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Electricity Consumption in Municipal Water Distribution Systems: Relationship with the urban form at city level

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Abstract

Municipal water supply systems account for the highest share of total electricity consumption out of the other energy-intensive municipal services such as wastewater pumping, treatment, and street lighting. The energy-efficiency in the sector has majorly been looked in terms of design and operational efficiency. The interaction with the urban form is quite unexplored.

With the increase in urbanization, expansion of cities and densification are leading to a burden on existing infrastructure and an urgent need for additional basic infrastructural facilities is being felt. The study aims to explore the relationship between the urban form of a city and electricity consumption for the municipal water distribution systems. The study focuses on the city of Ahmedabad. The urban form of a city corresponds to urban development parameters such as the spatial distribution of water users, net plot density, network length, and population density. The pumping electricity consumption in the study has been divided into two parts- municipal level and building level (as the municipalities in India supplies water for a certain head pressure).

Correlation analysis was used to find the kind of relationship that exists and its significance. The value of correlation coefficient obtained at city level showed a strong positive relationship between the pumping electricity consumption and network length configuration ($r= +0.633$) while a very weak relationship with the population density ($r= 0.098$). Municipal level pumping electricity consumption doesn't decrease much with the increase in density. However, the building level pumping electricity consumption showed a usual trend with the highest electricity consumption in bungalow societies, high rise apartments (>5 floors) followed by mid-rise apartments (3-5 floors) and the least in the row housing. The findings of the study at both, municipal level and building level pumping electricity consumption pave the way forward for shaping Ahmedabad's future urbanization in an energy-sensitive manner.

Keywords: Urban form; Electricity consumption; Water distribution systems; Building stock

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1. Introduction

Indian cities are urbanizing fast. With the increase in urbanization, cities are subject to expansion and densification, majorly characterized by the low-density suburban development. This puts pressure on existing infrastructure, need for the additional infrastructure and the basic municipal services like water supply, drainage, and streetlights, etc. in addition to the inefficient use of our limited land resources [1, 2]. These urban forms making the cities disperse have been a matter of consideration for the city planners and managers in the past few decades. The way in which the future direction of the city's urban form should be planned, regulated and municipal services extended for efficient future city development.

Municipal services such as water supply systems and street lighting together account for 4% of the total electricity consumption in India [3]. For municipal water supply systems alone, energy audits have shown that electrical energy costs account for 40% to 60% of the total revenue expenditure pertaining to the water sector in the municipal budget [4]. The energy savings and monetary savings in the municipal water systems has majorly been looked in terms of systems design efficiency and operational efficiency[5]. The interaction of urban form with these energy-intensive municipal systems is quite unexplored [6].

This paper tries to bring together the context of energy-intensive municipal infrastructure services provisioning and urban growth by investigating the relationship between the identified urban development parameters and electricity consumption by the municipal services namely water distribution systems (WDS). The study is divided into two parts. First, municipal level pumping electricity consumption. Second, building level *(only residential)* pumping electricity consumption as the municipalities in India supply water for a certain pressure head height.

2. Research questions, methodology, and tools

Four urban parameters were identified based on literature from a few existing research studies namely command area served, net plot density, network length, and population density[7,8]. The paper addresses the following research questions to investigate whether and how the electricity consumption in pumping water by the municipal water distribution system is related to each of the identified urban development parameters.

- Is there a strong positive relationship between the square kilometer of the urban area served, the plot density and the total network length in the urban area served by a water distribution station (WDS) and electricity consumption by the WDS?
- Is there a negative relationship between the population density (persons/square kilometer) and electricity consumption by the corresponding WDS?

Ahmedabad being a 'data-rich' city in terms of availability of time-series of data on electricity and water consumption was selected as the area of study. As a methodology of the research, first, the study focuses on understanding the internal urban form of Ahmedabad i.e. its land-use, population density, and building typology as per the current division of the city into 48 wards which are clubbed together into 6 administrative zones namely North, East, South and Central

Zone making the Eastern Ahmedabad and West Zone and New West Zone making the Western Ahmedabad. Second, understanding the city's water infrastructure. Ahmedabad Municipal Corporation (AMC) has 95% water network coverage by area[9]. A decentralized system of four treatment plants supplies water to around 226 Water Distribution Stations (WDS**)** spread across the city. Third, understanding the electricity consumption measurement system in place i.e. SCADA (Supervisory Control and Data Acquisition) for capturing time-series electricity consumption data of the vast water distribution network. As per the study year 2018, the study is focussed on 185 WDS (81%) which are currently under SCADA monitoring in AMC[10].

2.1. Data collection and sampling

For the municipal level electricity consumption, two major datasets were obtained. First, the command area of WDS which is defined as the extent or boundary to which a WDS supplies water. Second, SCADA zonal reports for the daily average electricity consumed by the WDS.

The total sample size of command area was 80 which was 36% of the total number of approximated WDS (226) in the city. The sampled population covered was 32% of the total population estimated in 2018.

For the building level water pumping electricity consumption, the building samples collection was aimed at three major residential building typologies**:** High Rise (>5 floors), Mid-Rise (3-5 floors), Low-Rise (<3 floors). A survey questionnaire was prepared to collect the baseline data on electricity consumption for pumping water.

The statistical tool of **correlation** was used to find out whether and how strongly the identified urban development parameters are related to the electricity consumed by the WDS.

3. Analysis and Findings

3.1. Municipal level

Correlation value was calculated for the city on an average and zone-wise. The correlation coefficient values obtained for the command area served ($+0.5 < r < +0.8$) and network length ($r > +0.6$) showed a strong positive relation at the city level which indicated with an increase in the command area served and increased network length, electricity consumed by the corresponding WDS also increases considerably. The impact of network length on the electricity consumption was analysed to be affected by the pipe properties such as diameter, length, energy loss to friction with an increase in road length, and hence the network length.

Net plot density in the study was taken as a proxy to the number of connections which was assumed to be one per final plot (the number of connections per plot was not available with AMC). The correlation coefficient values obtained showed a weak negative relation ($-0.3 < r < 0$) for the zones in eastern Ahmedabad and strong positive relation ($+0.5 < r < +0.7$) for the zones in western Ahmedabad. For analysing this variation, land-use land-cover (LULC) plot-wise of the sampled WDS was studied. Spatially, eastern Ahmedabad has a greater number of

plots under slum type informal settlements and industrial units in comparison to western Ahmedabad[11]. And, according to the city's service statistics, only 75% of the slum households in AMC have water connections[9]. AMC supplies a limited amount of water to Industrial Units. Therefore, it was inferred that many plots may be a part of the command area, but individual plots might not be having a connection or might be having a shared connection.
Population density showed a very weak positive relationship ($r < +0.1$) at the city level and for the zones in western Ahmedabad but a weak negative relationship ($-0.4 < r < -0.2$) for the zones in eastern Ahmedabad. This indicated that municipal level electricity consumption doesn't get much affected with the increase in population density. To understand the impact of density at building level pumping electricity consumption, building samples surveyed were analysed.

3.2. Building level

The building level pumping electricity consumption for the three different residential building typologies showed the usual trend with the highest consumption in bungalow societies, high rise apartments followed by mid-rise apartments and then the least in the row housing (Fig. 1).

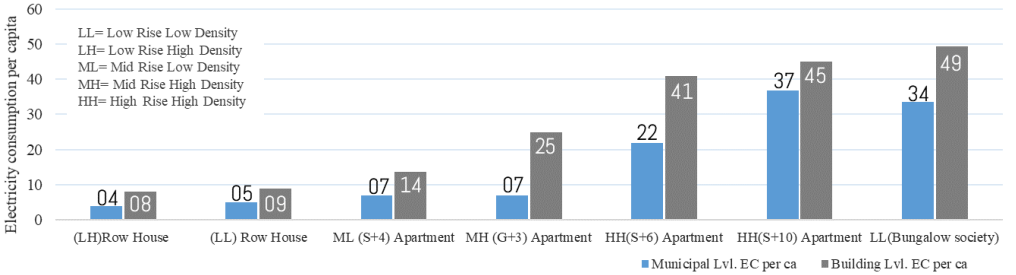

Fig. 1: Building level vs. Municipal level electricity consumption per capita

The combined findings both at the building level and municipal level can be summarized as shown below in Table 1 and Fig. *1* which confirmed that municipal level pumping electricity consumption follows the concept of economies of density and varied accordingly.

Electricity consumption per capita	High-Rise	Mid-Rise	Low Rise	
			Row Housing	Bungalow Societies
Building Level	High	Medium	Low	High
Municipal Level	High	Medium	Low	High
Urban Density	Low	Medium	Medium	Low

Table 1. Pumping electricity consumption per capita at both municipal level and building level

4. Scenarios for Ahmedabad's future urbanization

Depending on the findings both at the municipal level and building level, the study concludes

with the three probable scenarios Ahmedabad could undergo for shaping the future urbanization
as the city expands in an energy-sensitive manner which is summarized in Table 2 below.

	Scenario I	**Scenario II**	**Scenario III**
Urban Density	<50 ppha (persons per hectare)	50-145 ppha	>145 ppha
Built Development	Low Rise (Bungalow type)	Mid-Rise (<5 floors)	Mid/High Rise
Cost at both ends	High	Medium	High at Building Low at Municipal
Access to services	Less%	High%	Higher%
Land Coverage	High	Medium	Less

Table 2: Ahmedabad's future urbanization scenarios

5. Conclusion

From the three scenarios, it was concluded that density as an important parameter of urban form and synonym of energy – efficiency doesn't always mean high rise development. Medium-rise, high-density urban areas can achieve a similar level of density as high-rise *(medium evidence, high agreement)*. Thus, the study concludes with an endnote for the city planners that a good mix of mid-rise, high-rise can be an optimum way forward for shaping a city's (Ahmedabad) future urbanization in an efficient manner wherein land market dynamics will play a major role.

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