government of Tamil Nadu. (2013). *Chennai River Basin Report Vol 1 & 2.*