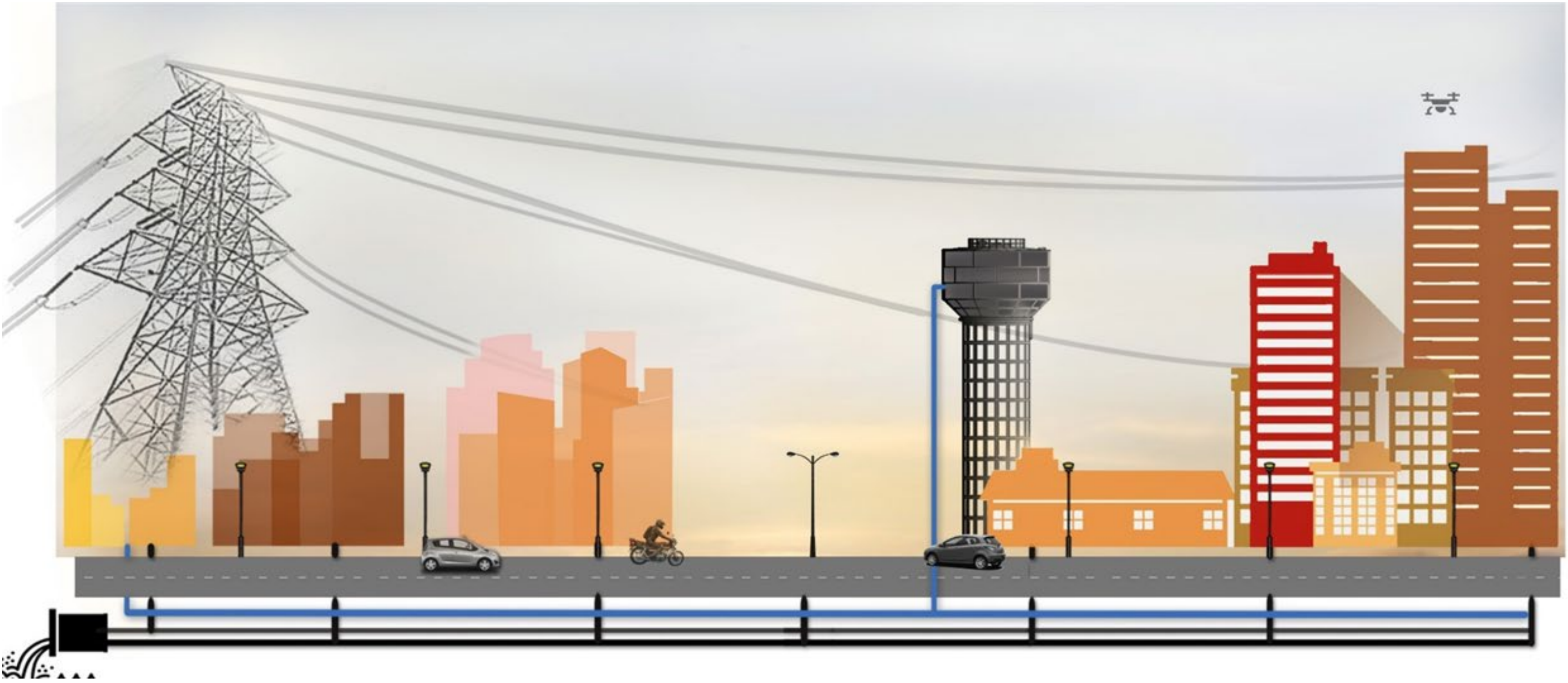

India-UK Joint

Integrated Urban Model for Built Environment Energy Research

(iNUMBER)

Water-Energy Nexus

March 2020

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India-UK Joint Integrated Urban Model for Built Environment Energy Research (iNUMBER)

Work Package 2 (WP2): Incorporate Municipal Energy Services

Water-Energy Nexus

March 2020

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iNUMBER is a four-year (2017-2021) research project to help cities reduce their energy demand and improve their municipal services. This goal is led by CEPT University, Ahmedabad and supported in India by Indian Institute of Technology Bombay, Mumbai. It is led by University College London, London, and supported by the University of Oxford, Oxford.

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Acronyms

iNUMBER	iNtegrated Urban Model for Built Environment Energy Research
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
SCADA	Supervisory Control and Data Acquisition

Abbreviations

EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
ULB	Urban Local Body
BIM	Building Information Modeling
WP	Work Package
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
BEE	Bureau of Energy Efficiency
GoI	Government of India
MuDSM	Municipal Demand Side Management
IGEA	Investment Grade Energy Audit
MEEP	Municipal Energy Efficiency Program
MoHUA	Ministry of Housing and Urban Affairs
PSU	Public Sector Undertakings
SLNP	Street Light National Program
KWh	kilo Watt hour
AMC	Ahmedabad Municipal Corporation
EE Cell	Energy Efficiency Cell
SMC	Surat Municipal Corporation
LPCD	Liter per Capita per Day
WDS	Water Distribution Station
kWh	Kilo Watt hour
ppha	People per hectare
CPHEEO	Central Public Health and Environmental Engineering Organization
LPCD	Litres per Capita per Day
NRW	Non-Revenue Water
CWAS	Centre for Water and Sanitation
kl	Kilo litre

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Executive Summary:

iNUMBER is an Indo-UK collaborative research project that was co-created to address the Newton research topic: “Integration of information, communication and renewable energy technologies at building, community and city level interventions”. The project aims to address this research topic by developing a data-driven Intelligent Urban Model for Built Environment and Energy Research (iNUMBER). The primary focus of this tool is to support the Indian Municipalities to understand the variations in energy demand and thereby assist in providing clean and sustainable energy services to its citizens. iNUMBER being a four-year collaborative research project (2017-2021), Ahmedabad has been selected as the primary case city for the research. Further, the project could be extended by considering other cities as well.

The key objective of the project is to develop a City Energy Model that includes the 3D building stock and the municipal services energy model. The project aims to achieve the same by linking the existing and new data sets and testing the validity of the developed model for a range of scenarios in accordance with different data availabilities. To achieve this overarching objective, the project has been sorted into 3 work packages (WP) as mentioned below,

1. WP1: Create 3D Building Stock Model
2. WP2: Incorporate Municipal Energy Services
3. WP3: Improving Data Granularity

This WP2 primarily focuses on the activities of stakeholder organizations and institutions with a primary focus on Urban Local Bodies (ULBs). There are two major outcomes under the work package 2. The first outcome is, ‘Feeder for City Energy Model’. This includes the integration of the energy data pertaining to the municipal services such as water supply, wastewater management, stormwater management and the lighting in public spaces into the City Energy Model. The second outcome is, ‘Developing a framework for capturing energy consumption in delivering the municipal services’. This focusses to develop a Municipal services information system for Ahmedabad city to evaluate the municipal services based on their energy consumptions. Further, the framework will be tested by considering other cities as well.

Under outcome 1-The work progress till now provides an overview of the municipal services in the context of the Ahmedabad city. Further, it demonstrates a work plan for identifying and gathering the energy data pertaining to these above-mentioned municipal services for incorporating the same into the City Energy Model.

Under outcome 2- The work progress till now demonstrates the methodology for developing the framework toassess the energy consumption in the delivery of municipal services. This report focusses only on the details pertaining to the Outcome-2.

The progress under Outcome-2 is detailed out in two parts. The first part of this report provides details pertaining to the Water-Energy nexus to understand the energy consumed in the delivery of municipal water services. This part will detail out the assessment of the energy consumption in water supply service at three levels namely: City level, State level and Community level. Further, it will also demonstrate the impact of the urban form and urban morphology of the cities on the energy consumption in the water supply service. The assessment of the energy consumption at city level and at the community level is carried out by considering the datasets pertaining to the city of Ahmedabad. Further, the assessment at the state level is carried out by considering the datasets of a total of 93 sampled cities from the states of Gujarat and Maharashtra.

The second part of the report intends to detail out the assessment of the fuel consumption in the municipal waste collection and transportation services. Municipal Solid waste Management being one of the major services at the city level, it consumes significant amount of fuel energy in the collection and transportation of the waste. The assessment of the quantity of fuel consumed in the collection and transportation of the waste and the impact of the urban form of the city on the same is discussed in the second part of the report.This methodology will further be extended to assess the energy consumption in the delivery of other municipal services such as wastewater management, storm water management and lighting in public places.

The integration of the outcomes from all the 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth work package, the activities under iNUMBER will further be integrated with other projects, related research in India, and across the world. Further, this integrated approach will develop new areas of inquiry related to future building stock and municipal services in India.

1 Introduction

Cities have often been described as the engines of economic growth (Colenbrander, 2016). Currently, 55% of the world's population is residing in the urban areas. This proportion is expected to stretch to 68% by 2050 (United Nation, 2018). As per new data sets launched by United Nations, it is observed that the overall shift in the human residences from rural to urban areas, combined with the overall growth of the world's population could add around 2.5 billion more people to urban areas by 2050. It is expected that, nearly 90% of this increase in the urban population would be accounted by Asian and African countries alone.

As the urban population increases, the demand for the basic amenities and living comforts will also increase. Thus, it is very important to plan and allow the urbanization to attain in a sustainable manner. In order to attain this, it becomes very necessary for the cities to develop and provide required amenities towards meeting the future demand of its citizens. One of the primary aspects that need to be accounted with the process of urbanization is the provision of the secure energy for the better health and comfort of the citizens.

As the urban population increases, the city's demand for the clean energy will also increase. Thus, with the changing lifestyle and growing cities, it becomes very important to understand the energy demand of the city and identify more efficient methods of utilizing available resources in catering the demands. This can be achieved by assessing and understanding the variations incurring in the energy demands of the city. These variations can only be studied by constant observation and analyses of the data sets specific to the respective services. Thus, the tools capturing variations in the demand for the energy over the time and space will serve the greater cause in understanding the trends, rationalizing the energy demands and thereby assist in planning and attaining a sustainable energy services for the cities.

iNUMBER focusses on developing one such tool for assessing and understanding the variation in energy demand of the city over time and space. iNUMBER is an iNtegrated Urban Model for Built Environment Energy Research. The research program aims at developing a City Energy Model to help in planning a secure energy supply for the urban population. Further, the tool will support the urban energy management process and assist municipalities and local partners for developing a data driven intelligent urban model for assessing the built environment energy and the municipal planning.

1.1 About iNUMBER

'iNtegrated Urban Model for Built Environment Energy Research (iNUMBER)' is a four-year collaborative research project between India and United Kingdom to help cities reduce their energy demand and improve their electricity and water services. Funded by the Newton-Bhabha Fund, iNUMBER is jointly supported by the UK Engineering and Physical Sciences Research Council

(EPSRC), and Economic and Social Research Council (ESRC) in partnership with the Government of India's Department of Science and Technology.The main objective of iNUMBER is to work towards reducing greenhouse gas emissions, stabilizing the electricity grid, and help the ULBs in rationalizing and planning the city's energy demands thereby, assisting in provision of secure and sustainable energy services. The tasks under the project are to develop a new model of building & municipal energy demand, grounded in appropriate empirical data and applicable to reducing energy demand in a wide range of different contexts and with varying data availability.

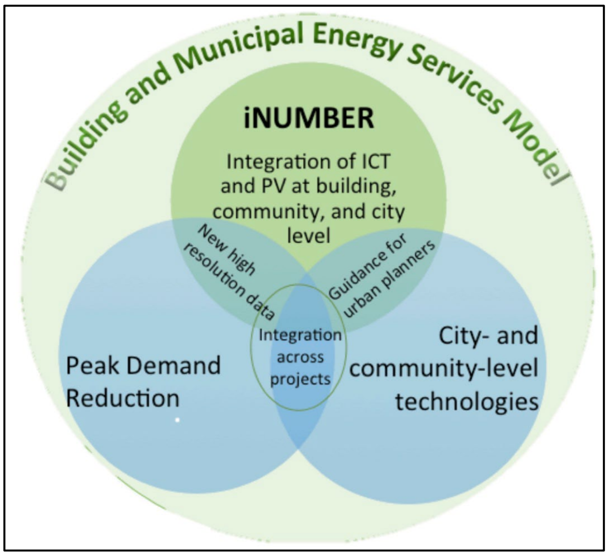


Figure 1: Schematic representation of the iNUMBER project

iNUMBER was co-created from the India-UK workshop to address the India-UK Newton research topic, "Integration of information, communication and renewable energy technologies at building, community and city level interventions" by developing a data- driven intelligent urban model for built environment energy research and municipal planning. It supports Indian municipalities and local partners by diagnosing urban energy problems, testing solutions, verifying progress and improving policy through state of art monitoring, data science and analytics. It will also meet interrelated elements of the other two topics, "peak demand reduction" by contributing new high-resolution data city and community technologies by providing guidance to urban planners.

The iNUMBER project is systematically sorted into 3 work packages (WP) and are classified as described below,

1. Work Package 1: Create a 3D Building Stock Model

The WP1 aims at identifying and analysing various approaches suitable for capturing the urban environment using advanced aerial survey technologies and develop a 3D Building stock model. WP1 incorporates existing geographical and administrative datasets available at the city level and integrates the information with the developed 3D Building Model. Finally, WP1 in association with partners investigates techniques to scale up Building Information Modelling (BIM) based energy simulations to develop a viable City Energy Model, thereby allowing municipalities to effectively optimize their current and future energy demands.

2. Work Package 2: Incorporate Municipal Energy Services

The WP2 primarily focusses on assessing the energy consumption in delivering the municipal services. The energy data sets obtained with regard to the municipal services feeds into the City Energy Model. Further, the work package also focusses on developing a framework for evaluating the municipal services with respect to their energy consumption.

3. Work Package 3: Improving Data Granularity

The WP3 primarily focusses on gathering intense datasets at dwelling unit leveland common amenities at community level pertaining to the energy consumptions, indoor environment parameters and thermal comfort conditions. The data sets collected in this work package regarding the energy consumption will act as feeder for the City Energy Model, thereby assisting in improving the data granularity of the model.

The integration of the 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth impact work package, the activities under iNUMBER will be integrated with other projects, related research in India, and across the world. Further, the integrated approaches incorporated in each of these work packages will help in answering additional questions and develop new areas of inquiry related to the future building stock and municipal services in India.

1.2 Work Package-2: Incorporate Municipal Energy Services

The WP2 aims at incorporating the energy consumptions in the delivery of the municipal services into the City Energy Model. Further, the work package also focusses on comprising the activities of the stakeholder organizations and associated institutions with the primary focus on ULBs.

The integration of all the municipal energy data sets and the understandings pertaining to the concerned stakeholder interaction and decision making processes will supplement in developing a framework for the ULB services tool. This framework will be helpful for the ULBs in evaluating the municipal services with respect to their energy consumptions. Thereby, the tool will assist the concerned decision makers in rationalizing their further advances towards better management of the system.

1.3 Scope of Work Package 2

As described earlier, the work package 2 primarily focusses on assessing the variations in the energy demand pertaining to the delivery of the municipal services. This is not the first attempt in India which is focusing on monitoring the energy consumptions pertaining to the municipal services. There have been manypast efforts in India at the central level, state level and ULB level which aimed to mandate the ULBs to monitor their energy consumption in delivering the municipal services. Further, there have also been many initiatives towards enhancing the operating efficiencies of the systems associated with the municipal services. The *Table 1* represents the learning from the review of such past initiatives undertaken by the governing bodies in India.

Table 1: Initiatives undertaken by governing bodies in India towards monitoring the municipal energy services; a review

Initiatives Undertaken	*Coverage of the Initiative*	*Key highlights*
JnNURM (2007-2014)	National level: (65 cities)	There have been many reforms brought at the state and the city level(Government of India. Ministry of Urban Development, 2009). The reforms included, ➢ To mandate the monitoring of the energy consumption in municipal services through regular energy audits. ➢ To mandate water audits for monitoring the losses.
AMRUT (2015-2020)	National Level: (434 cities)	The reforms under the mission mandate ULBs for optimization and conservation of energy in the Municipal services. The reforms also mandate water audits for monitoring the losses (Government of India. Ministry of Urban Development, 2009)
BEE (2002)	National Level	BEE is a statutory body set up by Ministry of Power (GoI) for bringing up programs for enhancing energy efficient sustainable practices and creating awareness among the cities pertaining to energy efficiency and energy conservation. (Ministry of Power, n.d.)
Municipal Demand Side Management (MuDSM) Program (2007-2012)	National Level: (175 ULBs)	The program was set up in 11th five year plan intending to enhance the overall efficiency of the ULBs thereby reducing the energy consumption in the municipal services. ➢ Situational surveys were conducted in the selected ULBs for assessing the existing status of the water pumping stations, sewage pumping stations, street lightings and buildings. ➢ Detailed project reports were prepared by ULBs based on situational surveys for undertaking an Investment Grade Energy Audit (IGEA). ➢ 12th five year plan focused on selecting sample ULBs and implementing the projects on ground.

		As the Gujarat state has already shown considerable efforts in the energy conservation and related projects, the state was considered among lower priority. Thus, Ahmedabad was not observed in the selected cities for the program.(Ministry of Power, n.d.)
Municipal Energy Efficiency Program (MEEP)	National Level: (All cities above 1 Lakh population)	MEEP is a central government initiative undertaken in association with MoHUA and Energy Efficiency Service Limited (PSU under Ministry of Power). ➢ MEEP majorly focused on retrofitting the inefficient municipality pump sets in water pumping stations and sewage pumping stations in 500 AMRUT cities. ➢ The program also aimed at replacing the inefficient pumps in the pumping stations of 100 selected cities under smart city mission.(Energy Efficiency Services Limited, n.d.)
Street Light National Programme (SLNP) (2015)	National Level	The SLNP was launched by central government towards replacing the conventional lights with the energy efficient lighting. The major objectives of the program includes, ➢ Replacing over 305Cr street lights across the country. ➢ Reducing energy consumption in street lighting and thereby assisting the distribution companies in managing the peak demands. The program estimated an overall annual energy saving of 9000 million KWh and an annual cost reduction of Rs. 5500 Cr for the ULBs.(Ministry of Electronics and Information Technology, n.d.)
Supervisory Control and Data Acquisition (2014-2019)	ULB Level	Under the SCADA initiative, the energy meters and flow meters will be installed in the systems associated with water supply and wastewater management. These devices will monitor and collect data sets pertaining to the flow rate, energy consumption and qualitative data sets such as pH, turbidity, chlorine level, etc. Ahmedabad Municipal Corporation (AMC) has installed the SCADA system for the water supply and waste water sector. These devices gather the data sets pertaining to water sector

		with a granularity of 15 minutes interval and the data sets pertaining to the waste water sector with the granularity of 1 hour interval. Further, as a part of Pan city proposal under the smart city mission, some of the cities that are selected under the mission have also proposed to install Supervisory Control and Data Acquisition (SCADA) system.
Energy Efficiency Cell (EE Cell)	ULB level (Surat, Ahmedabad)	Surat Municipal Corporation has set up EE Cell in 2001 with the aim of delivering basic services for their citizens at an optimum cost in an energy efficient manner. Under the supervision of this cell, the SMC conducted an energy audit for around 34 services that are having a contract demand of more than 75kwh Further, the similar cell has been replicated and incorporated by the (AMC) Ahmedabad Municipal Corporation. The main objective of the cell remained to reduce the energy consumption without depleting the performance of the system.(Ahmedabad Municipal Corporation, n.d.)

The study of the previous efforts by governing bodies suggests that there have been many initiatives that either mandate or promote the local bodies to monitor the municipal energy consumption. But it is observed that most of these initiatives are insisting ULBs to monitor their municipal energy on an annual basis or biennial basis. Thus, the data sets collected by the ULBs under these initiatives represent only the existing situations and cannot be used for any major analyses.

Further, it is also observed that most of the initiatives that focus on improving the municipal energy efficiency are majorly aiming tocapture only the energy perspective of efficiency.These initiatives do not focus on the resource perspective of the services. The *Table 2* represents the inferences observed from the review of the initiatives by the governing bodies.

Table 2: Inferences from the review of Government Initiatives

Initiatives	*Initiatives towards monitoring Energy*	*Initiatives towards monitoring both Energy and Resource*	*Granularity of data captured*
National Missions		AMRUT	Annual or Biennial
		JnNURM	Annual or Biennial
National Programs	MuDSM		One time
	MEEP		One time
	NSLP		One time
ULB Level initiatives		SCADA	Hourly basis
	EE Cell		Monthly basis

The variations in the energy demand of the municipal services and the efficiency of the system involved in municipal services can be better understood with the real time datasets pertaining to the same. Such system will help in monitoring of the energy consumption and the variations occurring across the different time period, different seasons and space. As most of these previous initiatives by the governing bodies do not focus on monitoring both energy and the resource aspects of the services, the datasets gathered during these initiatives will not help to greater extent in understanding the correlation between the municipal services and their energy consumptions. Thus, the WP2 ofiNUMBER project intends to focustowards developing one suchtool that assist ULBs in understanding and managing the variations in the energy demand with respect to the municipal services and assist them inbetter managementand planning of the operations with respect to the same.

Ahmedabad has been selected as the primary case city for the project. Further, project will be scaled up by considering different cities as well.

1.4 Outcomes of Work Package 2

The major outcomes of the work package include,

1) Feeder for the City Energy Model:

This focuses on capturing the energy consumption in the delivery of municipal services such as water supply, waste water management, storm water management and the lighting in public spaces. Further, the data pertaining to the same is integrated into the City Energy Model.

2) Developing a framework for capturing energy consumption in delivering the municipal services:

This focusses on developing a Municipal services information system for the Ahmedabad city. This framework will help in evaluating the municipal services with respect to their energy consumptions. Further, the framework will be tested by considering other cities as well.

The outcome-1 and outcome-2 of the work package are complementary to one another. The work pertaining to both the outcomes will be happening in synchronous to one another. The *Figure 2* will provide a brief overview about the work flow with respect to the two outcomes of the work package 2.

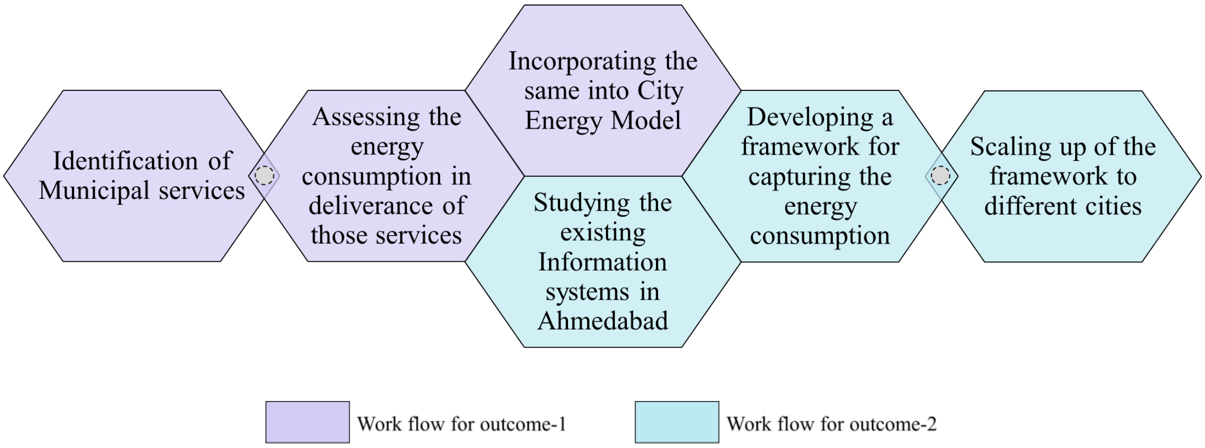


Figure 2: Overview of the work package 2

The *Figure 2* highlights the work flow with regard to the two outcomes of work package2. Further, it also signifies the way the two outcomes are complementing each other towards achieving the larger goal of the project.

The energy consumption in the delivery of the municipal services is captured and integrated in the City Energy Model. The understanding of the impact of urban form and morphology of the city on the energy consumption in the delivery of municipal services will assist in developing the framework. This framework will assess the variation in energy demand for municipal services with the varying urban characteristics. Further, this framework will be scaled up to different cities by identifying the variable parameters.

1.5 Work Plan for capturing energy consumption in deliveringthe municipal services

The second major outcome of the Work Package 2 is focused on developing a framework for capturing the energy consumption in the delivery of municipal services. Two primary objectives undertaken in line to achieve this outcome are as follows,

i. Developinga framework to assess the energy consumption pertaining to the municipal services for the city of Ahmedabad

ii. To scale up the framework with the scope of understanding and assessing the municipal energy consumption in different cities

With the increasing urbanization, the energy demands of the city will also increase. The varying patterns of urbanization will have varying impacts on the energy demand of the city. The literatures and studies suggests that these spatial organization of these urban development patterns and water supply networks of the cities have significant impact on the energy consumptions associated with the respective utilities (Larson & Yezer, 2014a). Thus, in order to develop a framework to assess the energy consumption in municipal services, it becomes very important to understand all the parameters that are associated with the same.The inclusion of these integrations will provide an impetus towards understanding the

In order to develop a framework assessing the energy consumption of the cities, firstly; it is important to understand the impact of the urban parameters on the energy consumption. Thus, the study primarily focusses on studying the effects of the urban parameters on the energy consumption in the delivery of municipal services. This will assist in identifying the parameters that have significantly larger impact on the energy consumption in the municipal services. Based on the outcomes of the study will draw inferences regarding the effectiveness of the current development regulations in line with the energy aspects of the basic city services. This will also assist the policy makers and decision makers at the city, state and national level in understanding the significance of the urban form and urban morphologies of the cities on the overall efficiency of the utilities. Thereby, demonstrates the potential scope for reducing the overall carbon footprint of the cities through a planned approach for the future developments.

This report comprises of the two parts. The first part of the report details out the assessment of the energy consumption in the Municipal water supply service. This part will detail out the assessment of the energy consumption in water supply service at three levels namely: city level, State level and community level. The first part of the study will discuss the impact of the urban form and urban morphology of the cities on the energy consumption in the water supply service. The assessment of the energy consumption at city level and at the community level is carried out by considering the datasets pertaining to the city of Ahmedabad. Further, the assessment at the state level is carried out by considering the datasets of a total of 93 sampled cities from the states of Gujarat and Maharashtra.

The second part of the report intends to detail out the assessment of the fuel consumption in the municipal waste collection and transportation services. Municipal Solid waste Management being one of the major services at the city level, it consumes significant amount of fuel energy in the collection and transportation of the waste. The assessment of the quantity of fuel consumed in the collection and transportation of the waste and the impact of the urban form of the city on the same is discussed in the second part of the report.

The work pertaining to both the first and second part of the research are progressing simultaneously. Thus, each section of the study will contain the way forwards indicating the future lines of progress.

Part-1: Municipal Water Supply Service

2 Impact of urban characteristics on municipal water supply-Case of Ahmedabad

This section of the study intends to understand the relationship of the existing urban characteristics on the energy consumption in the delivery of municipal water supply. The city of Ahmedabad which is in the central part of Gujarat is considered as the case city for this study. This case city is selected by considering the availability of high granular and reliable datasets possessed with the municipal corporation.

The water supply value chain includes Source, Water Treatment Plant, Water Distribution Stations and Distribution Network. From the analysis of the past 10 years budgetary expenses, it was observed that nearly 51% of the total revenue expenditure pertaining to the water utilities is being spent on the electricity charges. Further, upon studying the ratio of energy consumptions at various segments of the value chain, it is observed that the water distribution stations accounts to a major share of energy in the supply chain. The details pertaining to the same is depicted in the Figure 3.

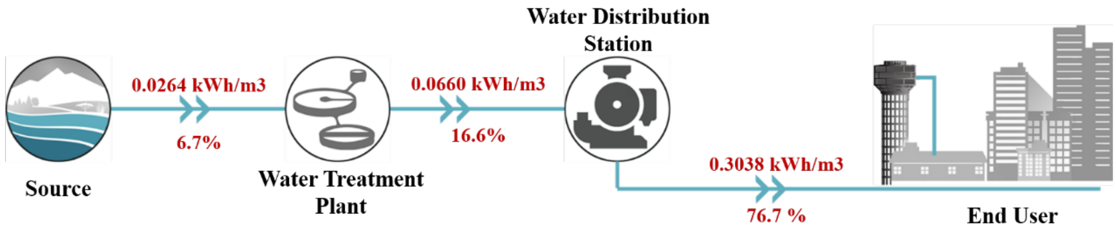


Figure 3: Value chain wise energy consumption in water utilities

Thus, this study considers that segment of value chain as the primary focus area for assessing and understanding the impacts of the urban characteristics on the energy consumption in water supply services.

Looking at the levels of water supply service in the Ahmedabad city, it is observed that around 97% of the city's area is covered with the municipal water services (Centre for Water and Sanitation, 2018). Nearly 1330 ML of water gets treated and supplied to the end users through 226 Water Distribution Stations (WDS). These 226 WDS are spatially spread across six administrative zones and 48 wards. The Ahmedabad Municipal Corporation (AMC) has the Supervisory Control and Data Acquisition (SCADA) system in place to monitor and co-ordinate the operations pertaining to the water utilities. The SCADA system monitors the quantitative and qualitative aspects of the service. The system monitors, measures and collects data pertaining to the water supply and energy. The SCADA data is logged and stored at the granularity of 15minutes interval. Nearly 185 out of 226 WDS are currently connected under the SCADA network. This credits the city to have connected with one of the largest SCADA networks in the country. The Table 3 provides overview about the spatial spread of these WDS connected to SCADA that are spread across the different administrative zones of the city.

Table 3: Administrative zone wise distribution of WDS connected under SCADA

Administrative Zones	Number of WDS monitored by SCADA
North Zone	24
South Zone	40
Central Zone	16
East Zone	30
West Zone	34
New-West Zone	41
Total number of WDS monitored by SCADA	185

The SCADA system measures the data pertaining to the water resource and energy consumed in the operations of the water utility. At the water distribution station level, the SCADA monitors and records a set of real-time data and generates fourtypes of reports that capture qualitative and quantitative data. The fourtypes of reports that are generated by the SCADA are;Daily report, monthly report, zonal report and Daily pump report. In case of the daily reports, the data pertaining to all the parameters areloggedat every 15 minutes interval and in the case of the monthly reports only the peak values of the day for the respective parameters will be recorded. The Table 4 represents the summary of the datasets that are gathered by SCADA at the WDS level.

Table 4: SCADA datasets for the Water Distribution Stations

Type of Report	Datasets measured	Granularity of the data
Daily Report	Pump level datasets (Voltage, Average current, Power Factor, Active Energy)	15 minutes
	Total number of pumps operating	

	Runtime of eachpump	
Daily Pump Report	Inlet volume	15 minutes
	Outlet volume	
	Qualitative data (Ph and Turbidity)	
	Pressure	
Monthly Report	Total pump run hours in a day	Daily basis
	Total inlet and outlet volume in a day	
	Total units consumed in a day at the WDS level	
Zonal Report	Total inlet and outlet volume in a day	Daily basis
	Peak pressure attained in a day	
	Total units consumed in a day at the WDS level	

As represented in the Table 4, the SCADA system in Ahmedabad monitors and procures long term datasets pertaining to the quantitative, qualitative and electrical aspects of the water utilities at WDS level. The administrative and engineering aspects of the water service is handled by the two dedicated departments under Ahmedabad Municipal Corporation, namely; Water Operations Department and Water projects department. The Water Projects department handles all the ofcivil work and water resource management for the water utilities. The Water Projects Department possesses the datasets collect and manage all the datasets pertaining to the network maps and baseline inventory of the services under the water utility. The Operations department handles all the electrical aspects of the utilities. The Water Operations department is responsible for storing, managing and usage of the SCADA datasets towards enhancing the operations of the utility.

2.1 Data collection

In order to understand the impact of the urban characteristics on the energy consumption at WDS, it is important to understand the network coverage and operations pertaining to the distribution station. The major datasets that are considered in the study are as explained in the Table 5.

Table 5 : Datasets required for the study

Datasets required	Definition	Source of data
Command area of WDS	The geographical area that is being served by the WDS is the command area of that WDS	Water projects department- Ahmedabad Municipal Corporation
Electricity data	The energy consumed at WDS in pumping the water	SCADA- Ahmedabad Municipal Corporation

The network maps and the command areas for the water distribution stations are obtained from the Water Projects Department under Ahmedabad Municipal Corporation. Due to the involvement of multiple stakeholders within the department, the obtained datasets were not in an uniformed format. Some of these datasets were obtained in hardcopies, while some in different digital formats such as *.pdf and *.dwg. Thus, all these datasets were digitised and converted to a common shape file format for the further analysis.

The electricity data that are required for the study pertaining to the water distribution stations are obtained from the zonal reports generated by SCADA system. As the complete datasets were not available, one day's zonal reports were obtained for all six administrative zones for ten months of the year 2018. The overview of the datasets obtained for the study is represented in the

Figure 4.

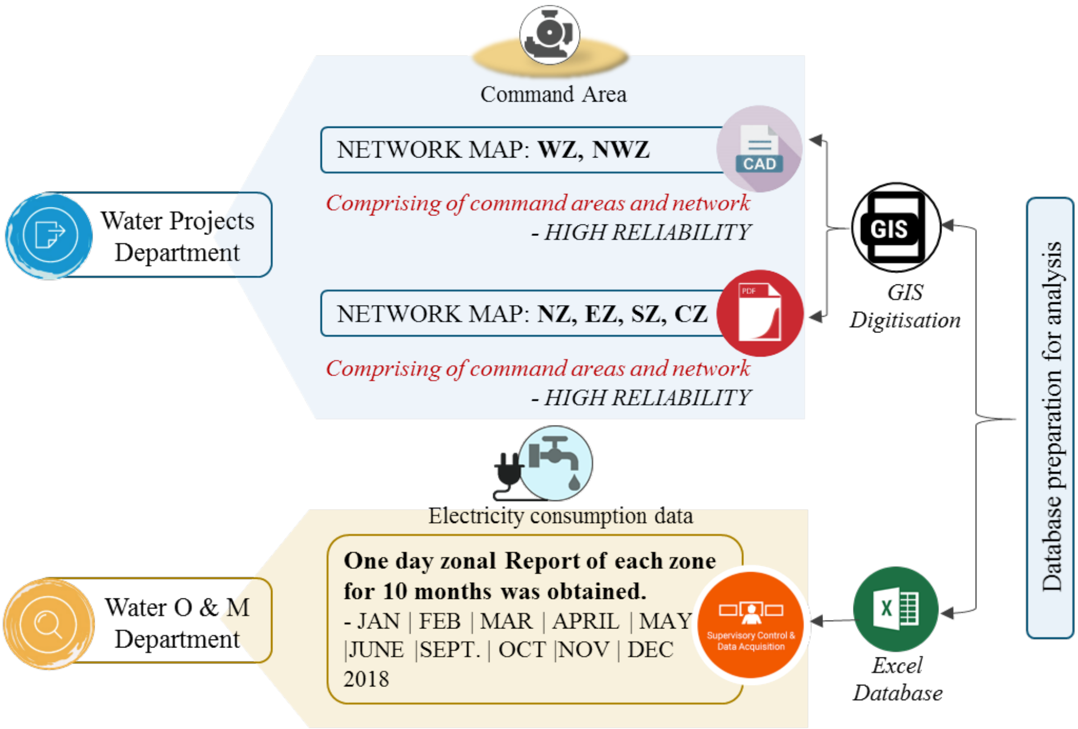


Figure 4: Overview of the datasets obtained for the study

Considering the following datasets obtained for the current study, the unbiased sampling methodology is adopted for selecting the representative samples of the WDS for the study. This method primarily intended to sample the study area by considering the wards with highest and lowest population densities and the Water distribution Stations with highest and lowest electricity consumption. Due to the limitations in the availability of datasets, an unbiased sampling was conducted by considering the availability of the electricity consumptiondatasets from SCADA. Thus, out of total 226 WDS, only 185 WDS with the SCADA system were filtered and considered for the sampling.

However, among the available of 185 WDS, the command areas of the respective distribution stations were obtained for only 80 WDS. These 80 WDS with the data pertaining to their electrical consumption and command area are selected as the actual study samples for the current study.

The selected sample size of these 80 WDS accounts to nearly 36% of the total WDS in the city. Further, the command area of these 80 WDS comprises nearly 32% of the total population of the city. The spatial distribution of the sampled command areas across the different administrative zones are represented in theTable 6

Table 6: Spatial distribution of the selected WDS

Zone	Total No. of WDS under SCADA	Total WDS sampled
West Zone	34	27
New West Zone	41	13
North Zone	24	14
Ease Zone	30	10
South Zone	40	16
Central Zone	16	0
Total	**185**	**80**

The spatial distribution of the command areas of the sampled water distribution stations are

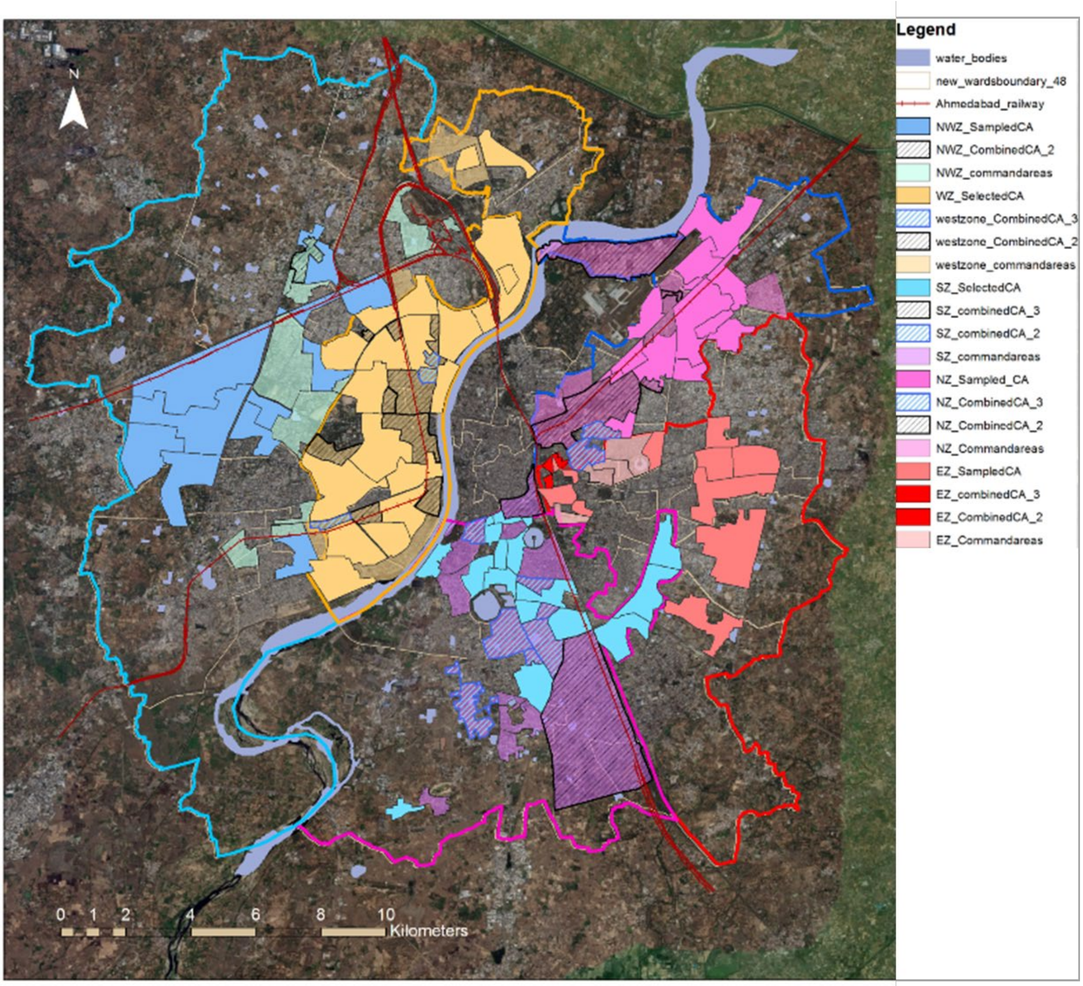


Figure 5 : Spatial distribution of the sampled command areas

represented in the Figure 5.

2.2 Impact of the urban parameters on the energy consumption in water distribution station

The literature suggests that the energy consumption in the water utilities are the function of the urban parameters such as command area of the WDS, Plot densities in the command area, network length, population density and the volume of the water supplied.

The effects of these urban parameters on the water utilities are studied using the best suited statistical tool, correlation. Correlation will assist in identifying the type of the relationship shared between the two parameters and will also assist in understanding strength of the relationship shared between the parameters. The correlation analysis of the parameters will give the correlation coefficient that varies from -1 to +1. Positive value indicates that the dependent variable will increase with the increase in the other variable. Negative value indicates that the dependent variable will decreases with the increase in the other variable. Further, the stregth of the relationship will be detarmined by the scale represneted in the Figure 6.

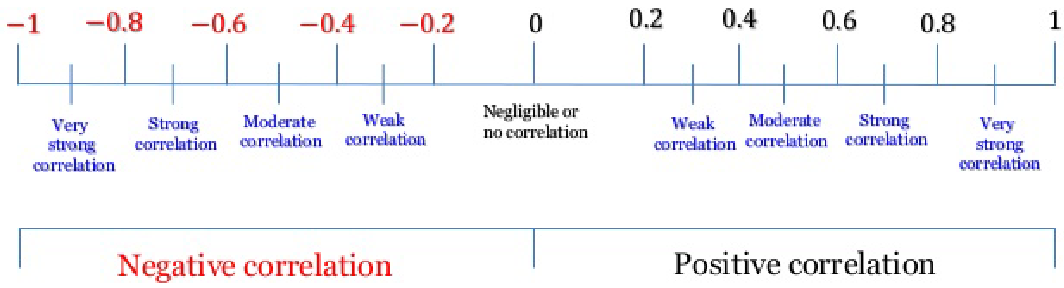


Figure 6: Scale representing the strength of the correlation

2.3 Analysis and Observations

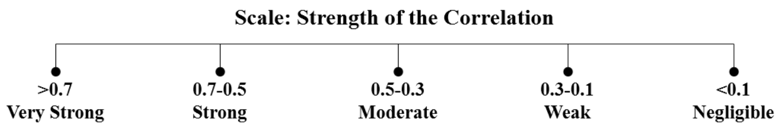
The correlation of the identified urban parameters was studied to understand their effects on the energy consumption in WDS. These analyses are conducted at the city scale and the zonal scale. All the identified samples of 80 distribution stations were considered for the analysis at the city scale and the distribution stations belonging to the respective zones were considered for the zonal level analysis.

2.3.1 Volume of water supplied

The volume of water supplied by each WDS is a function of current and projected demand of the population residing in the command area that is being served. The correlation analysis was conducted to understand the impact of the volume of water supplied at both the city and zonal level. The observations pertaining to the same are as represented in the Table 7.

Table 7: Zone wise correlation between volume of water supplied and energy consumed

Administrative Zone	Correlation coefficient
North Zone	+0.954
East Zone	+0.967
South Zone	+0.953
West Zone	+0.961
New West Zone	+0.962



The Table 7 clearly suggests that the volume of water supplied shares strong positive correlation with the energy consumed by the respective WDS in the administrative zone. Further, upon studying the city level impact by considering all the 80 sampled WDS, it was observed that it shares strong positive correlation with a correlation co-efficient of +0.953.

The results obtained at the zonal and city level suggest that the energy consumed in the WDS will increase with the increase in the volume of water supplied. This linear increase in the electricity consumption can be determined by the equation-

$$\text{Unit consumed (kWh)} = 0.0723\ m^3 + 88.72$$

This equation suggests that the electrical units consumed will increase by 0.0723 times with every unit increase in the volume of water supplied by the WDS. The linear relationship between the electrical units consumed for the sampled water distribution station and the volume of water supplied is represented in the Figure 7.

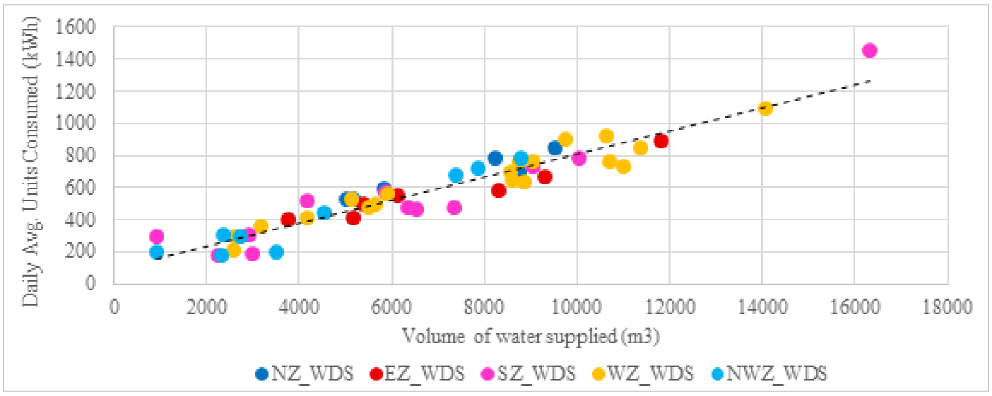


Figure 7: Graph representing the correlation of volume of water supplied and the electricity consumed

Further, in order to assess the impact on the efficiency of the pumps, the standard deviation graph has been plotted for all the considered samples of the distribution stations. It was observed that the increase in the volume of water increases the absolute energy. The unit consumed per m^3 of water supplied will not vary significantly. The standard deviation plot suggesting the same is represented in the Figure 8.

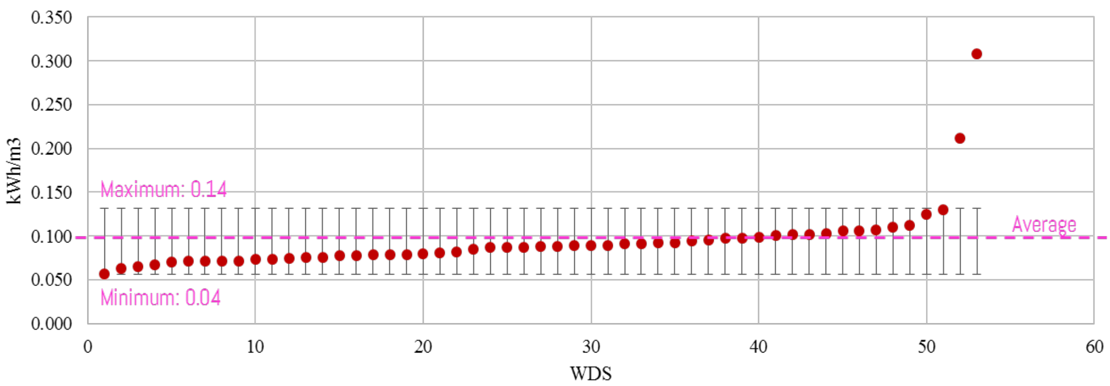


Figure 8: Standard deviation plot of units consumed per m^3

2.3.2 Command area served

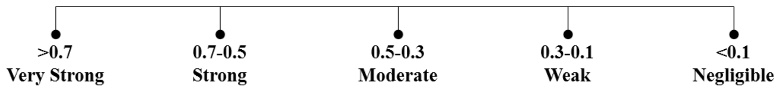
The impact of the command area of the WDS on its energy consumption is studied by the correlation analysis of the command area with the energy consumed in the respective WDS. The observation pertaining to the same are represented in the Table 8.

Table 8: Zone wise correlation between command area and energy consumed

Administrative Zone	Correlation coefficient
North Zone	+0.543
East Zone	+0.793
South Zone	+0.769
West Zone	+0.667

New West Zone	+0.531

Scale: Strength of the Correlation



The Table 8 suggests that the command area shares strong positive correlation with the energy consumed in the East and South zone. Further, the command area shares moderately positive correlation with the North zone, West Zone and New-West zone.

Upon studying the relationship at the city level by considering all the 80 WDS, it was observed that the command areas have moderately positive relationship (+0.503) with the energy consumed in the WDS. The relationship between the command area and the energy consumption in the WDS is as represented in the Figure 9.

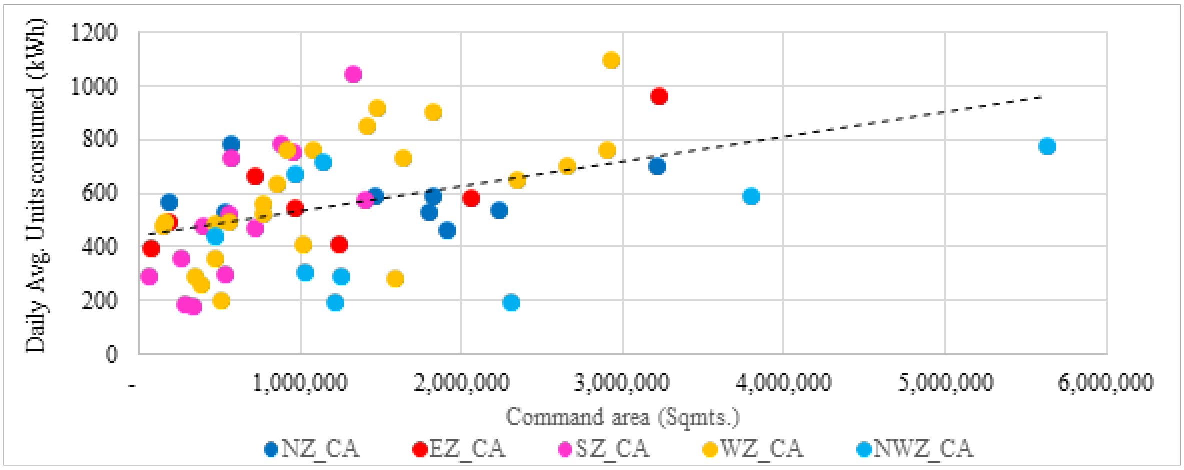


Figure 9: Correlation plot of the command area Vs energy consumed in WDS

In order to understand the difference in the strengths of the correlation among the administrative zones, the details pertaining to the characteristics of the command area are studied. It is observed that the command area of the water distribution stations varies in the network lengths and the number of water supply connections that are being served. Therefore, in order to obtain the better sense of understanding of the effects of command area, it is important to study the effects of the characteristics of command area such as network length and the total number of connections within the command area.

The exact data pertaining to the total number of water supply connections that are served by the respective WDS is not available with the Ahmedabad Municipal Corporation. Therefore, the plot density has been used as the proxy for the number of connections. The literatures suggest that the increase in the plot density of the command area will decrease the network length to be served. Further, high plot densities will also ensure closer proximity of the water connections to the WDS and hence reduces the pressure (Wong, Speight, & Filion, 2015).

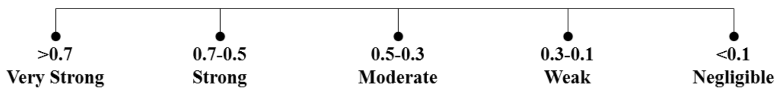
2.3.3 Plot density

The plot density of the command area is identified by dividing the total number of plots in the defined command area of a WDS by the net command area. Net command area is obtained by deducting the area under roads, railways and water bodies from the actual command area. The effect of these identified plot densities on the energy consumption of the WDS are studied using the correlation analysis. The observations found in the correlation analysis are represented in the Table 9.

Table 9: Zone wise correlation between Plot density and energy consumed

Administrative Zone	Correlation coefficient
North Zone	-0.139
East Zone	-0.135
South Zone	-0.240
West Zone	+0.625
New West Zone	+0.697

Scale: Strength of the Correlation



From theTable 9 it is observed that the plot density in the command area of the WDS shares negative correlation with the energy consumption in the North zone, East zone and South zone. Whereas, it shares positive correlation in the case of West zone and New west zone. Further, when studied considering all the 80 sampled WDS it was observed the plot densities in the command area has weak positive correlation with (+0.143) with that of the energy consumption. Although, the impact of the plot densities very less at the city level, these characteristics will have considerable impact on the energy consumption at zonal level.

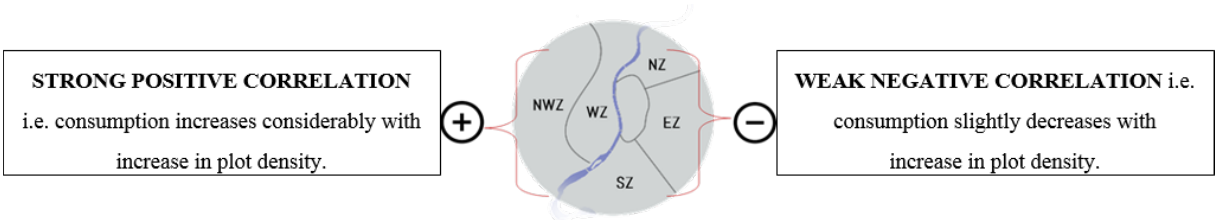


Figure 10: Zone wise impact of plot density on energy consumption in WDS

In order to understand the variation in the effects of the plot densities on the energy consumption of the WDS, the characteristics of these administrative zones were studied. The land use and land cover of the command areas of the 80 sampled WDS are mapped and studied for the same. The Figure 11represents the land use pattern of the selected command areas.

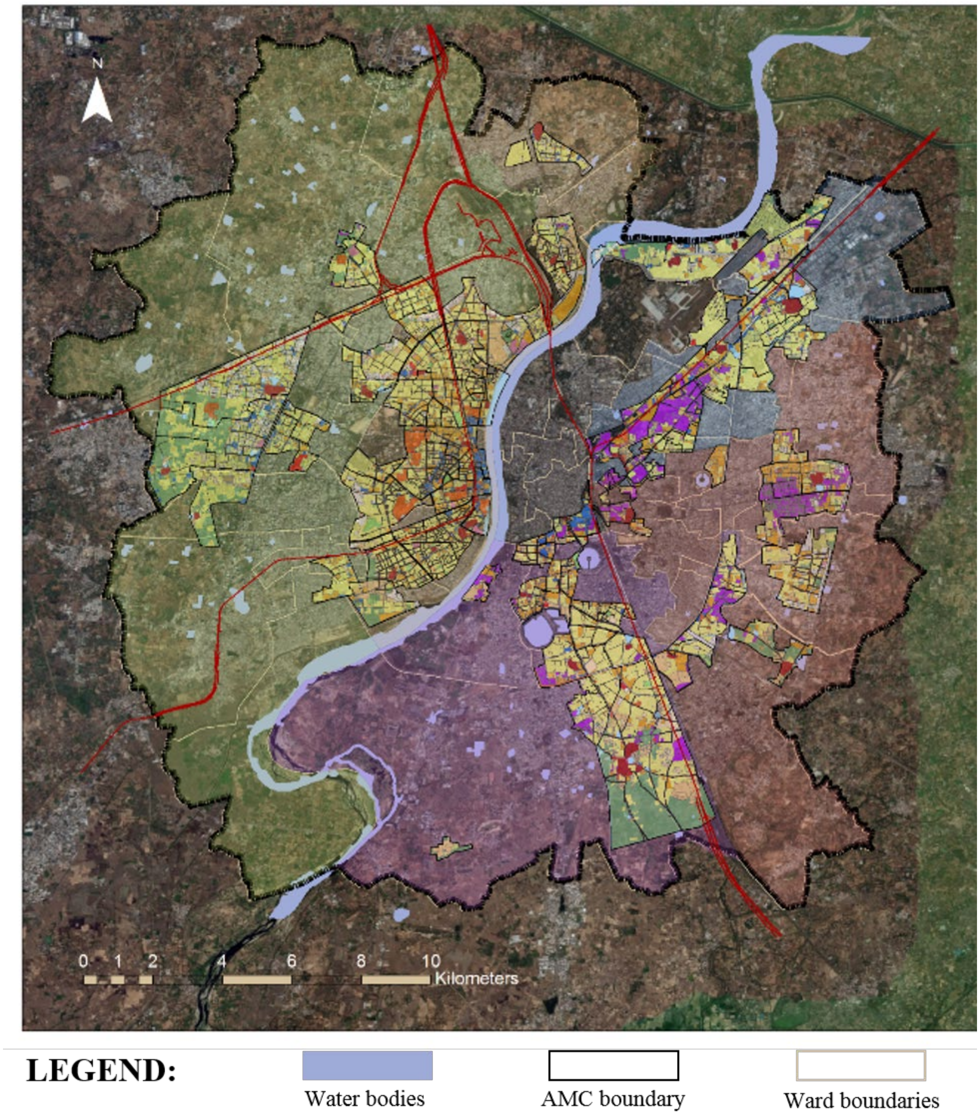


Figure 11: Land use and land cover of the sampled command area

The eastern side of Ahmedabad comprises of the North zone, east zone and south zone. From the land use and land cover analysis it is observed that the administrative zones on the eastern side of the city majorly comprises of the following typologies.

- Slum Type, Kachha, Unplanned, Informal Settlements.
- Row Houses.
- High-density Low Rise Residential Units.
- Small and Heavy Industrial Units.

Similarly, upon analysing the administrative zones on the western side of the city, it was observed that they have comparatively lesser share of permanent slum type, Kachha, unplanned, informal settlements. West zone comprises majorly of low-rise low density and some high-rise high-density apartments while the New West Zone comprises majorly of bungalow society, farmhouses,

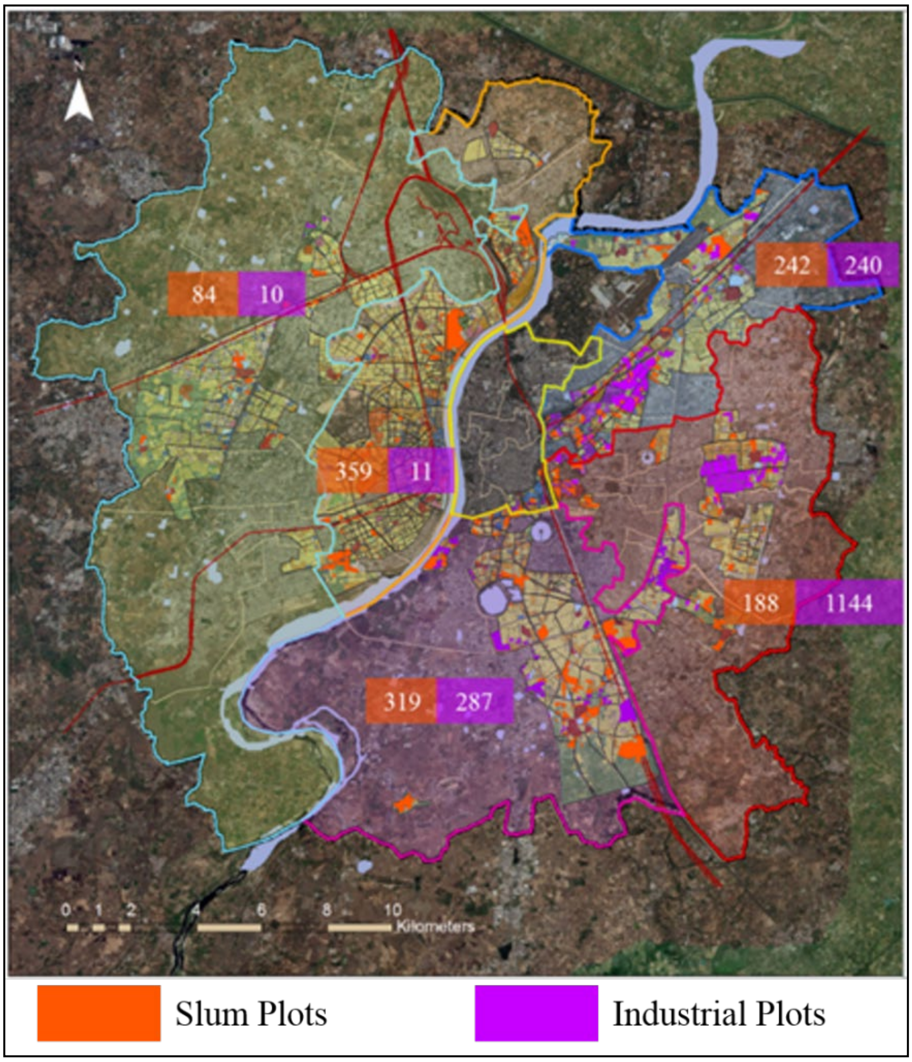


Figure 12: Number of slums and industrial typologies in the respective administrative zones of Ahmedabad

commercial buildings, affordable housing apartments, etc.

In order to understand the details pertaining to the spatial differences in the built use and land use patterns between the eastern and western Ahmedabad, the absolute number of slums and industrial plots under the sampled command areas were identified. TheFigure 12 represents the total number of slum and industrial plots in the respective administrative zones of Ahmedabad.

From Figure 12it is observed that the major share of slum and industrial plots areseen in the eastern side of the Ahmedabad. Further, upon closer investigation, it was evident that majority of these plots either does not have any connection or have shared connections. Thus, generally these plot are bound to have lesser number of AMC water connections than the others. The level of water services in Ahmedabad suggest that, only 75% of the slum households in Ahmedabad have water supply connection from AMC (Centre for Water and Sanitation, 2018). Further, the industrial units are dependent ground water sources.Thus, even with the higher number of plots in the eastern zones, the number of plots with AMC water connections is lesser. This reflects the decreasedelectricity consumption with the increase in plot density of the eastern zones of Ahmedabad

Table 10: Total number of slum and industrial plots

Total number of plots	Eastern Ahmedabad	Western Ahmedabad
Slum Plots	749	443
Industrial Plots	1671	21

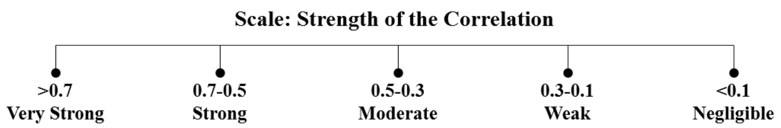
The western zones of Ahmedabad with larger share of permanent settlements that have larger number of AMC connections. Thus, the increase plot density increases the energy consumption in the western zones.

2.3.4 Network length

Network length has been considered for the study to understand the total area spread by the water distribution system. In order to get an idea about the characteristics of the sampled command areas, the network length within the sampled command area has been studied. The correlation of the total network length in the command area and the energy consumption in the respective WDS is as represented in the Table 11.

Table 11:Zone wise correlation between network length and energy consumed

Administrative Zone	Correlation coefficient
South Zone	+0.710
West Zone	+0.763
New West Zone	+0.604



The table suggests that the network length has a strong positive correlation of the energy consumption in the WDS. Assessing the impact of the network length at the zonal level, it is observed that the eastern Ahmedabad comprising of the south zone and west zone shares strong positive correlation with network length. Whereas, the western zones of Ahmedabad such as new west zone and west zone shares moderately positive correlation. This infers that with the unit increase in the network length, the energy of the respective WDS in the eastern zone will increase at a higher rate than that of the WDS in the western zones. The eastern zones have older network and the network in the western zones have newer network. The distribution in the older network are subjected to friction loses resulting the higher energy consumption.

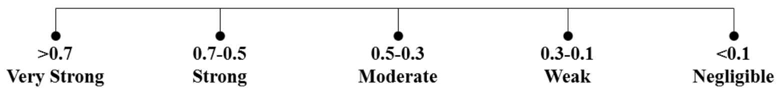
2.3.5 Population density

The population density of the command area gives idea regarding the impact of the spatial spread of the end users on the energy consumption in the WDS. Considering the theories of economies of density, it is suggested that the WDS serving the command areas with higher population density will consume comparatively lesser energy than the WDS serving lower dense command areas. In order to validate the theory, the correlation analysis has been conducted considering the population densities of the sampled command areas.

Table 12:Zone wise correlation between population density and energy consumed

Administrative Zone	Correlation coefficient
North Zone	-0.437
East Zone	-0.207
South Zone	-0.038
West Zone	+0.070
New West Zone	+0.051

Scale: Strength of the Correlation



At the city level, the population density of the command areas shares weak positive correlation with the energy consumption of the WDS. Further, at the zonal level, it is observed that the eastern zones of Ahmedabad share weak negative correlation and the western zones of Ahmedabad shares weak positive correlation. The Figure 13 represents the difference in the relationship of the population density among the different administrative zones of Ahmedabad.

The Ahmedabad Municipal Corporation supplies water with a certain pressure head irrespective of the population density and built density of the service area. In the areas with higher population density, the diameter of the network will be higher to cope with the increasing demand. As the city of Ahmedabad is moderately dense and the sparse in the spatial characteristics, there is not much impact of the population density on the energy consumption of the WDS. The correlation coefficient of the population density at the city level is found to share very weak positive relationship (0.098) with the energy consumption in the WDS. Further, at the zonal level, it is observed that the eastern zones share weak negative correlation and the western zones share weak positive correlation.

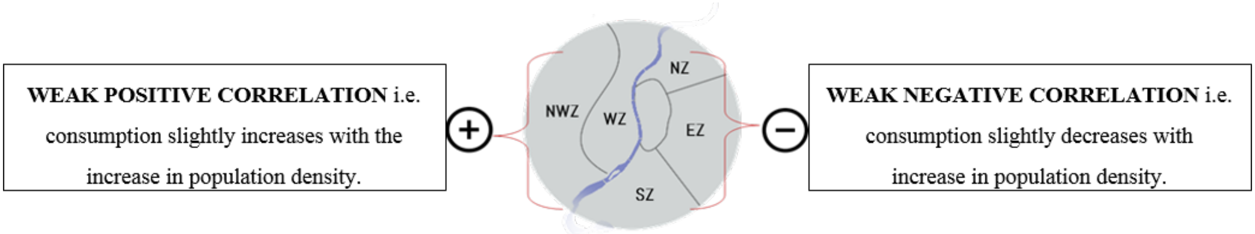


Figure 13: Zone wise impact of plot densities on the energy consumption in the WDS

This difference in the type of the relationship between the eastern and western zones is mainly because of the large number of slum and industrial populations located on the eastern part of the city. These settlements either does not have the water connection or has the shared connections. This reflects the decreased energy consumption even with higher population densities.

The urban characteristics such as population density, command area served, volume of water supplied, etc., will affect the energy consumed in the municipal water supply. The effects of these parameters and the scale of impact possessed by these parameters on the energy consumption in water supply is demonstrated in the above chapters. These parameters affect the energy consumed at the municipal level. The energy expenses of the same are the responsibilities of the Ahmedabad Municipal Corporation. The value chain of water comprises of the building level energy where in the end user will pump the water from underground tank to the overhead tank. Hence, building level energy consumption in the water pumping is also included in the study to comprehend and understand the overall energy consumption in the water services. The details pertaining to the sampling methodology adopted and the building level energy assessment related to water pumping are explained in the further chapters.

2.4 Building level energy assessment

In order to understand the building level energy consumption in water pumping, the sample buildings were selected considering the different typologies. The scope of the study was restricted only for the residential buildings. Further, considering the height of the building as the parameter, the buildings of flowing typologies were surveyed.

Table 13: Residential building typologies considered for sampling

Building height	Building Typologies
High rise (>5 floors)	Apartments
Midrise (3 to 5 floors)	Row Houses, Bungalow Societies, Low Rise Apartments
Low rise (<3 floors)	Affordable housing

The spatial location of the sampled buildings are as represnted in the Figure 14. Care has been taken to find the samples across different administrative zones of the city.

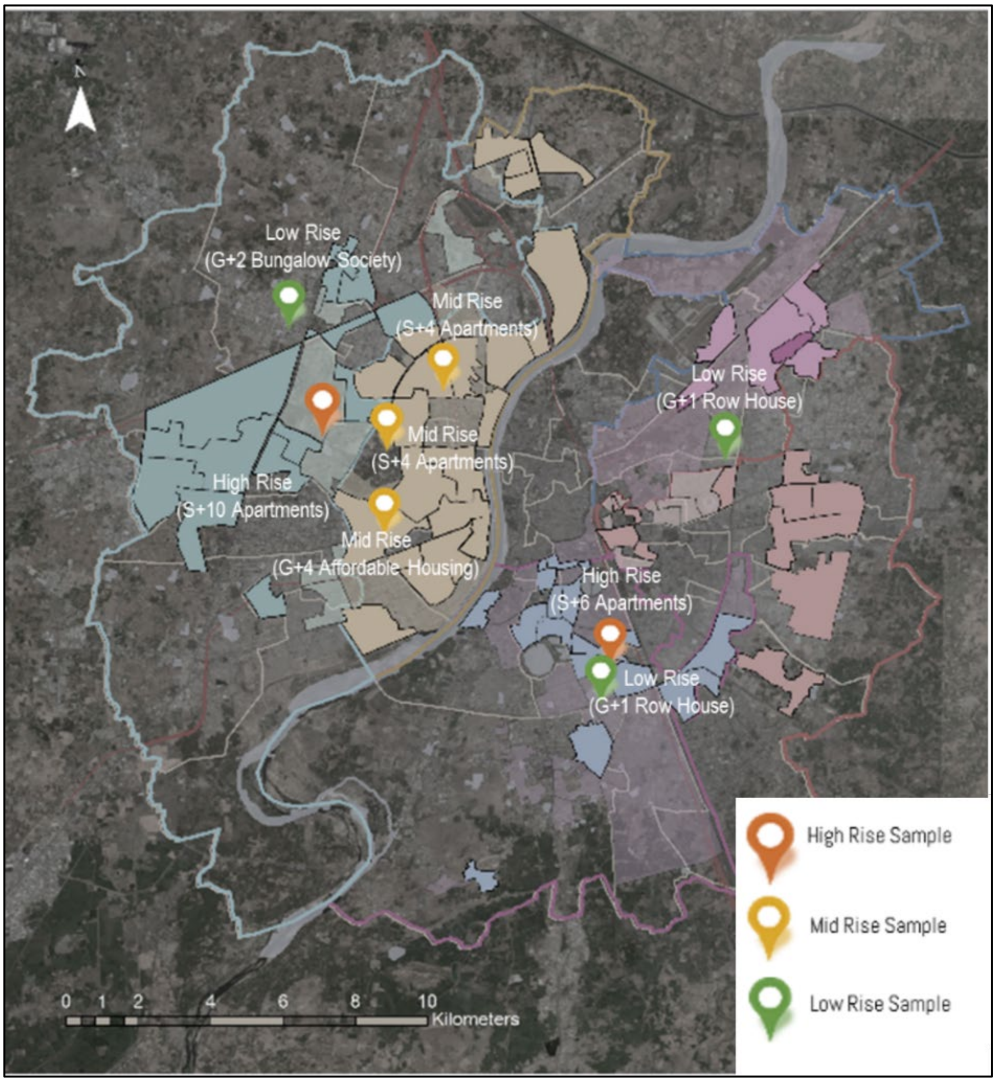


Figure 14: Spatial locations of the sampled buildings

The unbiased purposive sampling method has been incorporated in the selection of the buildings. In order to select the buildings among the different typologies, the building of maximum occupant was selected, and the all the other typologies have been selected to match with the building with the maximum occupants. This assists in maintaining the normality in the number of occupants in each typology thereby allowing to compute the per capita energy consumption in water pumping. The high-rise apartment (S+10) with the total occupancy of 210 has been selected as the standard. In accordance to the same, the number of building samples selected from the different typologies are as represented in the Table 14.

Table 14: Number of samples selected in each typology

Building Typology	Total number of buildings
High-rise high-density Apartments	2
Low-rise low-density bungalows	3
Low-rise low-density apartments	7
Low-rise low-density row houses	42

The findings pertaining to the building level energy consumption in each of these selected typologies are as represented in the Figure 15.

Figure 15: Per capita energy consumption in each of the sampled building typologies

From the Figure 15 it is observed that the low rise low density bungalow societies consume highest amount of per capita energy in the water pumping in comparison to that of the other typologies considered in the study. The low-rise high-density row house consumed the lowest amount of per capita energy in water pumping.

Further, a comparison analysis was conducted by considering the municipal level energy consumption and the building level energy consumption in water pumping. In this case, the per capita energy consumed in the respective WDS is compared with that of the building level energy consumed for the sampled buildings. The observations obtained in this comparative analysis are as represented in the Figure 16.

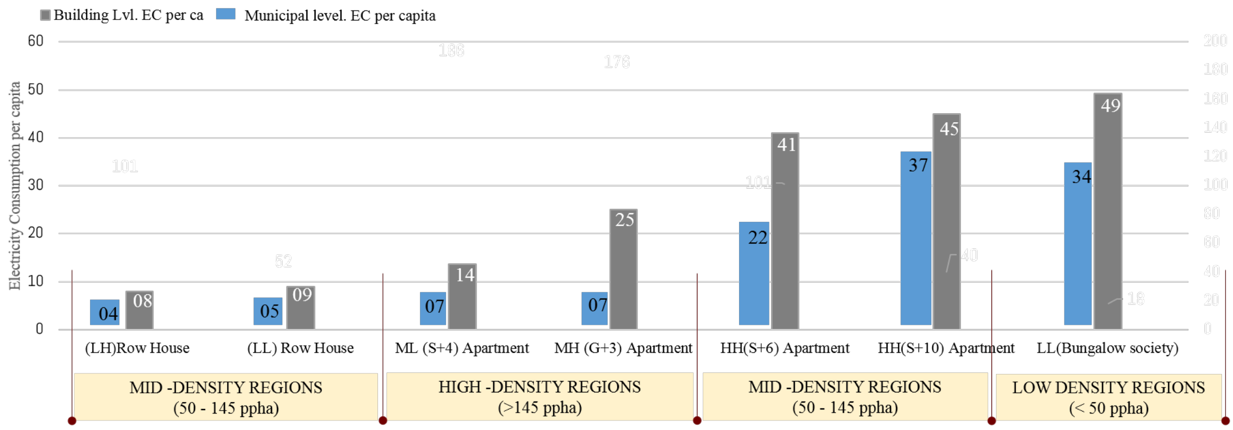


Figure 16: Comparison of the per capita building level energy in water pumping with that of the per capita municipal energy in water supply

From the Figure 16 it is observed that the energy consumed in water supply is the combination of both municipal level energy consumption and building level energy consumption. Therefore, in order to optimize the energy consumed in water supply, one need to understand and optimise the energy consumed at both the levels.

2.5 Synthesis

Considering the observations from the municipal level energy consumption and the building level energy consumption the scenarios can be derived for the energy efficient future developments. The density acting as a synonym of efficiency has been taken as an important urban parameter for deriving these scenarios for the energy efficient urban development patterns for the city of Ahmedabad. Along with density, other guiding parameters such as percentage share of the population getting access to these basic services, land coverage and per capita electrical energy expenditure at the building level and the city level are also considered.

i. Scenario 1- Low rise bungalow type development

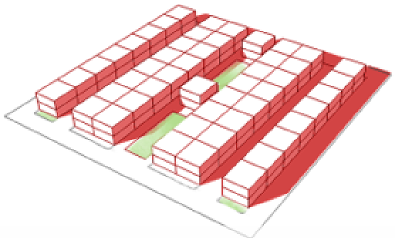


Figure 17: Scenario depicting low rise bungalow type development

If the city decides to grow with low-density (<50 persons per hectare) low-rise bungalow type development, the unit electricity cost will be high at both the municipal level and the building level. In this type of development, the number of the people getting access to the services is also low and the land cover will be higher in this type of development

ii. Scenario 2- Medium density low rise development

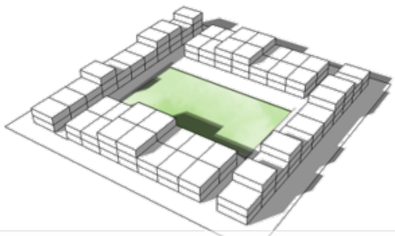


Figure 18: Scenario depicting low rise bungalow type development

If the city decides to grow with medium-density (50-145ppha) low-rise row housing type development, the unit electricity cost is medium at both municipal level and building level. Further, the access to the services is comparatively high and land coverage is comparatively lower.

iii. High density- midrise and high-rise development

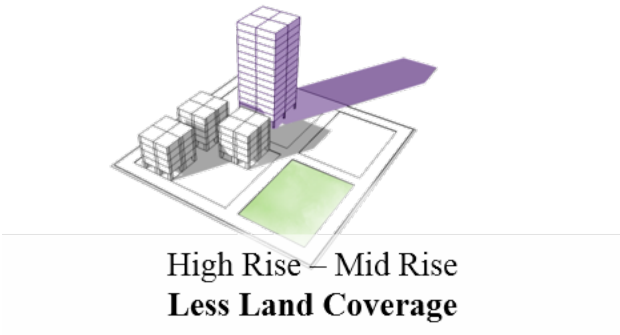


Figure 19: Scenario depicting low high-density midrise type development

High-density (>150 ppha) urban development with a mix of mid-rise and high-rise built typology. In this type of growth, the unit electricity cost will be higher at the building level but will be lower at the municipal level. Further, the access to services is to a higher number of people. Also, the land covered is comparatively very less which can be then opened to other social infrastructure development and green and open spaces.

From the three scenarios, it can be concluded that the densityis an important parameter of urban form towards attaining the optimization in the energy consumed in water supply. Further, its not only the high-rise development that reduces the energy consumption. The medium rise and high-density type of development will ensure optimization at both the municipal level and the building level and thereby enhances the overall efficiency of the system.

Thus, a good mix of mid-rise, high-rise seems to be an optimum way forward for shaping the future urbanization of the city of Ahmedabad in an efficient manner. The land market dynamics will play a its own role alongside all these developments and is scoped out in the current study.

3 Scaling up of the framework to different cities

After understanding the relationship of the urban form on the energy consumption at the city level, it becomes important to validate and test the obtained observations by considering a larger studycases. This signifies the need to scale up the established water energy nexus at the larger level that fits good for the cities of different sizes and characteristics. In order to understand this in detail, it is necessary to understand the behaviour of the cities of different urban forms on the energy consumption in municipal water service. This understanding will assist in developing a relationship between the spatial planning, municipal water service and electrical energy consumption with respect to the same.

In order to understand the relationship of the different urban forms on the energy consumption in water supply, the cities from the states of Gujarat and Maharashtra are considered as the case cities. The details of this assessment are explained in the further sections.

3.1 Factors affecting the energy consumption in municipal water service

There have been literatures in the past suggesting the linkages between the energy consumption and the physical forms of the city. Physical form of the city here refers to the spatial distribution, building typology, street pattern, location of the jobs and the residences. The studies suggest that the alteration of these physical forms can impact the overall energy consumption of the city (Salat & Bourdic, 2015). Further, according to the UN-Habitat, the interaction of certain urban characteristics constrains energy use and future pattern of growth of a city. These are the physical form, the built characteristics, the relation of transport corridors with population density, and to a certain extent the pattern of spaces (UN-HABITAT, 2016).

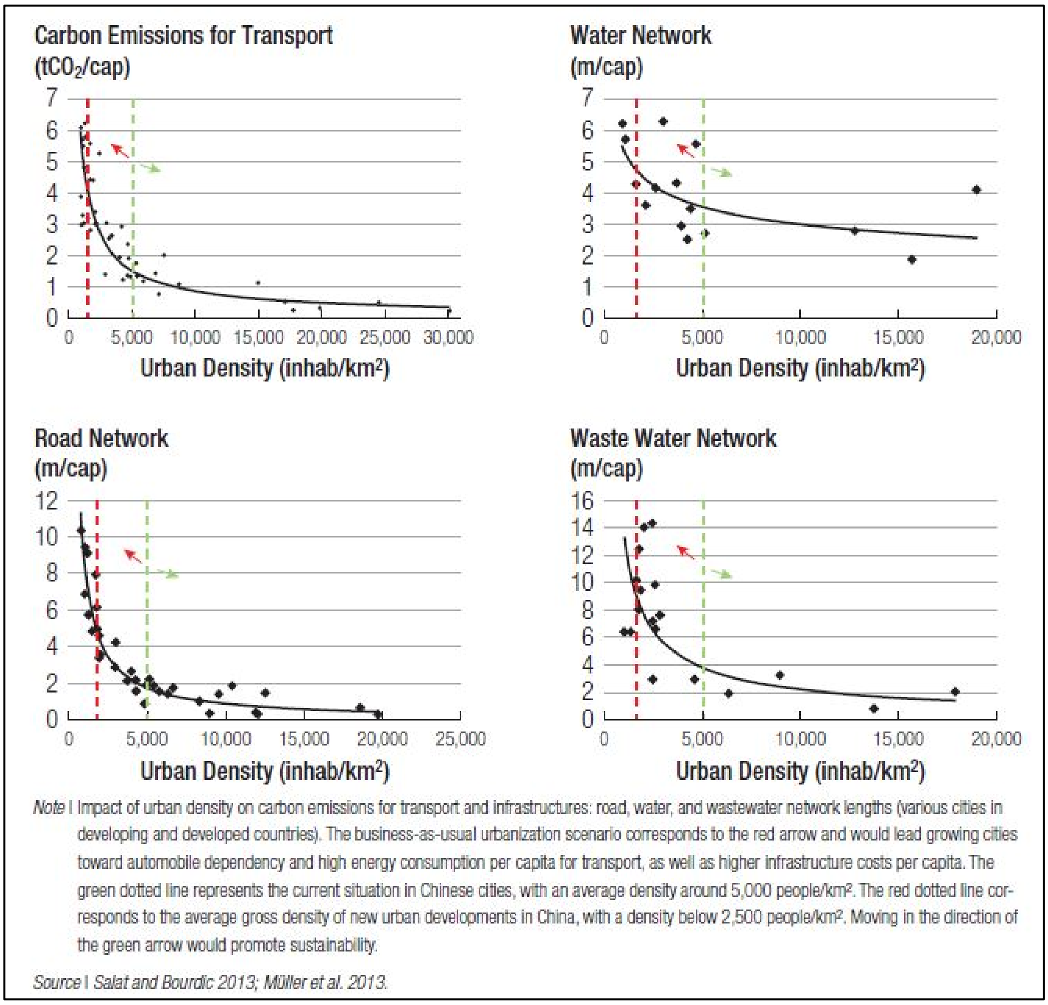


Figure 20: Plots representing the impacts of density on the infrastructure costs of the city

Source: (The World Bank, n.d.)

The literature also suggests the impact of the geographical and locational factors such as topography and climatic condition of the cities on their energy consumption (Larson & Yezer, 2014b). Factors like urban GDP and urban energy consumption per unit of urban land may also be considered as a factor for energy consumption. In this case, the areas with higher points of energy density are also the highest points of economic density (Salat, n.d.).

Apart from the density and topography, there are many other parameters that impact the energy consumption in the municipal water services. The Table 15 identifies the corresponding literature and the suggested urban parameters that impacts the energy consumption in the municipal water service.

Table 15: Literatures identifying the urban parameters that affect the energy consumption

Parameters impacting the energy consumption in municipal water supply	Literature describing the relationship of these parameters with the energy consumption
The physical form of the urban centre	(Salat, Chen, & Liu, 2014), (UN-HABITAT, 2016)
The density of household and population	(Larson & Yezer, 2014a)
Land use and FAR	(Bigio et al., 2014), (Salat et al., 2014)
Road network and density	(UN-HABITAT, 2016), (Salat et al., 2014)
Climate	(Salat et al., 2014)
Topography	(Salat et al., 2014)
Socio-economic indicator like economic density	(Salat et al., 2014)

Considering the learning from the past literatures, the following parameters are identified to have direct impact on the energy consumption in the municipal water supply.

- Population Density
- Urban Morphology
- Population served with the municipal water supply
- Area covered under municipal water supply
- Per capita water supplied
- Non-revenue water
- Source of water

For the convenience of the study and further understanding the identified parameters affecting the energy consumption in the municipal water supply are classified as,

- **Urban Development Parameter:** The parameters that are part of the characteristics of the city are considered as Urban Development Parameters. Population density and Urban morphology are the two parameters that are considered under this set of parameters.
- **Service level Parameter:** The parameters that characterises the service perspective of the water supply are considered as service level parameters. The parameters such as, total population served, total area covered, per capita water supplied, non-revenue water and the source of water.

Further, for studying the identified parameters for different cities, the cities also need to be classified with respect to these parameters. Hence, in order to study the service level parameters, the cities are classified considering the norms and guidelines. The details pertaining to this classification are explained in the Table 16.

Table 16: Classification of the cities based on service level parameters

Service level Parameters	Classification of the cities	Reference for the classification
Population served with the water supply	▪ Above 1 Lakh ▪ 99,999 to 50,000 ▪ 49,999 to 20,000 ▪ Less than 20,000	Based on the census classification of the Indian cities
Service Area	▪ Above 40 sqkm ▪ Less than 10 sqkm	Based on a stratified sampling of the available data, keeping in mind the distinction between large, medium and small-sized cities
Per capita water supplied	▪ More than 135 LPCD ▪ 90 to 135 LPCD ▪ Less than 90 LPCD	Stratified sampling referring theCPHEEO guidelines for water supply which mandates 150 LPCD for metropolitan cities, 135 LPCD for large cities and 90 LPCD for medium-sized cities.
Non-Revenue Water	▪ More than 20% NRW ▪ Less than 20% NRW	Classified based on the considered permissible level of NRW as per benchmarks

3.2 Selection of the case cities

The identified urban development and the service level parameters are tested by considering the cities from the states of Gujarat and Maharashtra. The Performance Assessment Systems from the Centre of Water and Sanitation (CWAS) have maintained and updated the data pertaining to the level of services for the municipal services. The states of Gujarat and Maharashtra being the two largest consumers of the electricity in the country. The PAS data base has the data for nearly 170 cities from Gujarat and 393 cities from the Maharashtra. The sample case cities required for testing the effects of the identified parameters on the energy consumption in water supply are selected from the total of these 563 cities.

The sample case cities for the study are selected based on the following criteria,

i. **Presence of networked services:** The scope of the study is limited to the cities with the networked water supply services. The study aims to test the effects of the identified parameters only on the energy consumption in the municipal water supply. Thus, the cities that have majority of the service covered by networked pipelines are considered as the samples for the study.

ii. **Network length:** In order to understand the energy consumed in the municipal water supply, it is very important to know the details pertaining to the network length. Hence, only the cities that have data pertaining to the network length are considered as the case cities for the study.

iii. **Electricity charges:** In order to conduct the energy assessments, it is important to have the details pertaining to the electrical units consumed and the charges. Hence, the cities that have networked services and the data pertaining to the electrical consumptions are considered as the samples for the study.

Among the 563 available cities from the states of Gujarat and Maharashtra, total of 93 cities have been selected for testing the impact of the identified parameters. These 93 selected cities fulfilled the above-mentioned criteria and the details pertaining to these cities are as represented in Table 17

Table 17: Number of cities selected and their size class

Name of States	Municipal Corporation	Class A	Class B	Class C	Nagar Panchayat	Total
Gujarat	6	9	19	16	11	61
Maharashtra	13	4	7	6	2	32

The spatial distribution of the cities considered for the current study are as represented in the Figure 21

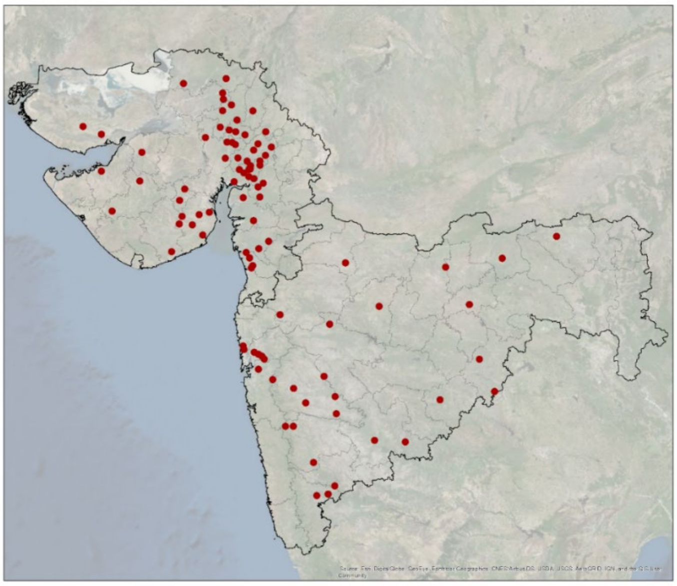


Figure 21: Spatial location of the sample cities selected for the study

It is observed from the Figure 21 that the sampled cities are spatially spread across the two states. Further, the selected cities also represent the variety in the spatial characteristics and the urban forms. The Figure 22 provides brief idea regarding the variations in the urban characteristics among the selected samples. The sample size of 93 cities consists of cities with population density as high as 340 people per hectare and the city with population density of 5 people per hectare. Further, the sample also consist of cities with the network coverage of 466 sqkm at the higher end and the cities of 1.5 sqkm coverage at the lower end.

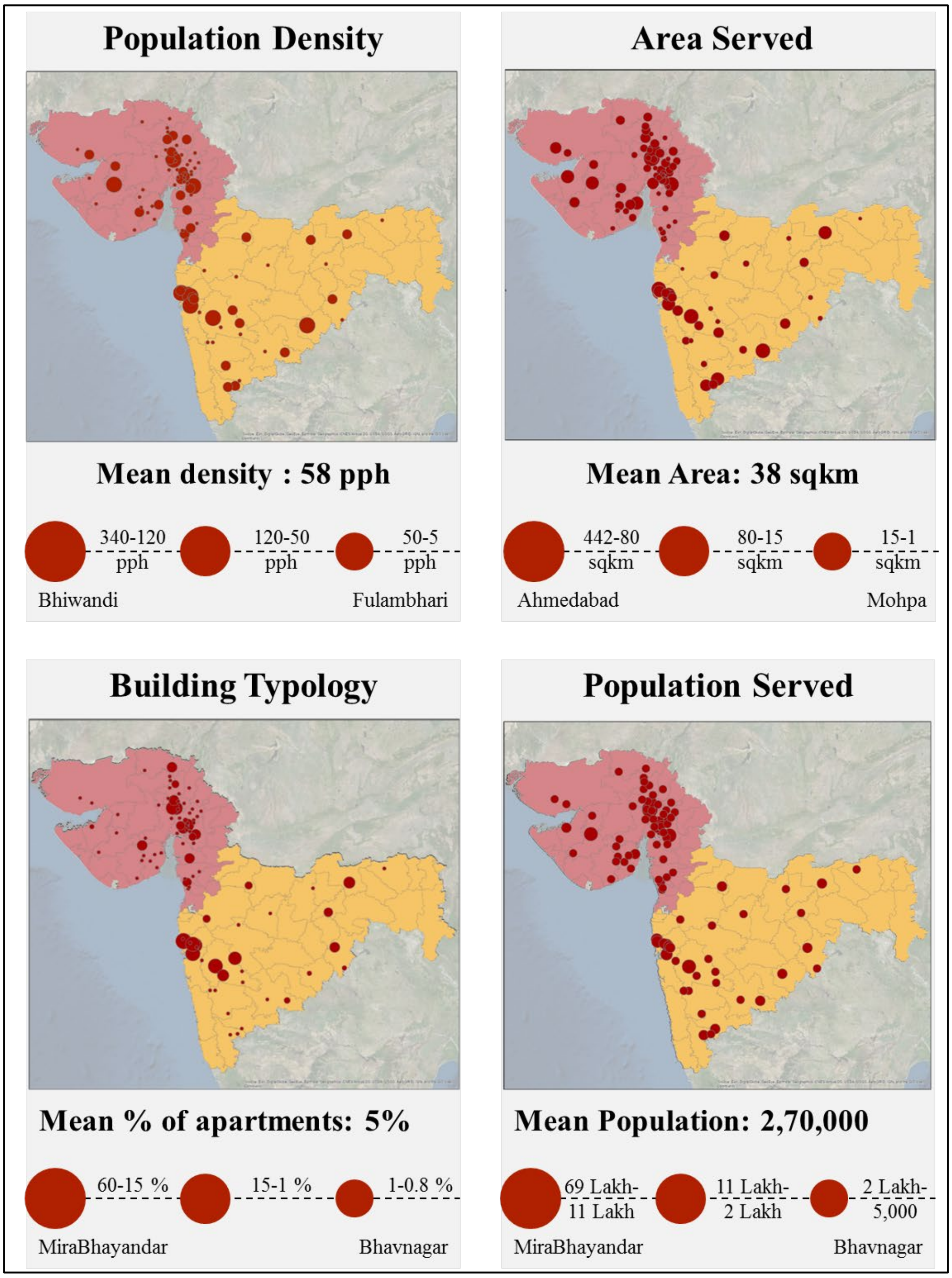


Figure 22: Representing the wide spectrum of verity in the sampled case cities

The urban level and service level datasets from the PAS, CEPT University is used to study the impact of the identified parameters on the energy consumption in municipal water supply (Performance Assessment System, 2018). The following types of datasets are obtained from the PAS data base for the further analysis,

- Service Level Indicators
- Local Action Indicators
- Background datasets

Including all the types of the database, the study has identified an overall of 9 indicators and 24 associated data heads. The overview of the total datasets obtained for each of the sampled 93 cities is attached in the Annexure A.

3.3 Analysis and observations

The impact of the identified parameters on the energy consumption in municipal water supply is studied by assessing the relative consumption in comparison with that of the other cities. Further, the energy consumption in municipal water services is assessed by considering the following units of measurements.

i. Units consumed in production of 1 kilolitre of water (kwh/m3)
ii. Units consumed in supply of 1 kilolitre of water for 100m length (kwh/100m)

These two units of measurements were used to assess the impact of the identified parameters on the energy consumption in production and supply of water at both gross urban scale and for the classified cities. The assessment at the gross urban scale were conducted by considering all the 93 sampled cities. The cities falling under the respective criteria are selected for the assessing the impact pertaining to those classifications.

In order to understand the relationship of the energy consumption on the identified parameters, it is important to understand the level of dependency of the variable parameter and the type of type of association shared with the same. The following statistical methods are used in the same order for understanding the same,

i. **Correlation:**The degree of dependency between two variables is referred to as correlation. This tool determines the relationship shared between the variables being measures. The study uses linear correlation to measure this relationship wherein -1 is a perfectly negative relationship, +1 a perfectly positive relationship and 0 indicating no relationship. In the context of the current study the correlation is used to assess the level of association between the energy consumption and the variable parameter.
ii. **Linear Regression:**The regression analysis is used to predict the values of the dependent variable from the given values of independent variables. This assists in understanding the level of dependency of the dependent parameter on the independent parameter. In the context of current study, the energy consumption in the dependent parameter and the urban parameters considered for the study are the independent parameters. The linear regression is denoted by 'M'.
iii. **Variance (P- Value):** All hypothesis tests use a *p*-value to weigh the strength of the evidence (what the data are telling you about the population). The *p*-value is a number between 0 and 1

and interpreted in the following way:A small *p*-value (typically $\leq$ 0.05) indicates strong evidence against the null hypothesis, so the study rejects the null hypothesis.A large *p*-value (> 0.05) indicates weak evidence against the null hypothesis, so the study fails to reject the null hypothesis.*P-values* very close to the cut-off (0.05) are marginal. In the context of the current study, the P value indicates the degree of confidence of the data used. The P value is denoted by through colour coding in further analysis. Green colour indicates higher confidence of the data and the Yellow colour indicates low confidence.

3.3.1 Observations at the gross urban scale

The analysis at the gross urban scale will assist in understanding the association between the identified variables or parameters and the electrical energy consumption by considering all the 93 selected cities. This will provide an insight about how the variables affect consumption at the gross urban scale and type of relationship shared and the level of impact of the same. The Figure 23provides a brief overview regarding the relationship shared by the identified parameters on the energy consumed in municipal water servicesat a gross urban scale.

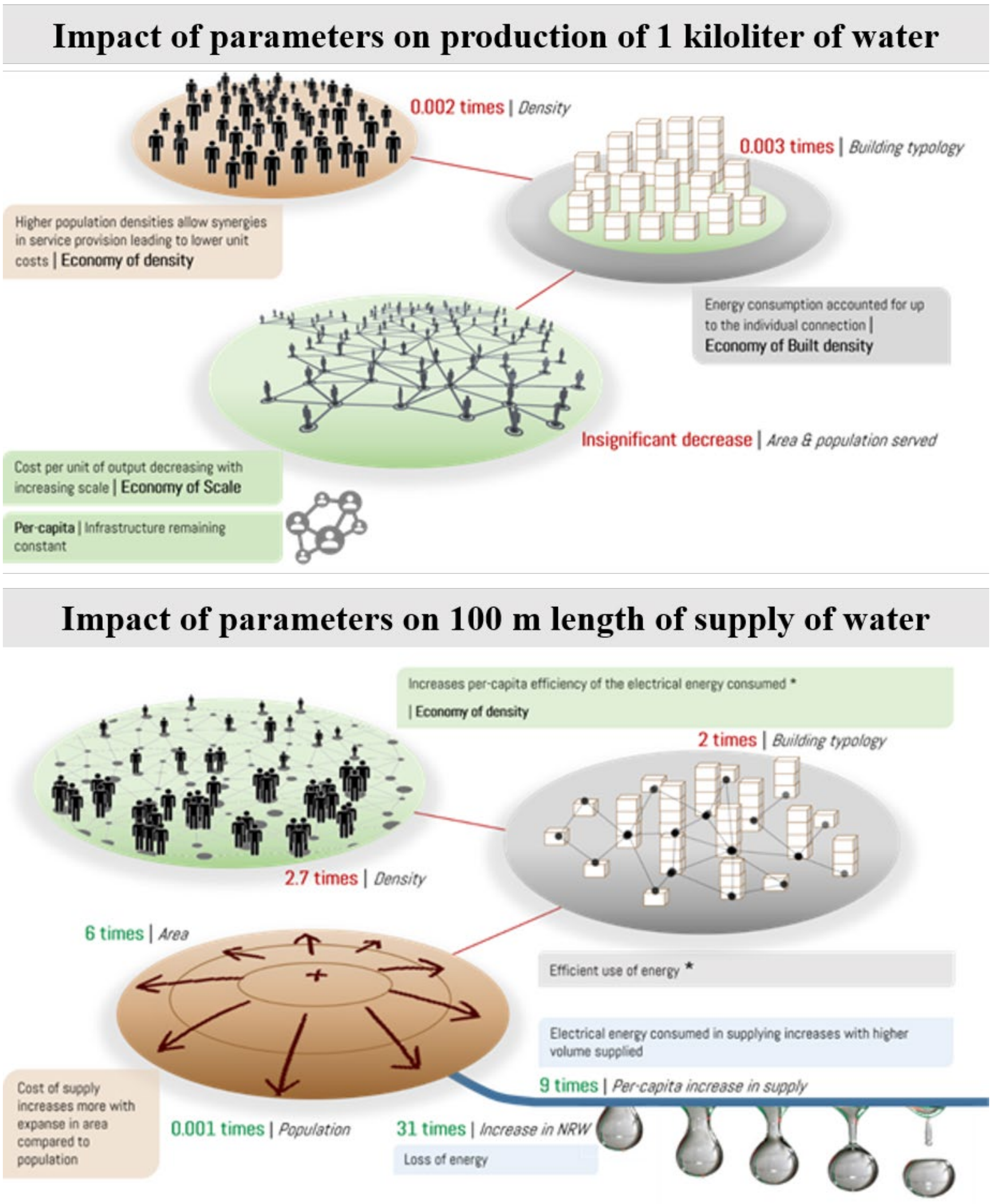
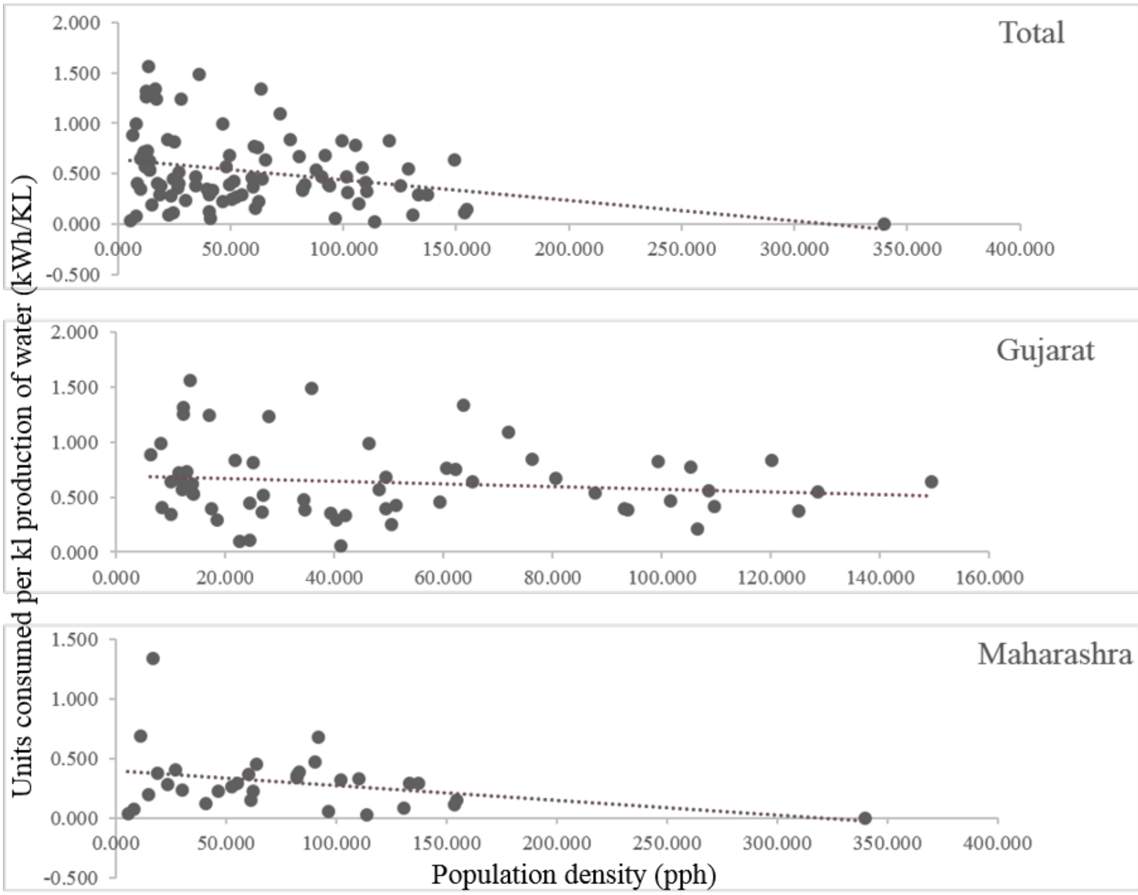


Figure 23:Overview of the impact of identified parameters on the energy consumption

3.3.1.1 Impact of Population density at a gross urban scale

Population density shares a negative relationship with unit consumed in production of 1 kilo-litre water. The association is found to be stronger for the combined total sample and in Maharashtra compared to Gujarat. This is mainly because ULBs in Gujarat have an average population density of 48 people per hectare compared to Maharashtra which has an average population density of 78 people per hectare. Whereas, the average unit consumed per kilo-litre of water is lower in Maharashtra at 0.30 kWh, and higher in Gujarat at 0.63 kWh. In the case of total samples, unit increase in density decreases energy consumption by 0.002 times (p value significant). This is mainly because the increasing population densities will allow synergies in service provisioning leading to lower unit cost.

Also referred to as ‘economy of density’. The Figure 24 describes the impact of population density on the unit consumed per kilo litre of water production.

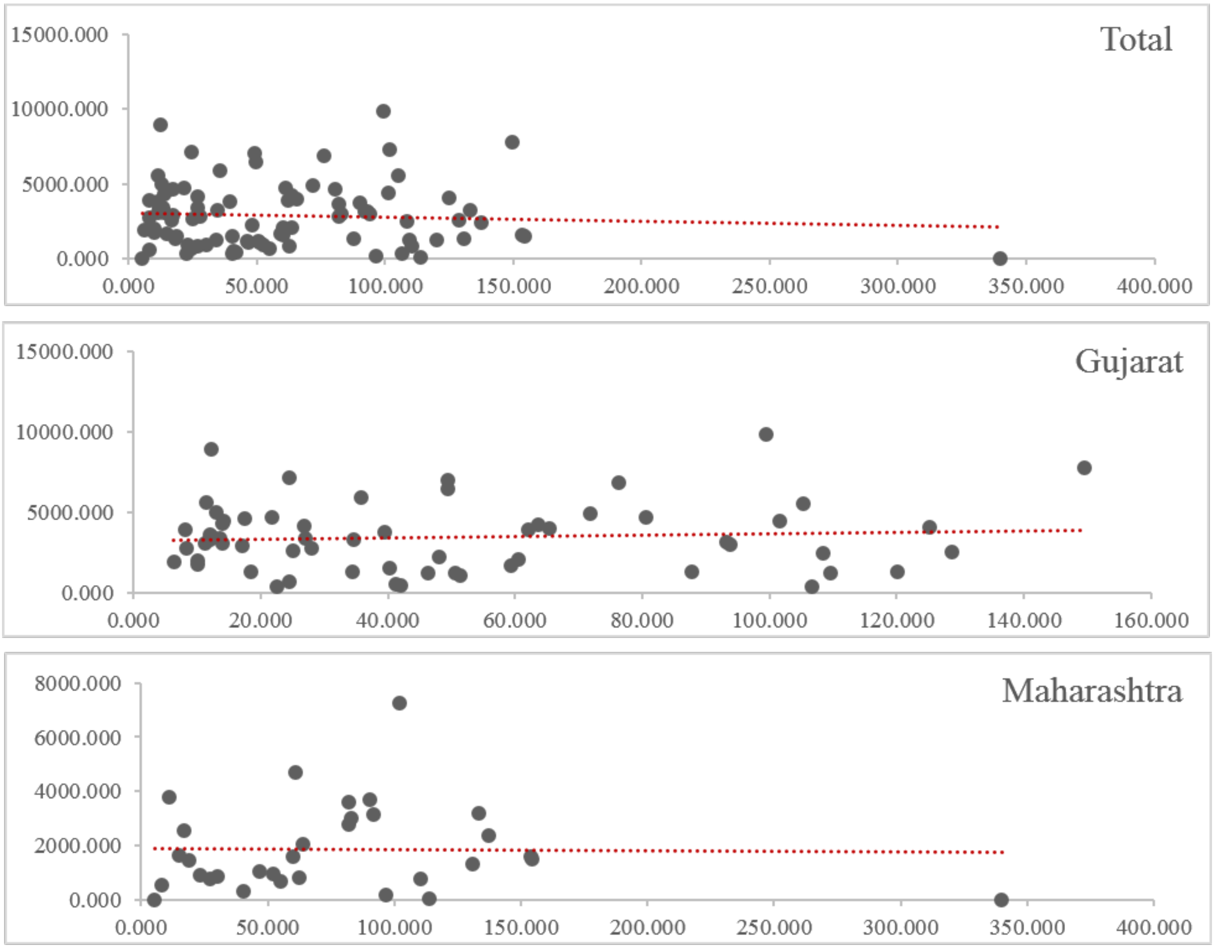


	TOTAL	GUJARAT	MAHARASHTRA
R	-0.293	-0.135	-0.320
M	**-0.002**	**-0.001**	**-0.001**
P	0.004	0.299	0.072

Positive relationship   Negative relationship   Significant   Low significance

Figure 24: Relationship between population density and unit consumed in production of water

Population density shares a negative relationship with unit consumed in 100m supply of water. The analysis suggests that Gujarat behaves differently as it shares a positive relationship with energy consumption (almost 4.5 times). This can be attributed to factors like higher average per capita water supplied, higher average coverage in Gujarat (82 percent) versus in Maharashtra (62 percent), and lower average cost of production compared to Maharashtra. It should also be noted that in the given sample, Maharashtra has 6 times the average number of house-holds in apartments compared to Gujarat, whereas Gujarat is seen to have lesser average population density and more sparse growth. Energy consumption is seen to decrease 0.3 times with increase in population density in Maharashtra. Although the relationship is very weak in nature and does not have a significant P-value. The Figure 25 describes the impact of population density on the unit consumed per 100m length of water supply.



	TOTAL	GUJARAT	MAHARASHTRA
R	-0.066	0.080	-0.015
M	**-2.739**	**4.514**	**-0.372**
P	0.529	0.539	0.934

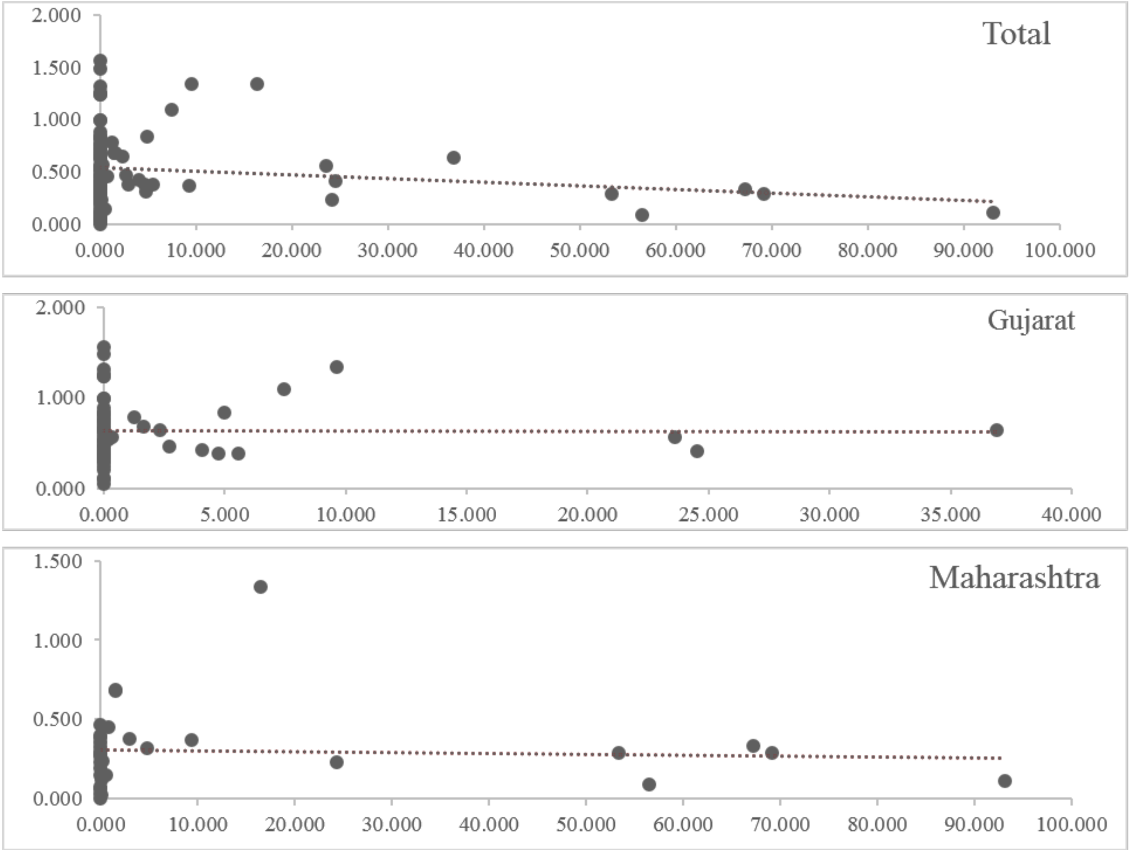
Positive relationship   Negative relationship   Significant   Low significance

Figure 25: Relationship between population density and unit consumed in 100m length supply of water

3.3.1.2 Impact of Urban Morphology at gross urban scale

As the data pertaining to the urban morphology is not available for all the cities, the percentage share of apartments in the city is used as the proxy for the same. Considering the context of Indian cities, the increased share of apartment suggests more compactness in the growth of the city.

In the case of gross urban scale, the urban morphology (building typology in this context) shares a negative relationship with the unit consumed in production of 1 kilo-litre water. The relationship is not strongly related because 60 percent of the samples within the 93 cities have zero percent of households residing in apartment blocks. When these samples are removed from the study, the scatterplot and correlation show a strong negative relationship between the two. This is because energy consumed has been accounted for only up to the apartment, and not individual connection. The building level cost of pumping is not added to the municipal cost. In the case of total samples, unit increase in density decreases the energy consumption by 0.003 times (P value not significant). The Figure 26 describes the impact of urban morphology on the unit consumed per kilo litre of water.

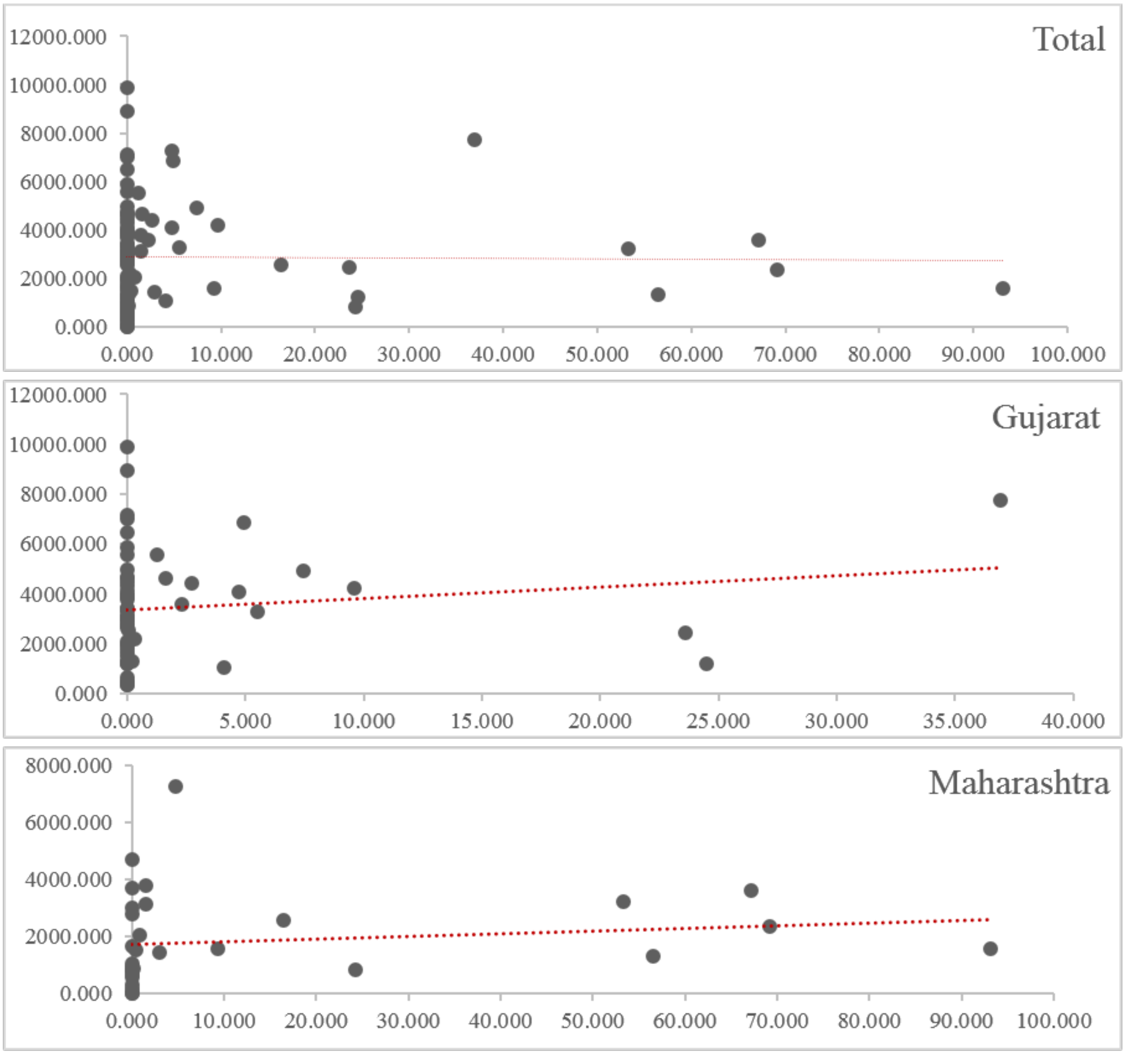


	TOTAL	GUJARAT	MAHARASHTRA
R	-0.162	-0.001	-0.057
M	**-0.003**	**0.000**	**-0.001**
P	0.122	0.997	0.757

Positive relationship   Negative relationship   Significant   Low significance

Figure 26: Relationship between urban morphology and unit consumed in production of water

Urban morphology (building typology) shares a negative relationship with unit consumed per 100 metre of network length. Energy consumption decreases 1.9 times, although the P-value is not significant. It is observed that Gujarat and Maharashtra do not share a negative relationship. As explained earlier, this is predominant number of samples having zero apartment connections. With exclusion of these samples, both the state's share a negative relationship with consumption. It is assumed that larger the number of apartments, lesser is the municipal water supply network length, and lesser the municipal energy consumption, notwithstanding the additional energy consumed at building level. The Figure 27 describes the impact of urban morphology on the unit consumed per 100m length of water supply.



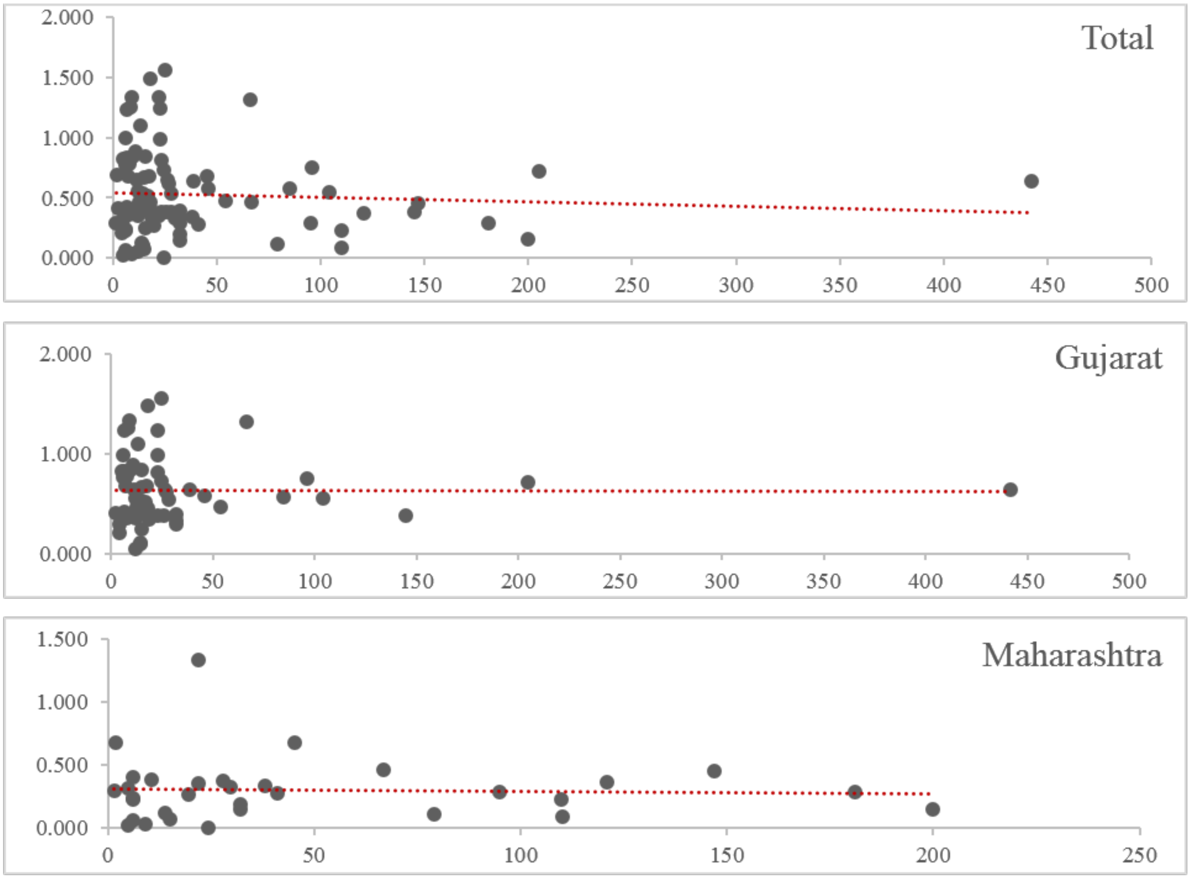
	TOTAL	GUJARAT	MAHARASHTRA
R	-0.015	0.140	0.146
M	**-1.983**	**46.026**	**9.237**
P	0.883	0.283	0.424

Positive relationship   Negative relationship   Significant   Low significance

Figure 27: Relationship between area served and unit consumed per 100m length of supply

3.3.1.3 Impact of area served at gross urban scale

The relation shared between extant of area served and unit consumed in production of 1 kilo-litre water supply is negative, but very weak. It may be assumed that larger the area served; lesser energy is consumed in production of water supply as unit cost of production is lowered. This can be better explained through the principle of 'economy of scale'. None of the P values are significant for the same. The Figure 28 describes the impact of urban morphology on the unit consumed per kilo litre of water.

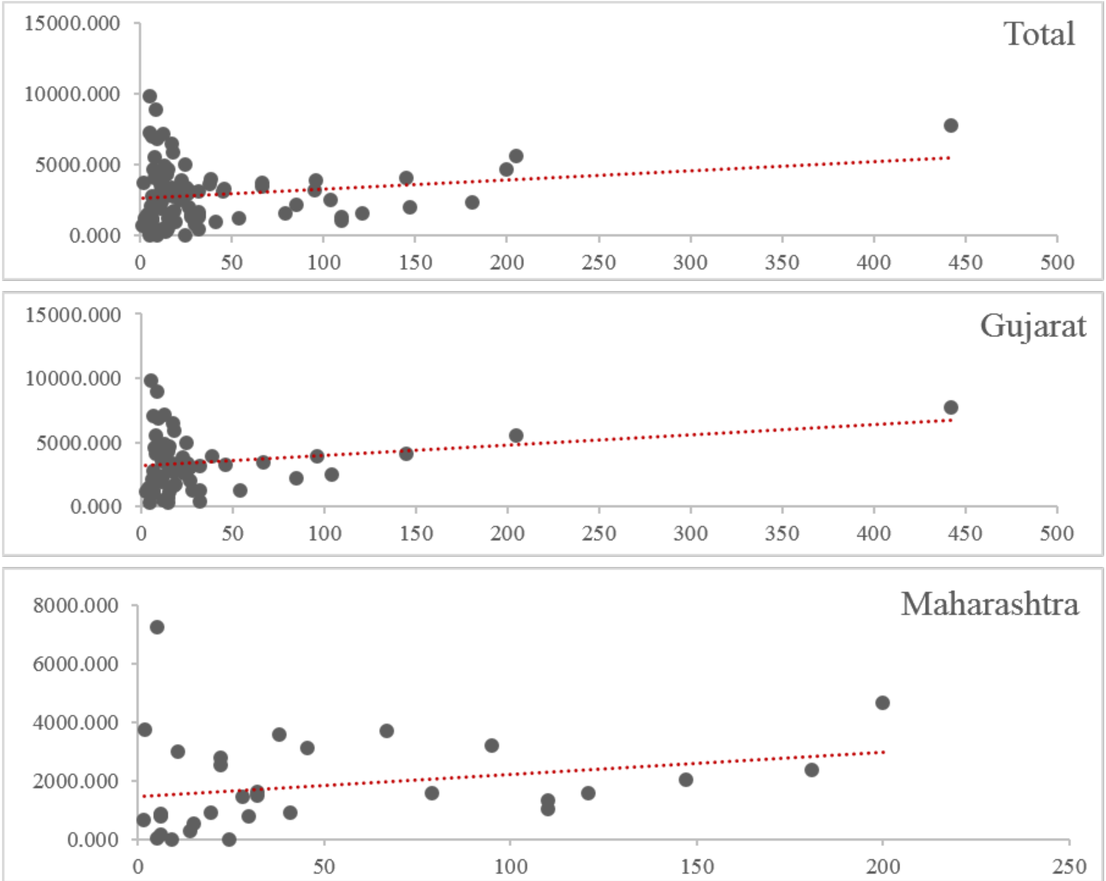


	TOTAL	GUJARAT	MAHARASHTRA
R	-0.062	-0.001	-0.044
M	**0.000**	**0.000**	**0.000**
P	0.555	0.994	0.809

Positive relationship Negative relationship Significant Low significance

Figure 28: Relationship between area served and unit consumed in production of water

In case of 100m length of supply of water, the energy consumption shares positive relationship with that area served by the network. The energy consumed will increase by 6.4 times with unit increase in area served. In Maharashtra, consumption is seen to increase by 8 times. Wherein, the P-value is slightly significant for both the states. The Figure 29 describes the impact of urban morphology on the unit consumed per kilo litre of water.



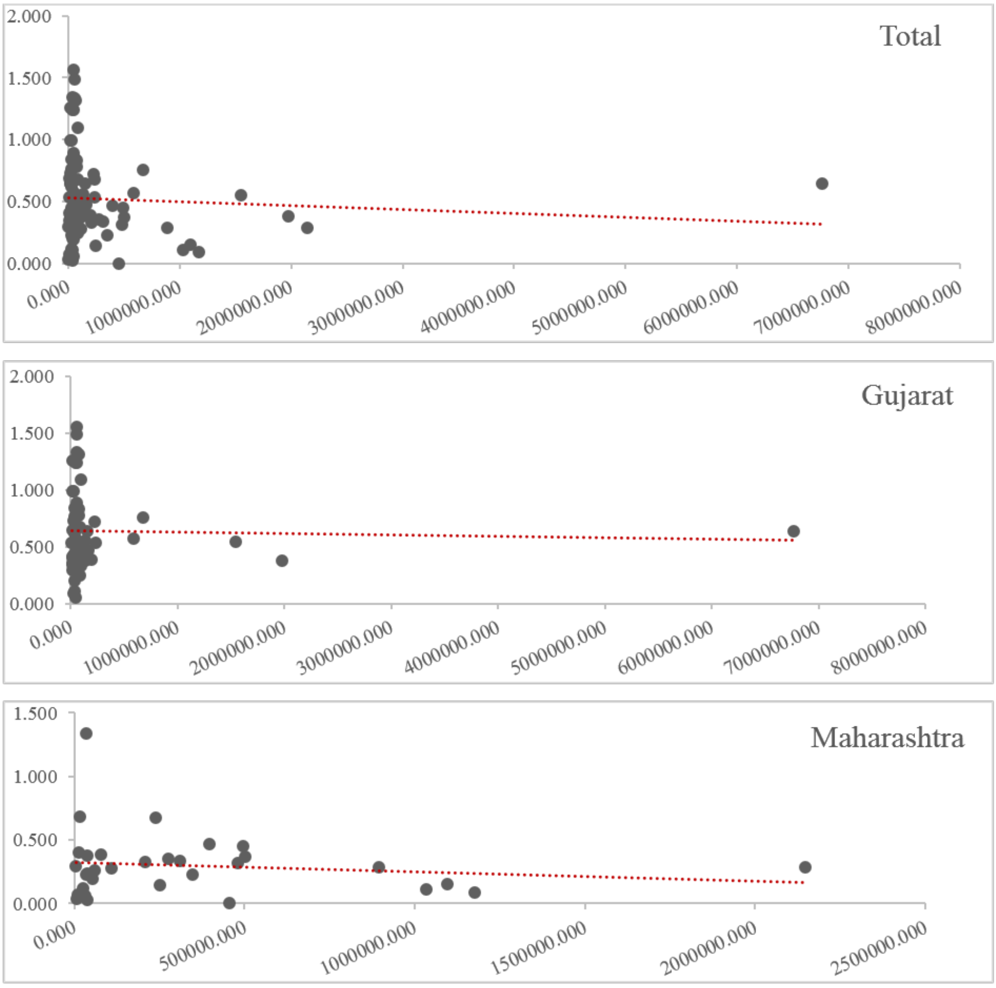
	TOTAL	GUJARAT	MAHARASHTRA
R	0.186	0.242	0.255
M	**6.431**	**8.095**	**7.518**
P	0.075	0.061	0.159

Positive relationship   Negative relationship   Significant   Low significance

Figure 29: Relationship between area served and unit consumed in 100m length of water

3.3.1.4 Impact of population served at gross urban scale

The extant of population served shares a weak negative relationship with unit consumed in production of 1 kilo-litre water supplied. Although the principle of 'economy of scale' is applicable in this variable, the decrease in consumption with increasing population is very minimal, without a significant P-value. The Figure 30describes the impact of urban morphology on the unit consumed per kilo litre of water.

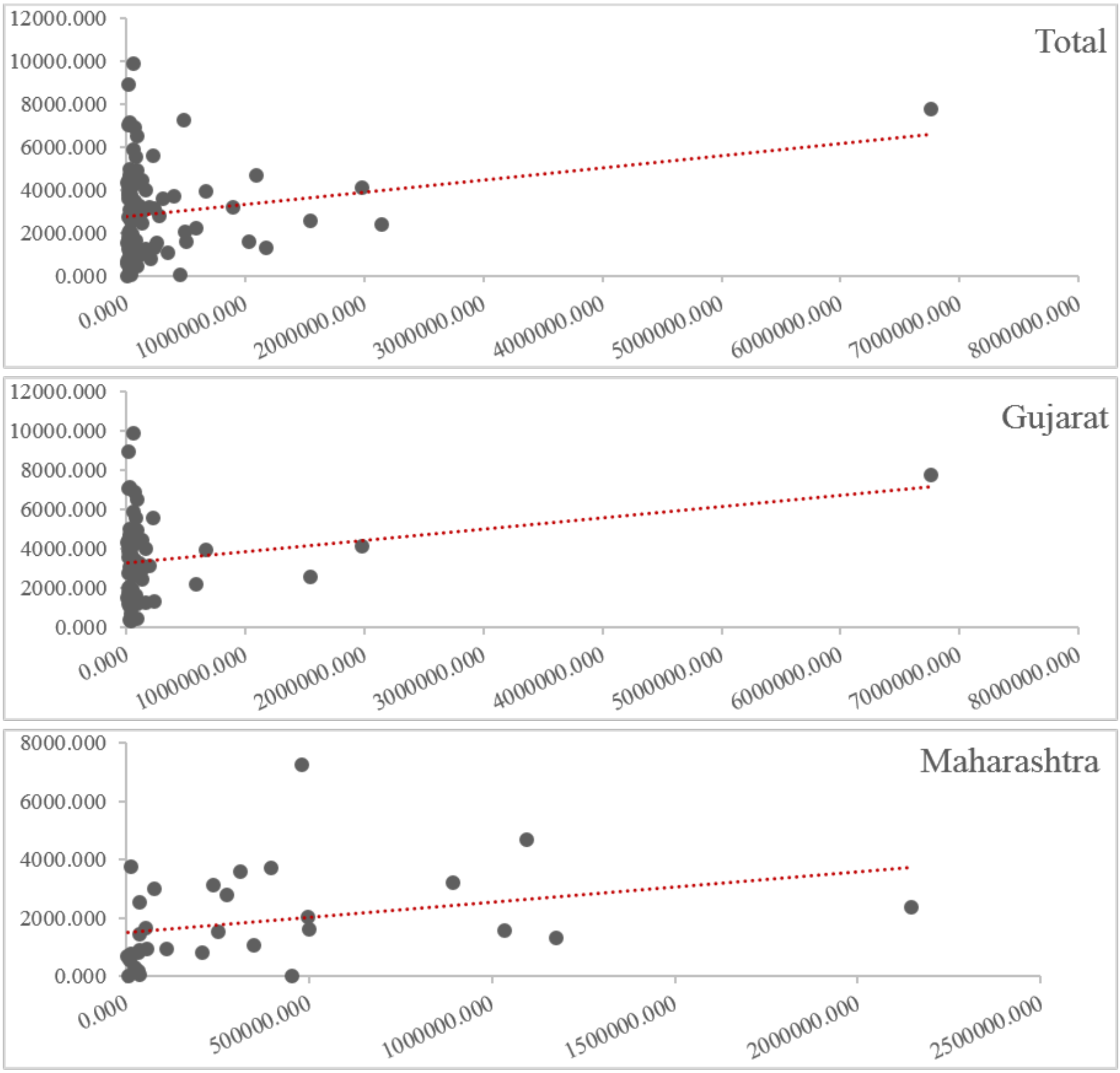


	TOTAL	GUJARAT	MAHARASHTRA
R	-0.072	-0.033	-0.143
M	**0.000**	**0.000**	**0.000**
P	0.495	0.799	0.435

Positive relationship   Negative relationship   Significant   Low significance

Figure 30: Relationship between population served and unit consumed in production of water

The energy consumption in 100m length supply of water shares positive relationship with the total population served. It is observed from the analysis that the energy consumption will increase by 0.001 times with every unit increase in the population served. The similar observation has been found in the case of Gujarat and Maharashtra. The P-value is significant for the case of Gujarat and moderately significant in the case of Maharashtra. Thus, it can be inferred from the observations that the network coverage area has greater impact on the energy consumption in water supply than that of the population served. The cost of water supply increases at an higher rate with the expanse in network coverage area than that of the population served. The Figure 31describes the impact of urban morphology on the unit consumed per kilo litre of water.



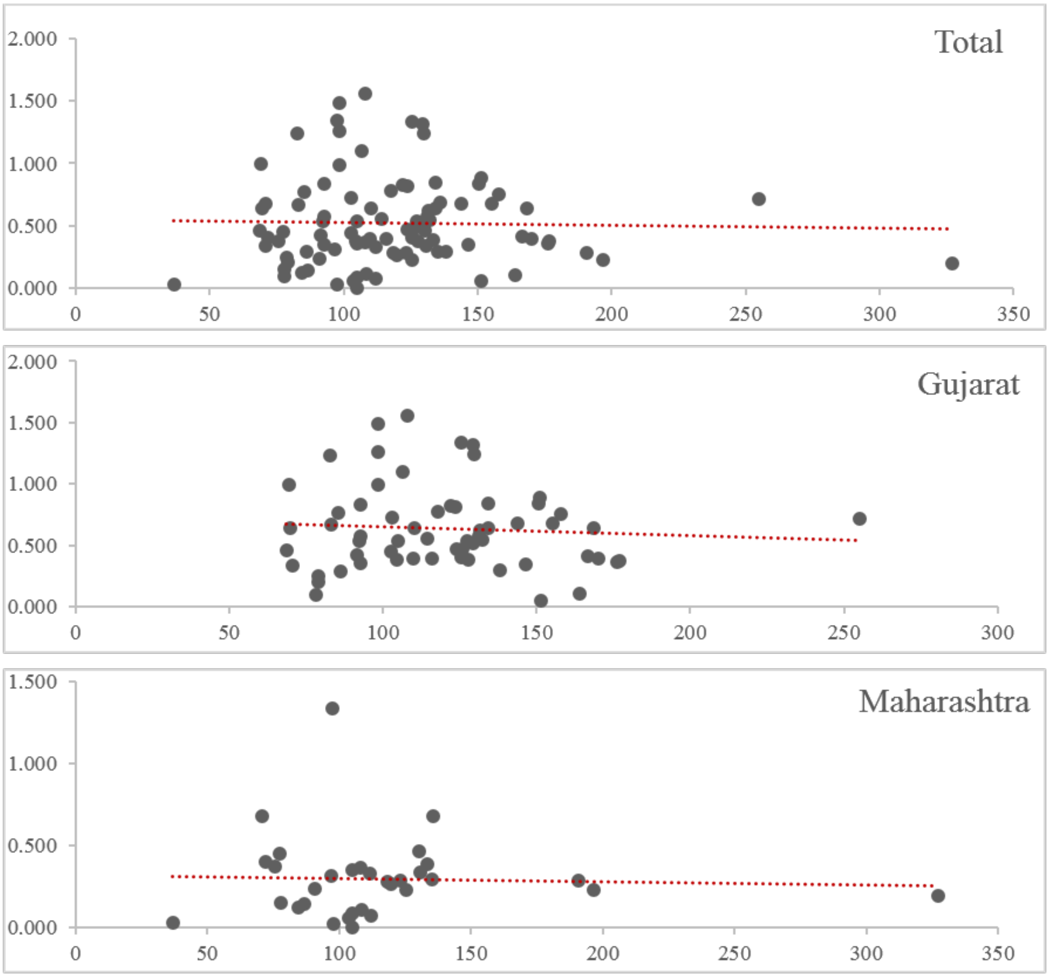
	TOTAL	GUJARAT	MAHARASHTRA
R	0.213	0.243	0.306
M	**0.001**	**0.001**	**0.001**
P	0.040	0.059	0.088

Positive relationship   Negative relationship   Significant   Low significance

Figure 31:Relationship between population served and unit consumed in 100m length supply of water

3.3.1.5 Impact of per capita supply at gross urban scale

Level of services often direct energy consumption pattern. Per-capita supply is shown to share a weak negative relationship with unit consumed in production of 1 kilo-litre water supplied. The P-value is seen to be insignificant in all the samples. But it can visually be seen that most of the cities with a higher supply of per-capita, fall in the lower end of consumption bracket. The study assumes that optimum energy is consumed as consumption is lowered with increase in volume of water supplied. The Figure 32 describes the impact of urban morphology on the unit consumed per kilo litre of water.

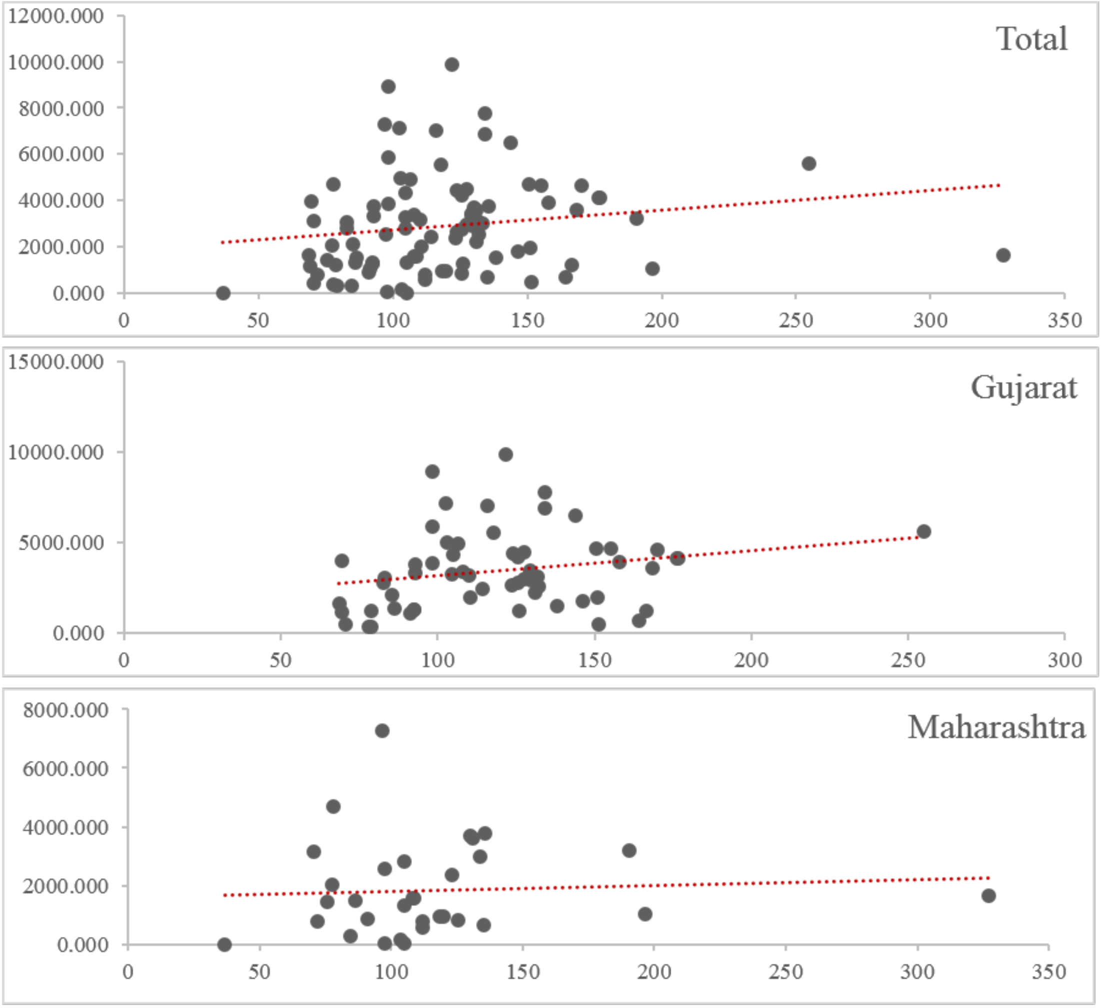


	TOTAL	GUJARAT	MAHARASHTRA
R	-0.025	-0.075	-0.039
M	**0.000**	**-0.001**	**0.000**
P	0.809	0.564	0.833

Positive relationship Negative relationship Significant Low significance

Figure 32: Relationship between per capita supply and unit consumed in production of water

In the case of 100m length of water supply, the energy consumed increases by 8.6 times (P-value not significant) with the increase in per-capita water supplied. The energy consumed in water supply shares positive relationship with the per capita water supplied. Similar observations are found in the case of Gujarat and Maharashtra. With the increase in the per capita supply of water, the energy consumed in water supply increases by 13.7 times (Low significance) in the case of Gujarat and it increases by 1.9 times in the case of Maharashtra. The major reason for this observation is that the per capita supply in Maharashtra is lower than that of Gujarat. The Figure 33describes the impact of urban morphology on the unit consumed per kilo litre of water.



	TOTAL	GUJARAT	MAHARASHTRA
R	0.164	0.219	0.062
M	**8.615**	**13.725**	**1.988**
P	0.116	0.090	0.736

Positive relationship   Negative relationship   Significant   Low significance

Figure 33: Relationship between per capita supply and unit consumed in 100m length of water supply

3.3.2 Observations at the classified cities level

After understanding the impact of the parameters at the gross urban scale, the study envisages to assess and understand the impact of the parameters on the clusters of the cities that are classified based on their similarities. The cities are classified as per the national guidelines such as URDPFI, CPHEEO, Service Level Benchmarking, etc., The Table 16 represents the details pertaining classification of the cities.

3.3.2.1 Impact of population density

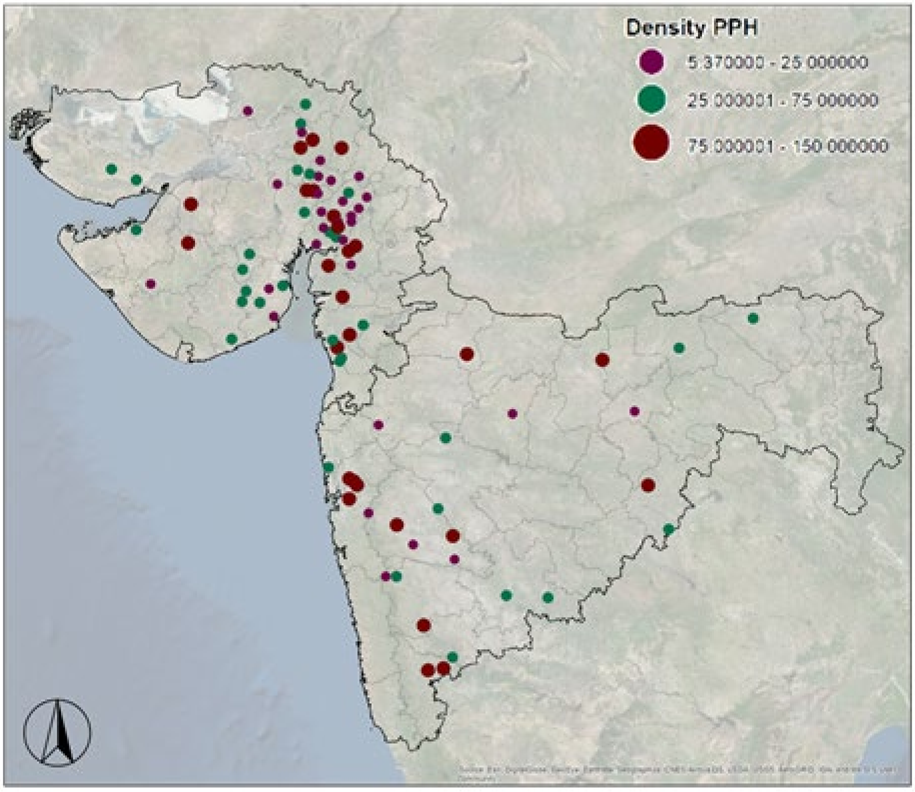


Figure 34: Population densities of the sampled cities

In case of highly dense cities (75 PPH to 150 PPH), the population density shares negative relationship with the energy consumption in 1kl production of water. Among the cities with higher population density, the energy consumption decreases by 0.002 times with an unit increase in the population density.

Further, the population density shares weak positive relationship with the energy consumption in production of 1 kl production, whereas it shares a weak negative relationship in case of the low dense cities. This observation is mainly because of the absolute reduction in the volume of water with the decrease in the population density.

In case of highly dense cities, the energy consumed in 100 metre length of supply shares negative relationship with the density. It is observed that the energy consumption in water supply decreases almost by 14 times in highly dense areas irrespective of the volume of water supplied. Whereas, the energy consumed by the network increases in mid-dense and low dense areas. This infers that the densification will reduce the energy consumed in the supply of water. It increases significantly in cities with lower population density.

Table 18: Association of population density with the energy consumed in production of water and 100m length supply of water

Population Density			
	High Density (75-150 pph)	Medium Density (25-74 pph)	Low Density (<25 pph)
kWh/kl production of water			
R	-0.4	0.1	-0.2
P	0.018	0.727	0.395
M	-0.00219	0.00168	-0.01241
kWh/100m length supply of water			
R	-0.3	0.1	0.0
P	0.123	0.399	0.900
M	-14.64413	0.00116	9.07978

3.3.2.2 Impact of Urban Morphology

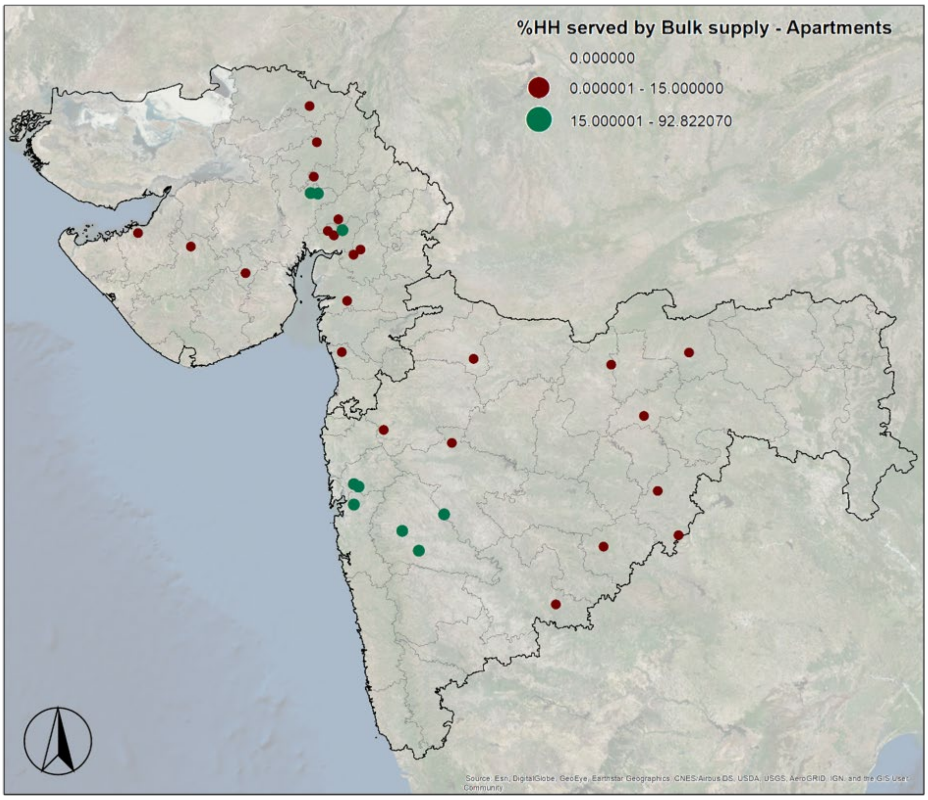


Figure 35: Urban Morphology of the sampled cities

The energy consumed in production of water decreases with the increase in the percentage of the households residing in apartments. This suggests that the increase in apartments decreases the municipal energy consumption in the supply of water. Whereas consumption increases 0.05 times with decrease in share of households living in apartments. This infers that the municipal consumption to water supply will be higher in the cities higher share of low rise and bungalows typologies.

Further, it is also observed that the energy consumption in 100m length of supply decreases by 2.6 times in the cities with larger share of apartments. In such a scenario, the share of building level energy consumption increases significantly. In the case of cities with lower share of apartments, the energy consumption in municipal water supple increases by 270 times. Thus, it can be inferred that the unit consumed in both production and supply is significantly higher in the cities with a lower share of apartments and with increased low-rise developments.

Table 19: Association of urban morphologyon the energy consumed in production of water and 100m length supply of water

Urban Morphology (Building Typology)		
	More than 15% share of apartments	Less than 15% share of apartments
kWh/kl production of water		
R	-0.6	0.5
P	0.053	0.018
M	-0.00901	0.05053
kWh/100m length supply of water		
R	0.0	0.4
P	0.925	0.059
M	-2.68494	270.05303

3.3.2.3 Impact of Population served

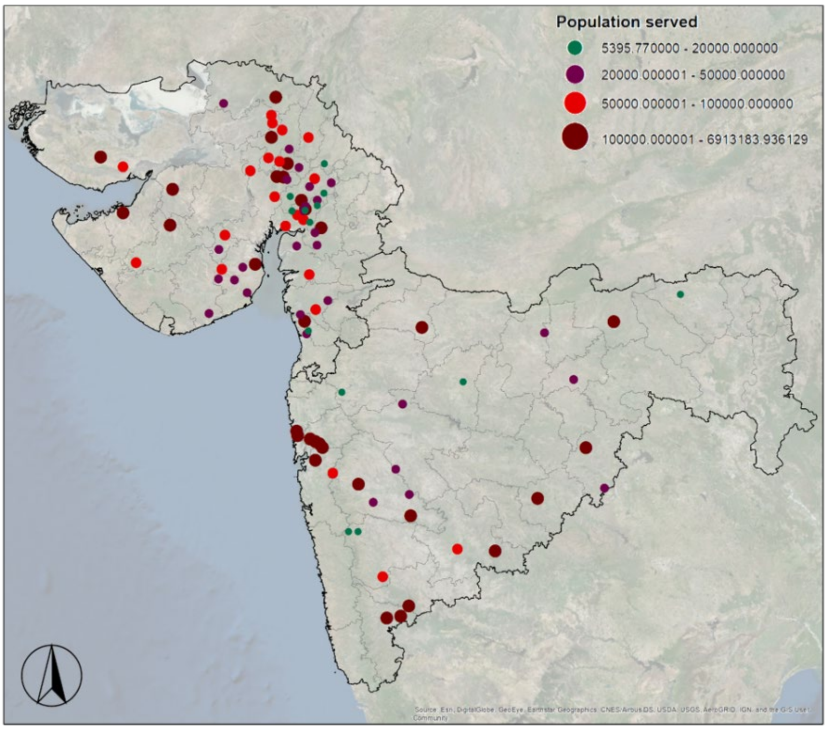


Figure 36: Variation in the total population served with municipal water services of the sampled cities

The unit consumed for production of water shares a negative relationship with the total population served. In case of cities with higher and medium range of population served with municipal water supply, the energy consumption in production of water decreases with an increase in population. This highlights the economy of scale bringing in the competitive advantage, lowering the per-unit costs involved in production of 1 KL production of water.

In the cities with lower range of population served with municipal water supply, the energy consumption in production increases with increase in population. The per-unit cost involved in production of water is higher for smaller cities with population ranging lesser than 20,000.

In the case of cities with higher and lower share of population served, the energy consumed per 100m length of water supply shares positive relationship with the population. However, in the case of cities with medium range of population served with municipal water supply, the energy consumed in 100m length of water supply shares negative relationship with the population. It can be assumed that very large and a very small base of population consumed more energy per network length.

For smaller population base served (less than 20,000), energy consumed per KL production of water is seen to increase by 0.00005 times and energy consumed per 100m length is seen to increase by 0.28 times. The population served, has more significant impact on the energy consumed per 100m supply of water than that in the case of production of water. Thus, it can be inferred that the smaller set of population served will consume significantly higher energy than that of the medium set of population. These observations will signify the optimization of scale and its advantages towards enhancing the service levels.

Table 20: Association of population served with municipal water supply on the energy consumed in production of water and 100m length supply of water

Population Served				
	More than 1,00,000	Between 50,000-99,999	Between 20,000-49,999	Less than 20,000
kWh/kl production of water				
R	-0.2	-0.3	0.0	0.7
P	0.209	0.175	0.990	0.011
M	0.00000	-0.00001	0.00000	0.00005
kWh/100m length supply of water				
R	0.1	-0.1	-0.3	0.6
P	0.783	0.650	0.176	0.043
M	0.00015	-0.01679	-0.07055	0.28618

3.3.2.4 Impact of Area served

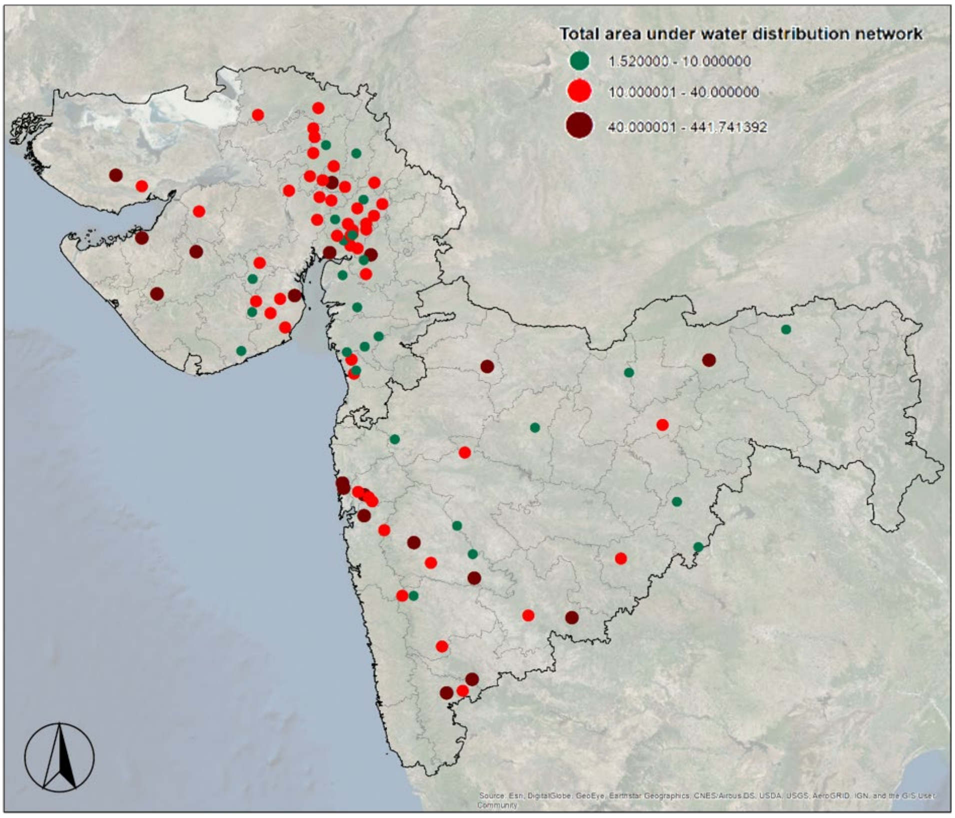


Figure 37: Variation in the total area served with municipal water supply

The energy consumed in production of 1 KL of water shares a weak negative relationship with the cities with larger area served (more than 40 square kilometre), and a positive relationship with the cities with smaller areas served (less than 10 square kilometre). It is observed that the energy consumed in production of 1 KL of water increases by 0.06 times for the cities with the smaller areas served.

However, the energy consumed per 100m length supply of water shares a positive relationship with area served, for both large and small areas. In the case of cities with larger area served, the energy consumed in water supply increases by 13 times for a unit increase in the area served. Whereas in the case of cities with smaller area served, the energy consumed in supply increases by 423 times for a unit increase in the area served. This is seen as an anomaly due to the sample set which belong mostly to class C and D cities with sparse development. Similar to the previous case, the cities with medium sized area served with municipal supply consumes lower unit in production and supply, bringing our attention back to the point on optimization of scale.

Table 21: Association of Area served with municipal water supply on the energy consumed in production of water and 100m length supply of water

Area Served		
	More than40 km2	Less than10 km2
kWh/kl production of water		
R	0.0	0.3
P	0.979	0.089
M	-0.00002	0.06395
kWh/100m length supply of water		
R	0.7	0.3
P	0.000	0.148
M	13.83017	423.61081

3.3.2.5 Impact of Per-capita water supplied

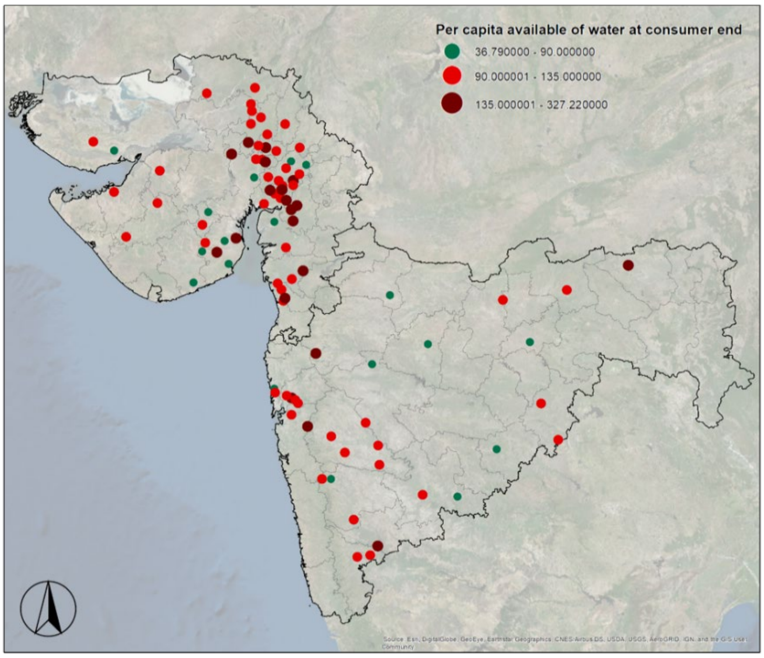


Figure 38: Variation in the total area served with municipal water supply

Energy consumed in production of 1 kilo litre of water shares a positive relationship with the amount of per capita water supplied. It is observed that higher the per capita supplied, lower is the energy consumed per unit supplied. Similar inferences are observed for energy consumed per 100m length of water supply network; however, the energy consumption remains almost same with increase of per-capita supplied.

Thus, energy consumed in production becomes lower progressively as per capita increases. But energy consumed per 100m length of supply is higher for both very low per capita and very high per capita. The energy consumption is observed to the least for the cities with medium per capita supply of water.

Table 22: Association of per capita water supply on the energy consumed in production of water and 100m length supply of water

Per Capita Water Supplied			
	Lower per capita (< 90 LPCD)	Medium per capita (90 - 135 LPCD)	Higher per capita (>135 LPCD)
kWh/kl production of water			
R	0.1	0.0	0.0
P	0.650	0.949	0.994
M	0.00301	0.00026	0.00002
kWh/100m length supply of water			
R	0.2	0.1	0.3
P	0.481	0.500	0.263
M	18.96258	15.91598	17.69590

3.3.2.6 Impact of Non-revenue water

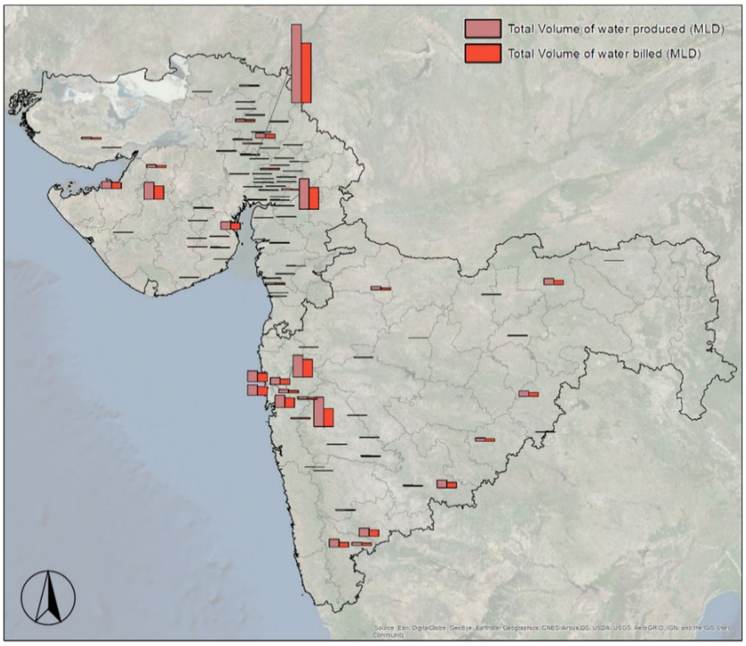


Figure 39: Variation in the level of Non-Revenue water among the selected samples

In case of cities with Non-Revenue water more than 20% share weak negative relationship with both energies consumed in production and supply of water. Whereas, the numbers suggest an increase in the energy consumption in supply of water by 209 times among the cities accounting less than 20% of non-revenue water.

The decrease in the energy consumption with the increase in the percentage of Non-revenue water is mainly because of the physical losses and reduction in the volume. Hence, to maintain or improve the efficiency of the system it becomes necessary to look beyond these numbers and cut on the physical losses occurring in the system.

Table 23: Association of Non-revenue water on the energy consumed in production of water and 100m length supply of water

Non-Revenue Water		
	More than 20	Less than20
kWh/kl production of water		
R	-0.2	0.0
P	0.179	0.787
M	-0.01193	0.00490
kWh/100m length supply of water		
R	0.0	0.3
P	0.738	0.029
M	-19.23170	209.52253

3.3.2.7 Impact of the source of municipal water

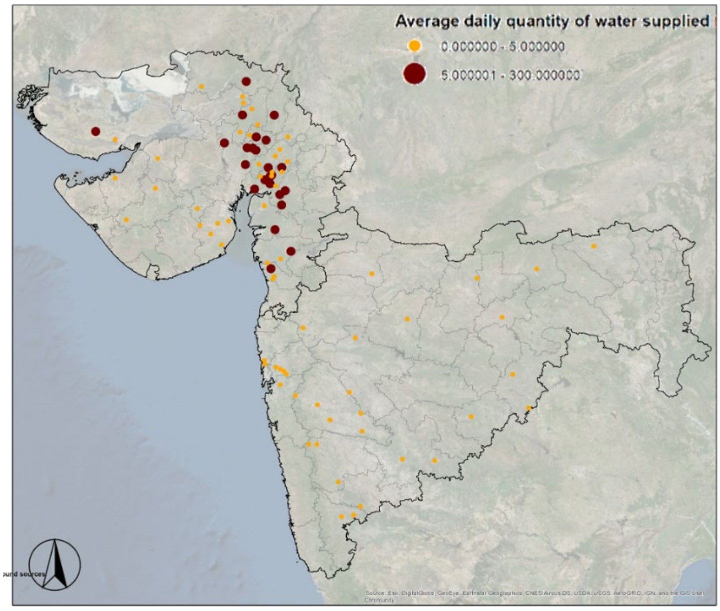


Figure 40: Variation in the dependency on ground water

The study shows that while source of water supply is not a big determinant in terms of the unit consumed in production and supply of 1 kl of water. The energy consumed in both the cases share a weak negative relationship with similar variation in the energy consumed. But when unit consumed per 100 metre length of water supply is considered, there is a considerable difference between the two in terms of the decrease in the energy consumption. The cities relying on ground water source have decrease in the energy consumption by almost 36 times, while cities replying on raw bulk purchase have decrease in the consumption by 10 times. The major reason for this observation is that the cities cut down on the treatment costs in the case of ground water. This decrease in the cost of treatment is reflected as the decrease in the energy consumed.

Table 24: Association of the source of water on the energy consumed in production of water and 100m length supply of water

Source of Municipal water		
	More than 5% ground water	More than 10% raw bulk purchase
kWh/kl production of water		
R	-0.2	-0.2
P	0.296	0.195
M	-0.00252	-0.00250
kWh/100m length supply of water		
R	-0.4	-0.2
P	0.015	0.453
M	-36.624	-10.447

3.4 Synthesis and Conclusion

The study confirms the impact of the urban characteristics on the energy consumption in the municipal water service. The development patterns of the city, its topography, demography and the built characteristics also impacts the overall energy consumption in the municipal water services. After understanding the level of impacts of each of the identified parameters, the municipal water service can be comprehended and synthesised in the following types for achieving an efficient system.

i. **As a Resource:**The outcome of population density and building typology assessment shows that cities need to aspire for compact development, with high densities, higher built density and a higher share of high rise which would be a function of economy of density.

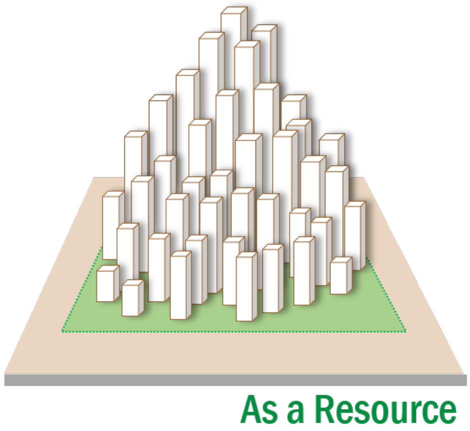


Figure 41: Municipal water supply as a resource

ii. **As a product:** It is observed that per unit cost of production decreases significantly with increase in the scale, which is a function of the economy of scale. This reduces per unit consumption. But it may lead to dis-economies of scale, which currently the Indian cities need not worry about.

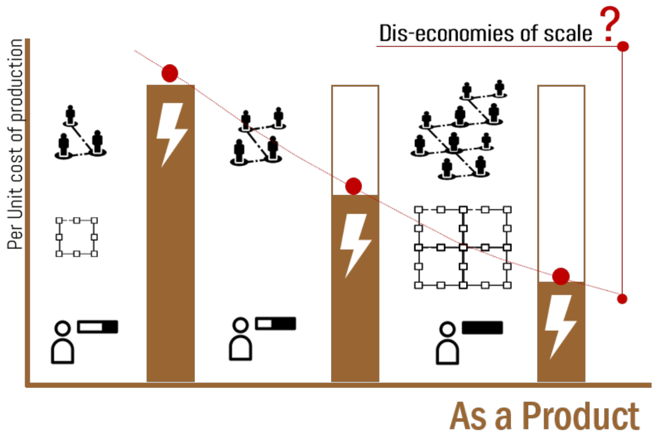


Figure 42: Municipal water supply as a product

iii. **As a service:** The outcome shows that unit cost per length is highest when scale is smaller and higher when scale is large. But it is lowest when the scale is optimum. This raises the question of whether decentralised approach needs to be adopted for electrical energy optimisation. This approach for service provisioning ranges between:

- Population served: 20,000 – 1,00,000
- Area served: 1 – 30 Sq. Km
- Per capita supplied: 90 – 135 LPCD

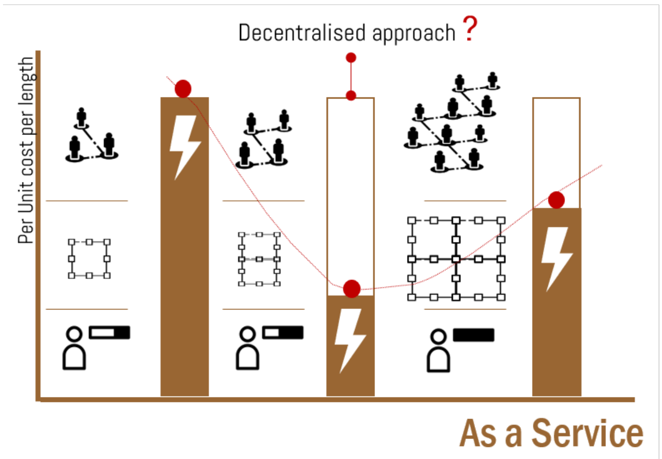


Figure 43: Municipal water supply as aservice

iv. **As a system:** Through analysis of Ground water versus bulk raw supply and the NRW, it is observed that decreasing energy consumption as a goal is not always beneficial when water is viewed as a resource.

Figure 44: Municipal water supply as a system

Overall, the relationship between spatial planning and energy is yet to be acknowledged in national programs and policy. It can be inferred that as a spatial tool, compact cities as a function of densification and increase in share of high rise can help cities reduce and optimise energy consumption. As a tool for service provisioning, cluster-based approach needs to be explored. It also conclusively implies that economy of density and economy of scale are driving principles to optimise unit cost of energy consumption spatially.

4 Building level energy consumption in the water services

The value chain of the municipal water supply completes at the building level. The municipal water supplied by the ULBs is stored in the underground tanks at building level and pumped to the overhead tank for further usage. This energy consumed in pumping the water at the building level is borne by the end users. Thus, the energy consumed at both municipal level and building level will provide the overall picture of the energy consumed in the municipal water service.

As discussed in earlier chapters, the urban form of the city is found to have a significant impact on the overall energy consumptions of the city. The potential impacts of the urban form on the municipal level is assessed in the earlier chapters. Similarly, the impact of the urban forms on the energy consumed at the building level will be assessed and quantified in this section of the study.

4.1 Factors of urban characteristics impacting the building level energy consumption for water services

Energy demand had traditionally been dominated by the buildings sector (which includes residential and services), although demand in industry has grown more rapidly since 2000. The true measure of progress in building energy efficiency, is determined by outcome based indicators such as energy intensity of buildings (kWh per m2), energy savings (kWh or ktoe) achieved from EE initiatives, penetration of ECBC-compliant and green buildings and penetration of EE appliances in the market(Alliance for an Energy Efficient Economy, 2018). The non-substitutable demand for electricity from the buildings sector can be expected to increase significantly purchasing power and standards of living.

The buildings sector (residential, commercial and public) is responsible for about 40% of overall energy consumption of the country. If the potential energy conservation and efficiency improvements and widespread installation of renewable energy supplies can be implemented successfully, the energy consumption can be reduced by 60% or more over a time horizon of 30 to 40 years(International Energy Agency (IEA), 2014). In addition to being large energy consumers, buildings are significant users of water, materials and other energy consuming equipment. The Figure 45 shows the potential life spans of the energy consuming equipment. The observations pertaining to the same highlights the significant scope for energy conservation opportunities in the building sectors.

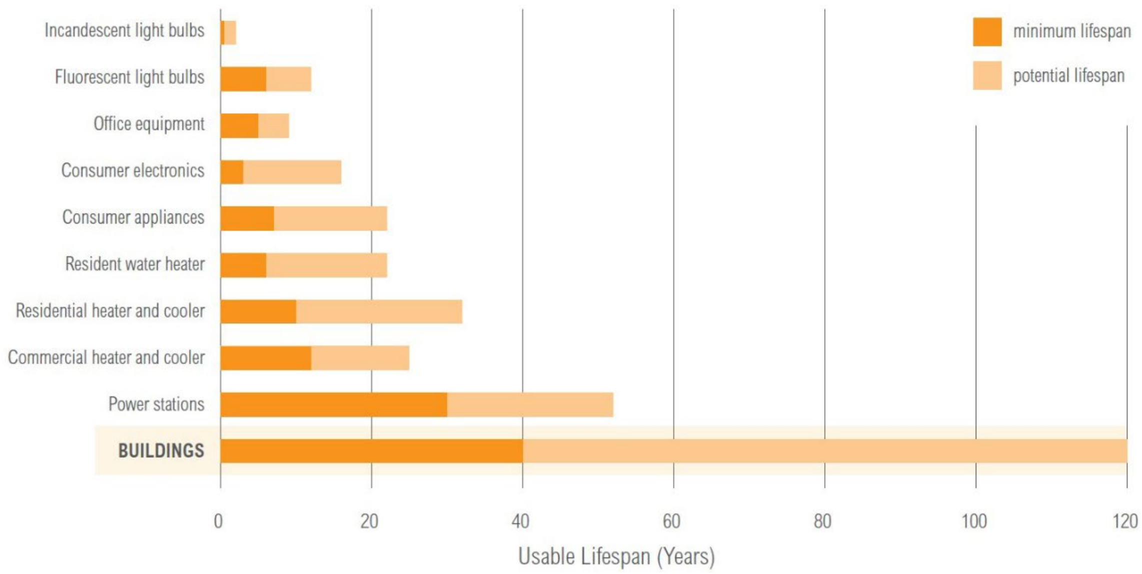


Figure 45:Economic lifespan of energy consuming equipment

Source:International Energy Agency. 2013. Transition to Sustainable Buildings: Strategies and Opportunities to 2050. http://www.iea.org/publications/freepublications/ publication/Building2013_free.pdf.

It is generally understood that the location of the building and the design of the building will have the primary impact on the overall energy consumed in the building. It is believed that the interventions in such physical planning and design willassist in achieving a more sustainable consumption patterns (Khalil, 2009).

Further the studies also suggest that the relationship between density and energy use is not straightforward. Changes to urban form and density are part of wider changes including decreasing household sizes, increasing number of households and increasing income levels the (Doherty, Nakanishi, Bai, Meyers, & Ecosystems, 2009b). The concept of integrated neighbourhood development describes a formation of energy clusters with respect to neighbourhood with similar characteristics. Large homogenous housing can be converted into "model energy – efficient districts" and provide good example of consolidation(Beratungs- und Service-Gesellschaft Umwelt mbH, 2011).

Also, Research provides evidence that compact urban structures and concentrated development facilitate efficient energy use(Große, Fertner, & Groth, 2016). A similar concept of compact urban form has been explored in the study called ***"Energy and the form of cities: the counterintuitive impact of disruptive technologies"*** *by* (Ahmadian et al., 2019)which highlights energy as a determinant of built and urban form and challenges an idea that a compact urban form, particularly for residential building is more energy efficient. The assumption has been that the energy supply for both fuel and electricity is from a centralized network, rather than generated at point of use, and the logical conclusion of these assumptions has been that a compact city will consume less energy than a dispersed city because travel distances will be less(Guhathakurta & Williams, 2015) and buildings will use less energy as there is a reduced ratio of surface area to volume of the building fabric where energy flows from(Rode, Keim, Robazza, Viejo, & Schofield, 2014).

According to Große et al., 2016, presented in paper "***Urban Structure, Energy and Planning***" describes that Transport patterns are interwoven with land-use, distribution of functions and the positioning of a city in the regional urban system. In terms of sustainable transport, cities encounter their limitations at their borders. Municipal transport planning addresses inner city transport. Increasing (energy intensive) mobility beyond municipal boundaries emphasises, however, the relevance of regional transport planning. Electric mobility is one of the most promising technological opportunities to increase the energy efficiency of transport systems and reduce the impacts per unit of energy used, such as carbon dioxide emissions. In addition, electrifying the transport sector would promote sustainable ways of generating electricity, such as wind and solar power(Inturri, G., Ignaccolo, 2016).

Considering the larger picture, it is observed that the integration of the urban energy consumption to urban form, density and morphology provides an opportunity to address climate change at this local level(Doherty, Nakanishi, Bai, Meyers, & Ecosystems, 2009a). From an urban metabolic viewpoint, energy is one of the most critical resource flows in urban environments. It is a primary driver of both the physical and economic systems; in the form of fossil fuels it is also a primary source of greenhouse gas (GHG) emissions and a driver of human-induced climate change. Therefore, managing urban energy use is fundamental to strategies to mitigate GHG emissions by reducing energy use or substituting fossil fuels with non-GHG-producing alternatives (Doherty et al., 2009a). urban form can influence non-transportation CO2 emissions, for example, via district-scale building thermal management (heating and cooling); combined heat and power generation; availability of local food and products; and embodied CO2 in roads, buildings, and other infrastructure(Marshall, 2008). The co-benefits of working towards energy and GHG emissions reduction targets should be emphasized in communication with stakeholders and the general public to increase awareness and acceptance of the consequences of local energy policies. (International Energy Agency (IEA), 2014).

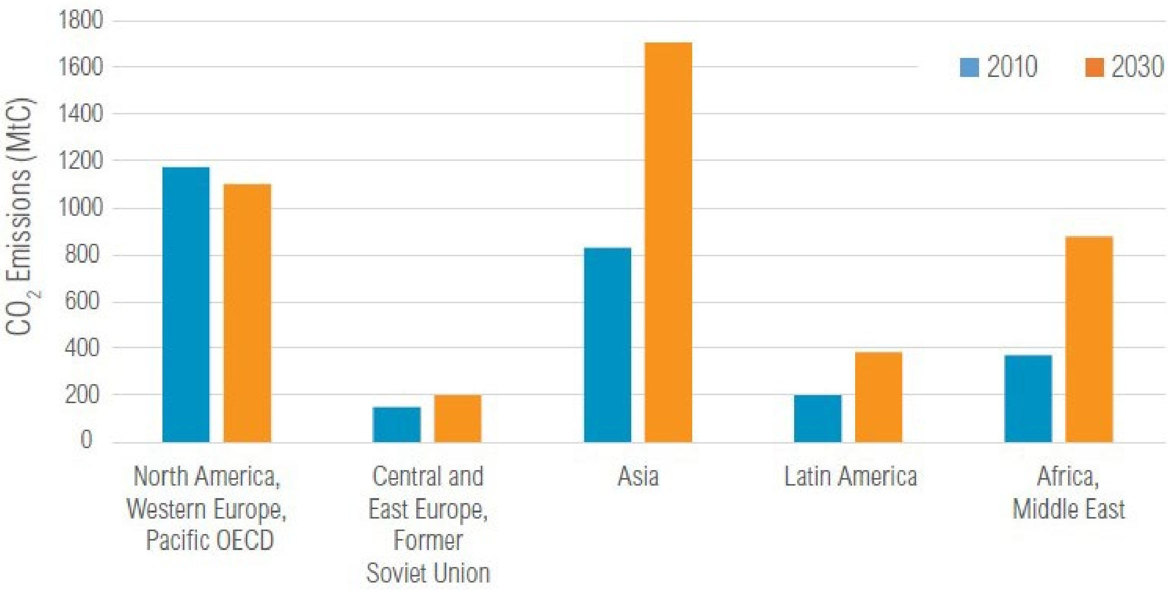


Figure 46: Building sector emissions by world region, 2010 & 2030 projections

Source: du Can, Stephane de Ia Rue, and Lynn Price. 2008. "Sectoral Trends in Global Energy Use and Greenhouse Gas Emissions." Energy Policy (36)4: 1386–1403

The literatures suggest that the urban morphology of the city is determined by the aggregation of the buildings, their typologies and dimensions. The larger functional unities of the city such as land use, gross population density and their arrangements will determine the urban form of the city. Further, it is observed that the relationship of density and energy use at the building level is contradictory. as the changes in the urban form widely refers to the change in demographics like increasing number of households, decreasing household size and population density (Doherty et al., 2009). Thus, the current study assesses the impact of building height, factor of urban morphology on the building level energy consumption in the water services.

4.2 Sampling methodology and data collection

At the initial stage, the study intended to understand the building level energy consumption in water services across different building typologies. Thus, a total of 32 samples were selected across four different typologies from different parts of the city. These 32 samples were identified based on the convenience based random sampling method. These set of identified buildings were considered for the pilot assessment of the building level energy consumptions.

A proper questionnaire was formed and the energy data pertaining to these buildings were collected through household surveys. The observations pertaining to these samples are represented in the Figure 47.

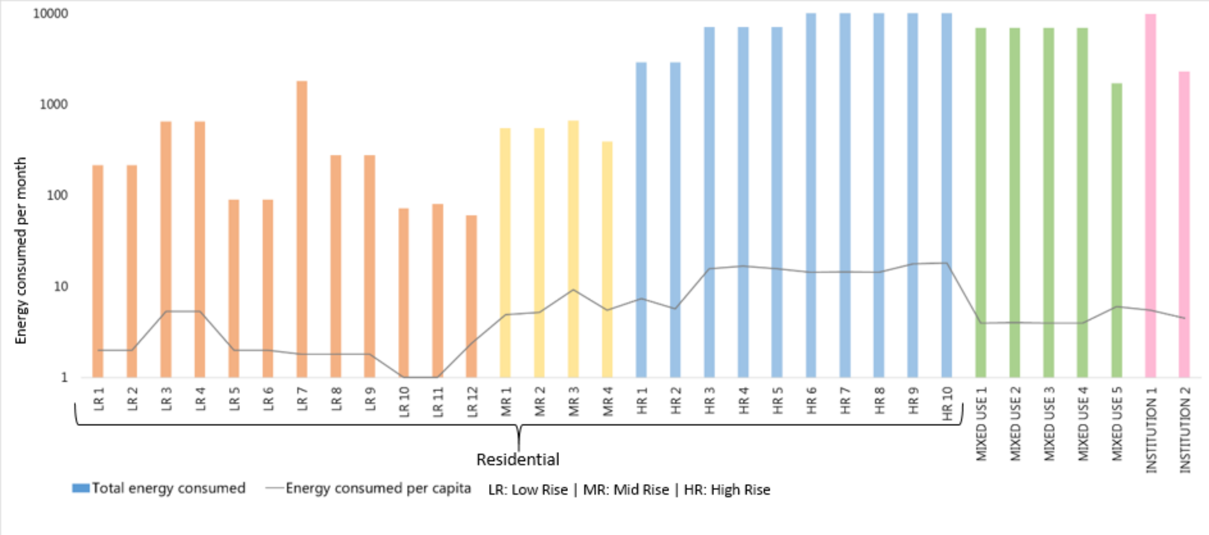


Figure 47: Building level energy consumption in water services across different typologies

From the observation of the pilot study and the related literatures inferred that the residential building uses a considerably significant share of water that the other typologies. Also, upon studying the predominant land use typologies of the city also highlighted the greater share of the land use being accounted to the residential typology. The existing land use pattern of the Ahmedabad city is as shown in the Figure 48.

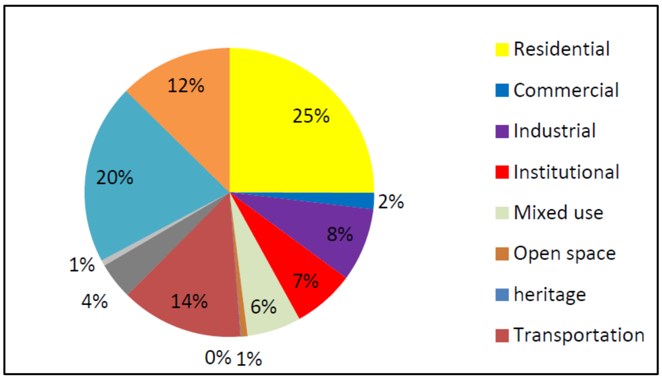


Figure 48:Percentage share of land use among different typologies

Thus, the detailed analysis pertaining to the assessment of building level energy consumption in the water services and the impact of the urban morphology on the same are studied by considering only the residential buildings. A stratified sampling method is adopted to identify and select the residential buildings samples. The areas with predominantly residential land use are identified from the Development plan of AUDA-2021. The required building samples are selected from these identified areas. The samples are selected from both eastern and western parts of the city to ensure the spatial distribution of the samples across the city. Further, to ensure the good mix of all the residential typologies, equal number of samples are selected among all the major residential typologies. The details regarding the same is explained in the Table 25.

Table 25: Number of samples selected under each residential typology

Residential typologies	Number of samples selected
Row house	30
Semi detached	30
Detached	30
Midrise apartment	30
High rise apartments	30

Overall 150 samples are selected for assessing the building level energy consumption in water services. The apartments, semidetached and detached samples predominantly found in the western side of Ahmedabad and the row houses are predominantly found in the eastern side. Thus, the samples of these typologies are accordingly selected from the respective areas.

4.3 Way forward

The required datasets for assessing the building level energy consumption in water supply services are identified. The energy data and the building occupancy data pertaining to the identified residential samples are collected through a proper questionnaire and household surveys. The analysis of the collected datasets and the detailed assessment of the impact of urban morphology on the building level energy consumption is under progress. The detailed assessment and the synthesis of the building level study in context of the larger picture of the project will be explained in the future report.

Part-2: Municipal Solid Waste Management

5 Assessment of City level fuel consumption in Municipal Solid Waste Management

India being a second most populous country in the world, generates nearly 1,50,000 tonnes/day of waste. 90% of which was reported to be collected by the urban local bodies.Just like in any other developing countries, in India the cultural notion of “not in my backyard" dominates the perception of the common man regarding solid waste management (Joshi & Ahmed,2016). With 42.5% of organic content the municipal solid waste in India could pose to be a major GHG emitter if not managed and processed scientifically; especially if the projected generation of 165 million tons per year in the year 2031 is reached (Planning Commission Report 2014). In this context, solid waste management is required to be developed further from a service provision perspective to an economic and ecological service perspective.

This section of the study will intend to focus on the fuel energy consumed during the collection and transportation phase of the MSW management and the fuel efficiency of the system. Ahmedabad is considered as the area of study and will be conducted within the consideration of Ahmedabad Municipal Corporation boundary. The study will involve assessment of vehicle performance and factors impacting their fuel efficiency. Further, this study will be limited to waste collection and transport system and not explore processing and treatment phases as in Indian context much of the processing and treatment is done privately or through informal arrangements.

5.1 Aim and Objective

The main aim of the study is to assess the extent of fuel consumption and the fuel efficiency in the process of collection and transportation of waste within the Municipal Solid Waste Management value chain

In order to achieve this aim, the following objectives were undertaken in the study,

i. Identification of factors which determine the degree of fuel efficiency in the value chain of Municipal Solid Waste Management.
ii. Assessment of energy performance criteria within the scope and the extent of availability of reliable data.
iii. Assessment of the degree of fuel efficiency achieved through the existing fleet in the solid waste collection and transportation in Ahmedabad and potential of further fuel savings within the collection and transportation system.

This report provides details pertaining to the first objective of this study. The study pertaining to the second and third objective is still in progress and the details about the same will be included in the next report.

5.2 Methodology adopted in assessing the city level fuel consumption in Municipal Waste Collection services

This study is carried out in four stages. The first stage of the study involves the review of available literature on the components of solid waste management that contributes to the energy footprint of the service. This stage also involves the review of global and local initiatives that integrate energy parameters to make MSW management more sustainable. Literature on prevalent best practices in tracking energy consumption and recognising potentials of Waste-to-Energy strategies were also reviewed in the process. The first stage was followed by the identification of goals and tasks in the second stage to achieve the study objectives and the data sets required for such tasks. These requirements were listed down in a matrix to further identify the sources of data and the approach required to acquire the data. A strategy involving pilot data collection was formulated in this stage. The third stage involved the pilot survey and data collection of a small sample of 4 wards, compilation of data, identification of data gaps and strategizing the further data collection procedures and the analysis of the available data. This stage also involved the establishment of preliminary relationships among the identified factors influencing fuel efficiency with the fuel efficiency of the sample. In this stage hypothesis was made which further gave a direction for analysis. The fourth stage of the study involved upscaling the data collection to 10 wards, field visits, conducting interviews with officers and staff at Refuse Transfer Station, collection of data, compilation of data and analysis of the data to test the hypothesis.

Pragmatic approach has been adopted in the process of this study. In the first two stages a top-down approach has been adopted where different literature lead us to the identification of study objectives and the required data. The third stage involves a trial and error approach to test the data collection strategies, availability of the required data and the usefulness of the data readily available. The fourth stage involves a bottom-up approach where the final set of available data are used to establish meaningful relationships through observation and data analysis. The final analyses have been triangulated further (Data triangulation) to arrive at a conclusion to the formulated hypothesis.

5.3 Role of Fuel in Energy Efficiency in Solid Waste Management

Organised collection and disposal of municipal solid waste has its roots in the late 19th century with the Public Health Act 1875 of London with introduction of hand drawn or horse drawn carts from the Local Governing Authorities for regular collection, removal and disposal of wastes from kerbside bins (then called “movable receptacles”). The first motored waste transport system was introduced in the 1920 with variety of energy inputs. These included Electric Vehicles, Petrol Powered Vehicles, Steam

Traction Vehicles and combination of Horse and Petrol-Powered Vehicles (Herbert, L., 2007). Since then, with rapid developments in the transportation and motor vehicles industry, the waste collection worldwide steadily shifted from non-fuel carts to fuel powered trucks and compactors. Today the solid waste collection fleets in all the developed countries consist majorly of fossil fuel powered light and heavy vehicles. With such a dependence on fossil fuel in the world to provide solid waste collection services, it has become essential to understand the fuel consumption in the solid waste management services.

5.3.1 Solid Waste Management Scenario: Global and Local

After the World War II, the developed countries turned their attention to the development of their cities and the urban economy. In the process many developed countries took up public health and urban refuse management as a priority. This brought the era which shifted the waste collection system from horse drawn carts to motorised trucks since the old army trucks had to be used in some way or the other. The Solid Waste Disposal Act by US Congress in 1965 set in motion the modern system of handling and disposing of municipal solid waste. Soon the issue of solid waste management became an integral part of environment protection worldwide (Hickman, H.L. Jr., 2003). By the 1980s the waste management policies and solutions worldwide became focused on the elimination of waste through landfilling and incineration activities without any thought to energy consumption or recovery. The scope of recycling and recovery was only realised at the turn of the ultimate decade of 20th century when many European countries revised their solid waste management strategies (Buclet& Godard, 2000). With the Agenda 21 of Rio Summit 1992, Solid Waste Management was recognised as a crucial aspect of Sustainable Development. Currently on the global front, solid waste management forms a key sector for combating climate change through initiatives taken by organisations like UNEP, ISWA and GPWM.

In India, although civic rules preventing nuisance in urban areas were in place since the colonial era, solid waste management remained a neglected part of city administration unlike contemporary European counterparts in the majority of the 20th century. Post-Independence, the policy makers in India passed laws such as Environment Protection Act and several rules under this act to reduce waste and pollution. However, the onus of implementation of these rules were on the local administration of the cities which until the 74th Constitution Amendment Act were not obligated to carry out such implementation. With the formation of 74th Constitution Amendment Act (74th CAA) in 1992, the urban local governments became solely responsible for solid waste management within their jurisdiction. The 74th CAA was followed by the Municipal Solid Waste Rules in 2000 formed as an aftermath of the Surat Plague. These rules laid the procedures to be followed to provide scientific management of waste. The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) launched by the Ministry of Urban Development in the year 2005 provided a platform for the implementation of solid waste management across 62 cities. The mission witnessed a revamp of the waste collection and disposal system where cities started deploying more and more sophisticated waste collection systems with dedicated covered trucks, compactors and GPS fitted vehicles. Subsequently, the municipalities had to ensure lowered carbon footprint and GHG emissions by managing municipal solid waste efficiently under the National Mission for Sustainable Habitat 2011 even if they were excluded from the energy intensive consumer categories in the National Mission for Enhanced Efficiency 2009. The momentum of growth in the sector was achieved finally through the Swachh Bharat Mission (SBM) in 2014 which was directly implemented through the ULBs where all ULBs were mandated to achieve specified standards within the mission period of 5 years. Simultaneously, the National Government amended the existing MSW rules to publish the updated Municipal Solid Waste (Management and Handling) Rules 2016 to aid progress in the initiatives through innovations in technology as well as mandating the extension of solid waste management services to peri-urban and newly urbanized areas outside the jurisdiction of the ULBs. The mission was complemented with a monitoring mechanism through Swachh Survekshan which ranked ULBs on the basis of performance with an additional grading system, the Garbage Free City initiative launched in 2018.

On the other hand, expansion of services meant increasing the fleet od vehicles for solid waste collection which contributes to the fuel requirements of the city. The growing dependency on fossil fuel for transportation in urban areas has long been a concern raised at several world summits. The Global Oil Crisis of 1973 had indicated the limited nature of fossil fuel availability and the subject came under the purview of Climate Change following the 1992 Earth Summit and Energy Conservation was taken up by the UNFCCC in 1997 as a means of combating the climate change. Urban areas worldwide being the highest consumers were encouraged to undergo energy audits by the respective nations. In Europe, the European Commission adopted the EU Action Plan 2015 for circular economy and further integrated it with waste to energy strategy and circular economy in 2017 to align with the 2030 Agenda for Sustainable Development. Many European countries incorporated waste-to-energy strategies under the ongoing Zero Waste Europe policy. India also encouraged its citizens for energy savings and energy rationing through several Institutional Dialogues and Financial Initiatives (Vaish, S., et.al., 2019). Bureau of Energy Efficiency (BEE) was formed by modification in the already existing Energy Management Centre under the Energy Conservation Act of 2001 by the Ministry of Power. Every energy intensive sector including cities were mandated by the act to undergo energy audits under the direction of the BEE. However, these audits did not include the fuel consumption for cities in any urban sector and focused on electricity conservation instead.

5.3.2 Perception of Energy Efficiency in Municipal Services

Although there is a robust policy framework for enforcement of energy efficiency at national and state levels, most of the energy efficiency parameters deal with building and industry level energy consumption and generation. Municipal services if considered for energy evaluation under any mission or scheme has exempted the inclusion of Solid Waste Management as a complete process for attaining energy efficiency targets. Integration of energy into solid waste management programmes have been done in a resource recovery perspective through encouragement of material recycling and reduction of new raw materials in the waste stream. However, these programmes do not provide platform for the municipalities to self-assess their energy inputs within the process. Several studies on individual components of the MSW management process reveals there is a potential to integrate energy performance of these components into municipal energy spectrum through assessment of energy consumption and energy generation potential in each stage of the entire process. Fuel consumption in the Solid Waste Collection process which contributes significantly to this municipal energy spectrum has long been overlooked as an essential input. There is a need to consider the fuel consumption in order to develop strategies to achieve energy efficiency in this service.

5.3.3 Fuel as an Energy Parameter in Solid Waste Management

Municipal Solid Waste Management involves a multistage value chain starting with the generation of waste and ending with scientific disposal of residue left after waste processing. These stages are waste generation, waste collection, transportation, waste processing and waste disposal. Among these stages, waste transportation from one facility to other forms a major component involving fuel energy consumption. Waste density, volume and composition determines the type and number of vehicles and number of trips required to serve the area. Location of transfer station and the road layout determines the trip length and speed for each vehicle to travel. These factors of the collection system determine the amount of fuel consumption in the process of waste collection (UN-HSP, 2010). Assuming a city to opt for only landfilling as a disposal strategy for the entire waste volume of the city, the fuel consumption in collection and transportation will have maximum contribution to the energy footprint of the solid waste management system. Hence, a systematic study of fuel consumption in the waste collection process is essential for evaluating the energy use in MSW management strategies.

5.3.4 Significance of Fuel Consumption in Solid Waste Collection

For municipal solid waste to be managed in the best possible way, the waste has to be source segregated, removed from the point of generation regularly and transported to such facilities where the waste can be treated, and materials and energy can be recovered prior to disposal. This level of service involves a cost which the Municipal body must bear by itself from its revenue accounts. The municipal body usually charges the public for the removal of waste from their premises through fixed taxes or charges, large increases in which might become unbearable. Collection and transport of waste hence attracts particular interest as poor optimization leads to high expenditure on fuel on the part of the municipal corporation to keep the system functional.

5.4 Factors Affecting Fuel Efficiency

Sustainability in waste collection and transportation system requires efforts to reduce energy consumption. Fuel consumption of vehicles depends on factors like road type, speed, acceleration, road grade, load mass, air conditioning, driving style. An effective tool to assess the extent of fuel consumption in any fleet of transport vehicles is to study the fuel efficiency of the vehicles in the fleet. Fuel efficiency of a vehicle can be defined as the volume of fuel required by the vehicle to transport a unit mass over a unit distance, usually expressed in terms of litre/ton/km or litre/ton/100 km. Studies have found that fuel efficiency of a vehicle varies for different urban settings and drive cycles (Wang, L., et.al., 2015; Ivković, I. S., et al., 2017). The fuel consumption in a waste collection system is hence not a function of any isolate factor but a nexus of different combinations of factors. These factors can be categorised according to their nature of influence as Vehicle Specific Factors, Urban Factors and User Specific Factor. Although very less literature is available on the assessment of fuel consumption in solid waste collection, literature available on the fuel efficiency parameters of heavy commercial vehicles and transport buses were referred to understand the complex nature of these factors that influence fuel efficiency.

5.4.1 Vehicle Factors affecting Fuel Efficiency

Factors that fall under this category are essentially the characteristics of the vehicle. These are non-external factors owing to the design and manufacture of the vehicle and will impact on the fuel efficiency of the vehicle in the same way in every given situation. Several literatures (Zacharof, N., et.al., 2016; Wang, L., et.al., 2015; Ivković, I. S., et al., 2017) indicate that the following factors have some degree of impact on fuel consumption and fuel efficiency in case of all kinds of vehicles.

Vehicle Tare Weight: This refers to the unladen or kerb weight of an empty vehicle. The tare weight of a vehicle is a function of its design or model. A heavy vehicle usually requires more energy to move a certain distance than a lightweight vehicle. In this process, a heavy vehicle will consume more fuel than a lightweight vehicle if both vehicles are assigned similar payloads.

Vehicle Payload: Since it is known that more energy is required to move heavy objects than a lighter one, the same principle applies for payload carried by the vehicles. Two vehicles with similar tare weight will consume different volumes of fuel if the payload they carry are different. The vehicle with lighter payload requires less fuel than the vehicle carrying higher payload.

Vehicle Rolling Resistance: The tyres of the vehicle along impacts on the fuel consumption since it contributes to the friction with the road surface. This factor is also a function of the road conditions as well as a function of the maintenance of the vehicles. Fuel consumption increases with increase in rolling resistance.

Vehicle Aerodynamic Drag: The design of the outer structure of the vehicle and its interaction with the air pressure during movement has an impact on the fuel efficiency of the vehicle. A flat frontage of the vehicle will increase the aerodynamic drag and the vehicle will require more energy than a low drag frontage to move over a unit distance at a given speed. This will increase the fuel consumption of the vehicle.

Vehicle Fuel Compatibility: The fuel type used in the vehicle also has an impact on the economic value of the vehicle although it does not affect the fuel efficiency of the vehicle. The choice of fuel however will impact in the overall energy efficiency of the fleet since a CNG compatible vehicle will consume less fuel per unit distance than a petrol or diesel-powered vehicle and ultimately result in fuel savings.

5.4.2 Urban Factors affecting Fuel Efficiency

Vehicles consume different volume of fuel to travel a unit distance in different urban conditions. Several urban factors which are essentially non-intrinsic to the vehicles influence this difference in fuel efficiency of the vehicles. Although literature pertaining the waste collection vehicles and their fuel consumption patterns in various urban setting were very less, similar literature pertaining to light and heavy commercial vehicles and trucks have been referred for the purpose of this study. These literatures (Menon, A., Bandivadekar, A., 2016; Ou, J., et.al., 2013, Marshall, J.D., 2008; Karathodorou, N. et.al., 2009) have indicated the role of following urban factors in fuel consumption and fuel efficiency of the vehicle fleet.

Distance of Dumpsite/ Landfill/ Transfer Station: The distance a vehicle has to travel to transport the waste from the point of removal to the point of dump has a direct impact on the fuel consumption by the fleet of vehicle. In case of a centrally positioned dumpsite in the city, the fleet will travel less distance than in the case where dumpsite is located far from the city in the outskirts. In spatially large cities it is advisable to set up multiple point of dump or multiple transfer stations so as to reduce the route length for individual vehicles and save fuel consumption in the fleet.

Route Length: The number of buildings on a route assigned to a vehicle and the length of road it traverses in order to serve all its assigned service point is called the route of the vehicle. Fuel consumption of a vehicle increases with increase in the route length assigned to it. The route length is again dependent on the built urban fabric along the route. In case of low-rise urban sprawl, the route length increases while it decreases in densely compact high-rise urban core areas.

Urban density: The density of buildings and dwelling units within a unit special area determines the amount of waste generated in that area and the number of point of services to be assigned to a given waste collection vehicle. Higher the density, lesser the number of buildings served by a vehicle in a single trip. This increase either the number of vehicle or the number of trips made by the same vehicle and eventually increase the fuel consumption by the fleet.

Road Network: The network of roads and size of urban blocks within a given spatial area also influence the length a vehicle has to travel in order to serve all the assigned buildings. Hence, route optimizations are incorporated while assigning routes to vehicles so that the vehicles travel minimum distance to cover the points of service.

Shape of a city: A spatially elongated city will require its waste collection vehicles to consume more fuel to transfer waste from the farthest boundaries of the city to the dumpsite/landfill. If a city is monocentric or polycentric, the distribution of the waste collection fleet will influence the total fuel consumption in the city for waste collection.

Traffic Conditions: Vehicles usually run at very low speed in heavy traffic conditions. Hence, if a waste collection vehicle has to traverse through a high traffic area within its assigned route, it will run at low speed and likely to consume more fuel.

5.4.3 User Factors affecting Fuel Efficiency

The behavioural aspects of the stakeholders that may impact on the performance of a technologically efficient waste collection fleet has also been studied to understand the controllable aspects of fuel consumption in the fleet (McKinnon., D., et.al., 2017; UN-HSP, 2010). The actors in the field of municipal solid waste handling and their role in ensuring fuel efficiency in the system can be enlisted as follows:

Segregation at source: High degree of segregation of waste at source eliminates the requirement of the intermediate stages like waste segregation stations and material recovery stations. Such approach can to an extent eliminate the requirement of specialised vehicles that can handle mixed waste and transfer them to a central facility. Segregation at source and decentralised disposal of dry recoverable material also reduces the payload of the waste collection vehicle.

Urban Planners: Planning of the waste collection routes and trip intervals if done in efficient manner ensures least distance travelled while ensuring 100% collection. Also, street layout and urban settlement zoning done at city level impacts the fuel consumption of collection vehicles.

Waste collection staff and Drivers: Skilled and qualified drivers of waste collection vehicles ensure smooth running of vehicle on road. Case specific planning of collection shifts and collection duration also ensures speedy service delivery and in turn reduces fuel consumption on road. The informal sector comprising of waste pickers who are involved in the parallel recycling market also considerably reduce the load on Municipal solid waste collection services and hence result in high efficiency of collection vehicles. In this scenario, the reduced volume of waste lets a vehicle cover a larger collection route, thus saving fuel.

Maintenance of Vehicles: Regularly maintained vehicles with advanced fuel-efficient engines perform better than old and worn out vehicles in terms of fuel efficiency. If the fleet consist of new vehicles, the overall fuel efficiency will remain low. With age, the vehicles consume more and more fuel to perform the same amount of work.

Operating Mass: Vehicles which run beyond their capacity consume more fuel than a vehicle which are utilised at its recommended capacity. Also, if a vehicle runs below its capacity, the fuel efficiency reduces due to the low mass carried over the distance at a given fuel consumption.

5.4.4 Summary

The study of available literature has led to the identification of quantifiable variates that influence energy consumption. While the framework of a policy or mission and the programmes undertaken under those policy provide opportunities to adopt new technologies, it is the responsibility of the planning agency and service providers to select those technologies that ensure least energy consumption. The vehicles procured for the collection service should conform to latest standards for ensuring energy savings.

Energy consumption in the collection and transportation stage of solid waste management value chain is a function of not only the technical specifications of the compactor equipment and vehicles, but also a function of skill of the stakeholder involved in the management process. Urban morphology parameters like population density and land-use of a locality hugely determines the amount of waste generated and in turn governs the trip frequency of a vehicle. Availability of a waste transfer station can reduce the fuel consumption owing to reduced trip length to be covered by primary collection vehicles. Trip lengths coupled with number of trips and the carrying capacity of a particular vehicle impact its fuel consumption.

Analysis of a large sample across all the functioning refuse transfer station within the city will provide the total fuel requirement of the city for ensuring efficient conservancy services. For the purpose of such an analysis, a detailed data requirement matrix was prepared to take forward the field surveys and data collection for the study.

5.5 Data Collection

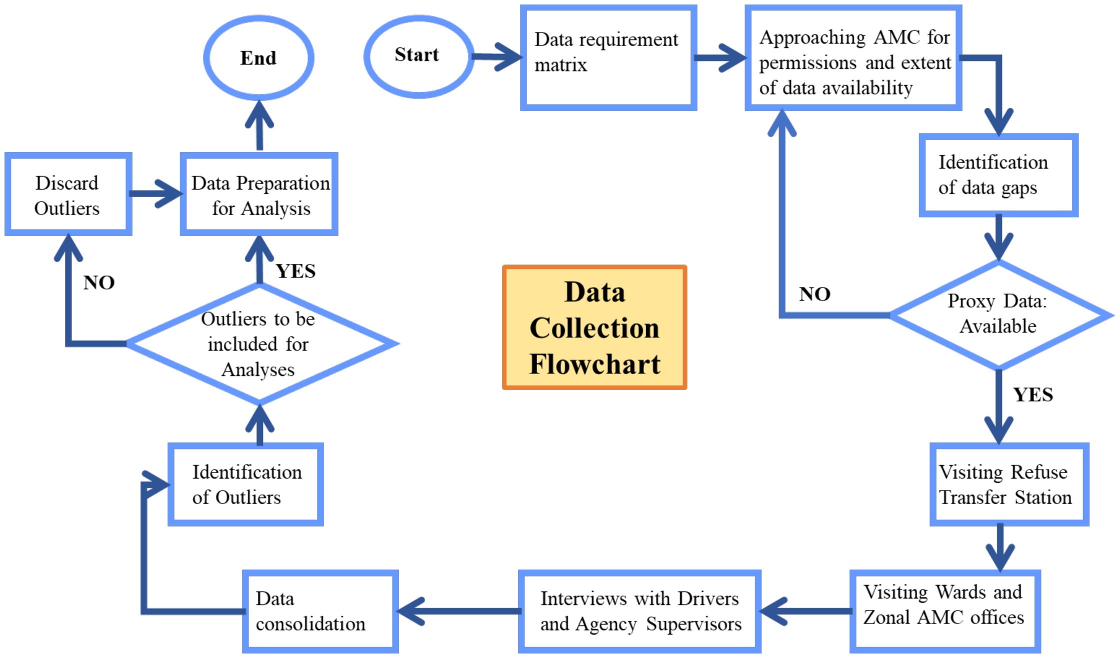


Figure 49: Flowchart representing the data collection methodology

As the required datasets were to be collected from different sources, a planned approach was adopted. In the initial stage, the data required for meeting the stated objectives of the study were enlisted based on the extensive literature review on similar studies carried out across the world. The sources form where the enlisted data were available were identified through consultation with the officials in the Municipal Corporations. Permissions were taken from the Municipal Corporation to collect the required data from their own and allied databases as well as for conducting questionnaire surveys of vehicle drivers and waste collection staff. In the first stage of the data collection, Pilot surveys were conducted at the JunaVadaj RTS and the wards under its service. The collected data was reviewed to identify the gaps in the collected data with reference to the data requirement matrix. Proxy data for such data gaps were identified within the collected data sets. The Municipal Corporation was approached for consultation regarding data gaps for which proxy data could not be identified. This whole process led to the consolidation of Data Collection Strategy which was adopted during the field and data collection across 12 wards in the West and Central Zone of Ahmedabad which are served by 2 transfer stations, viz., JunaVadaj RTS and Khadiya RTS. These zones were selected for survey on the basis of Purposive Sampling and Cluster Sampling as these zones were roughly representative of the whole city in terms of land-use and built fabric. In case of each zone, the transfer station (RTS) were the first point of approach in order to collect weighbridge record, vehicle ownership data and vehicle refueling log from contracted private agency supervisors. The second point of approach were the AMC Zonal Offices and Ward Offices for collection of route distribution data and route maps. Interviews were conducted with private agency supervisors, drivers and waste collection staff of sample routes. In the final stage the collected data was compiled and outliers in the data were identified. The outliers were then verified with the Sanitary Sub Inspectors of the concerned ward and the agency supervisors. The final data set including the primary, secondary and proxy data was organized and prepared for subsequent analysis. This data sets obtained for the current study are listed and briefed in the Table 26.

Table 26: List of datasets collected for the current study

Data Required	Data Source	Availability	Proxy Data	Status of Collection
Ward wise distribution of waste collection vehicles	AMC Zonal Office	Yes	–	Collected and Compiled
Load carrying capacity of each vehicle	RTS	Yes	–	Collected and Compiled
Aerodynamic Drag and Rolling Resistance	–	No	Not Available for specific vehicle model	Not Collected
Waste collection by each vehicle per trip	RTS- Weighbridge Records	Yes	–	Collected and Compiled
No. of trips per vehicle	RTS- Weighbridge Records	Yes	–	Collected and Compiled
Route length assigned to each vehicle	AMC Ward Offices- Ecoskipper	Yes	–	Collected and Compiled
Route characteristics for each vehicle	GIS map- Secondary Data from CEPT	Yes	–	Collected and Compiled
Distance of assigned route from RTS	AMC Ward Offices- Ecoskipper	Yes	–	Collected and Compiled
Total travel length of each vehicle	Agency Supervisors- Refueling Log	Yes	–	Collected and Compiled
Daily fuel consumption of each vehicle	Agency Supervisors- Refueling Log	Yes	–	Collected and Compiled
On duty running speed of vehicles	–	No	Daily duration of service divided by total travel length	Collected and Compiled
Vehicle condition	Agency Supervisors	No	Not Available for specific vehicle model	Not Collected
Ward Size	GIS map- Secondary Data from CEPT	Yes	–	Collected and Compiled
Population of wards	Secondary Data from Literature	Yes	–	Collected and Compiled

Traffic Condition on the Routes	–	No	Right of Way of the routes assuming traffic condition to be same	Collected and Compiled
Road characteristics of wards	—	No	Right of Way of the routes	Collected and Compiled
Road Surface Condition	—	No	Not Available for the routes	Not Collected
Building typology along each route	GIS map-Secondary Data from CEPT	Yes	—	Collected and Compiled

5.6 Way forward

The required datasets for understanding the fuel consumption in the collection and transportation of the municipal solid waste has been obtained. The collected datasets are intended to use in creating an inventory of the Fuel Consumption Data and using the same for feeding into City Energy Model. Further, the fuel consumption data is assessed in relation with the urban form of the city to understand the potential scope of the same in making decisions towards improving the services. The further study in line with this action is still in progress. The details pertaining to the same and the synthesis of the study in the larger picture of the project will be detailed in the future report.

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Appendix A Data sets obtained from the PAS, CEPT University

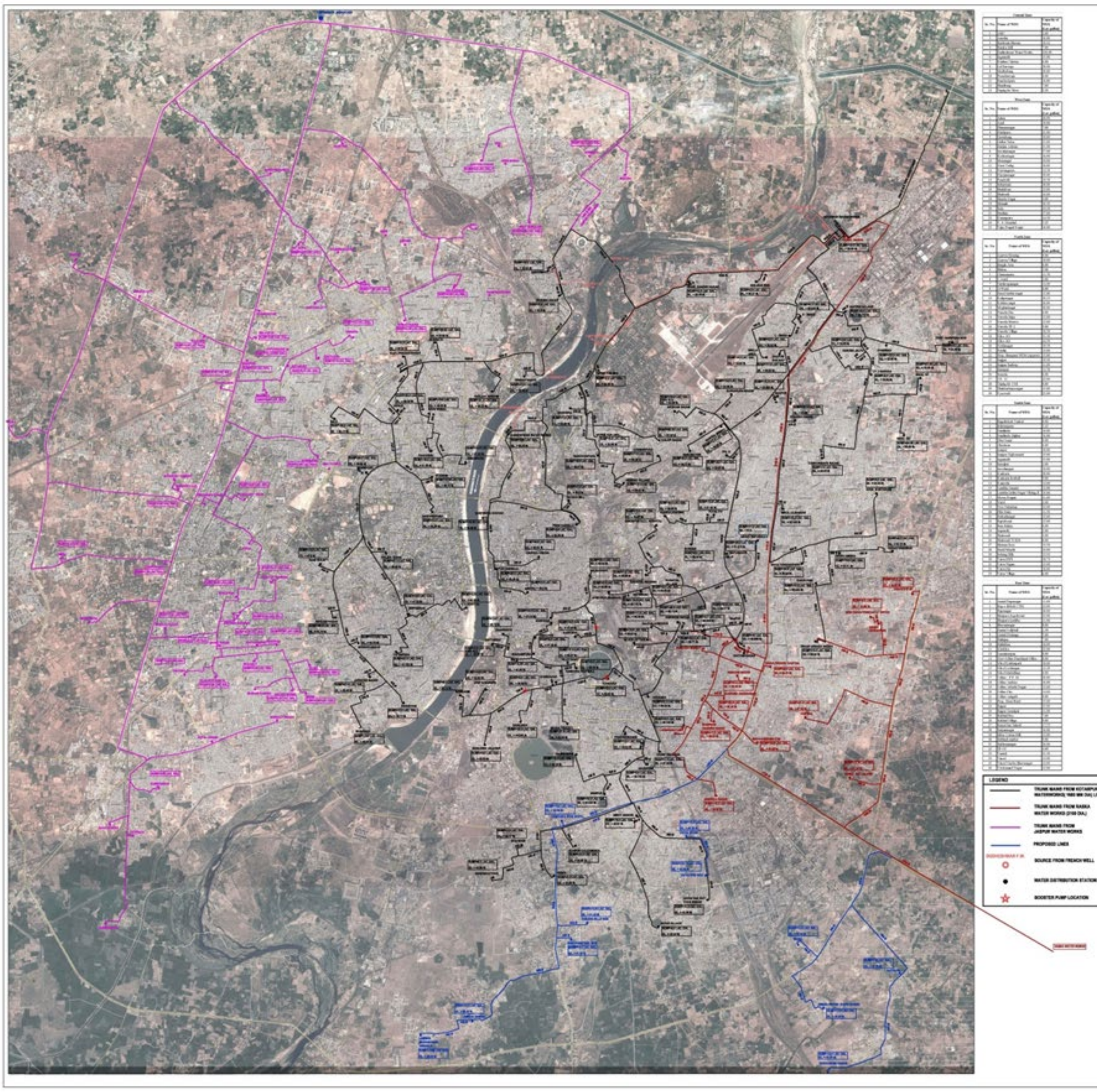
INDICATORS REQUIRED			Measure consumption	Classification of city	Parameters
WATER SUPPLY		UNIT			
SERVICE INDICATORS					
1	Coverage of WS connections	%		✓	
2	Per capita available water at consumer end	lpcd		✓	
3	Extent of NRW	%			✓
LOCAL ACTION INDICATORS					
4	Coverage of distribution network	%		✓	
5	Unit electricity cost of production of water	Rs/KL	✓		
WASTE WATER		UNIT			
SERVICE INDICATORS					
6	Coverage of WW network	%		✓	
LOCAL ACTION INDICATORS					
7	% of households with sewer connections	%		✓	
8	Coverage of sewerage network	%		✓	
9	Unit electricity cost of collection/disposal of WW	Rs/KL	✓		

DATA REQUIRED		Measure consumption	Classification of city	Parameters
1	Population (Present Year)		✓	
2	Number of Households (Census 2001/2011)		✓	
3	Number of Households (Present Year)		✓	
4	Population Density (Present Year)			✓
WATER SUPPLY				
COVERAGE-CONNECTIONS				
5	Domestic connections (Total)		✓	
6	Total Number of Water Supply Connections - Residential		✓	
COVERAGE-HH SERVED				
7	Households served by Domestic Connections		✓	
8	Households served by Bulk supply - Apartments		✓	✓
9	Households served by Bulk supply - Layouts/Societies		✓	
10	Per capita supply of water	✓		✓

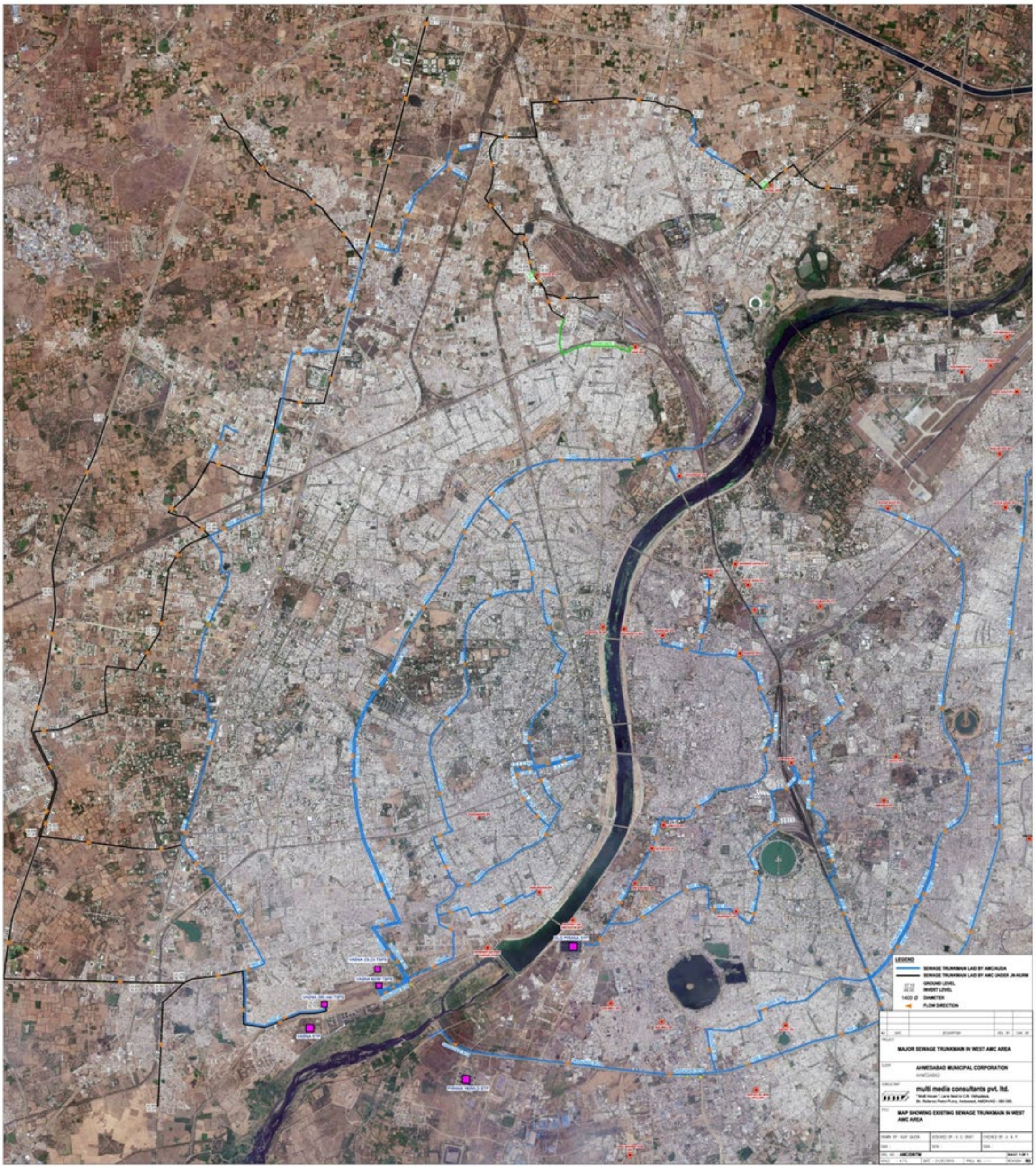
DATA REQUIRED		Measure consumption	Classification of city	Parameters
NRW				
11	Total Volume of water produced	✓	✓	✓
12	Total Volume of Water Billed		✓	✓
	Cost Recovery			
13	Electricity Charges/Fuel Costs	✓		
SANITATION AND DRAINAGE				
	Coverage of sewage network services			
14	Total Number of Properties in the City		✓	
15	Properties with sewer connections		✓	
	Adequacy of sewage treatment capacity			
16	Total Waste Water Generated	✓	✓	
COST RECOVERY				
17	Electricity Charges /Fuel Costs	✓		

ADDITIONAL INFORMATION				
WATER SUPPLY				
18	Length of trunk main	✓	✓	
19	Length of transmission mains	✓	✓	
20	Length of distribution network	✓	✓	
21	Total area under water distribution network			✓
SEWERAGE				
22	Total length of underground piped network	✓	✓	
23	Length of covered drainage network	✓	✓	
24	Length of open drainage network	✓	✓	

Appendix B Water Supply Network for Ahmedabad



Appendix C Sewerage Network for Ahmedabad



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