Environmental Science
Water Research & Technology

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal | View Issue

Cite this: *Environ. Sci.: Water Res. Technol.*, 2026, **12**, 1135

Water service provision in rapidly urbanising villages: a comparison of rural and urban governance in Mumbai and Chennai regions in India

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Received 24th September 2025,
Accepted 21st December 2025

DOI: 10.1039/d5ew00935a

rsc.li/es-water

As cities grow, adjoining villages also start urbanising, adversely affecting primary services, including drinking water services. Switching to urban governance is posed as a solution for addressing this problem. We compared various dimensions of water services available to households across towns in different stages of transition in two metropolitan regions in India to generate evidence on whether the transition of fast-urbanising villages to municipal governance results in improved water services. The data on dimensions of water services were collected through household surveys. The Kruskal–Wallis test was adopted to determine if the differences found in quantitative dimensions of water services available to households across fast-urbanising villages and towns under urban administration were statistically significant, while a chi-square test was employed for qualitative dimensions. Our results showed no better services in towns under urban administration for all dimensions studied. If some were better in towns under urban administration, others were better in urbanising villages under rural administration. We conclude that urban governance alone does not guarantee better services, and there are factors beyond governance contributing to improved services. The findings urge policymakers and programme implementers to look beyond the 'transition-to-urban governance' solution and work on institutional strengthening and context-specific approaches.

Water impact

Mere transition of fast-urbanising peri-urban areas to urban governance does not, in itself, resolve drinking water challenges in these transition zones. Strengthening the capacities of local governments is essential, irrespective of whether such areas fall under urban or rural administrative arrangements. Policymakers and programme implementers must therefore ensure meaningful involvement of these local governments in urban development planning and adopt inclusive, stakeholder-driven approaches when considering shifts in governance structures.

1. Introduction

One key finding of the *World Cities Report 2020* is that the global urban population will continue to rise, reaching 60.4% by 2030.[1] Notably, around 96% of this increase is expected to occur in less developed regions of East Asia, South Asia, and Africa. Furthermore, three countries, India, China, and Nigeria, are projected to account for 35% of the total global urban population growth between 2018 and 2050.[1,2] India, the most populous nation, is projected to add 416 million urban residents, substantially higher than China's 255 million and Nigeria's 189 million.[2] The report also highlights that the rate of spatial expansion of urban areas, including peri-urbanisation, is significantly faster than the rate of urban population growth. In India, census towns (CTs), villages exhibiting urban characteristics† identified as urban by the Census of India,[3] saw a remarkable 186% increase between 2001 and the last census held in 2011, adding 2500 new CTs.[4,5] These CTs contributed to nearly 30% of the increase in urban population, which only follows the combined effect of natural increase in urban population and change in administrative status of settlements.[6] This pattern contrasts sharply with China, where rural-to-urban migration has been the dominant driver of urban expansion,[7] and also

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† Census towns are large villages in India with a population size of 5000 or more, a density of at least 400 persons per square kilometre, where more than 75% of the male population is engaged in non-agricultural pursuits.

Nigeria, where almost 50% of the growth is triggered by the natural increase in urban areas, driven by declining mortality and high fertility.[8] These differences make India an especially compelling context for examining the dynamics of fast-urbanising settlements.

Studies indicate that 34% of the newly added CTs lie within a 25 kilometre radius of large town boundaries[9] and thus can be considered peri-urban. Although currently under rural governance, these CTs may eventually transition into statutory towns (STs),[10] which fall under urban governance[3] or merge with adjoining STs over time. This potential transition highlights the relevance of the peri-urban CTs in transition studies, and these CTs, along with the adjoining ST, form an ideal setting for examining rural-to-urban governance transition and subsequent change in services.

Previous research in the Global South indicates a decline in water service quality in peri-urban areas compared to adjacent metropolitan regions.[11–15] These service deficiencies often compel both low- and high-income households (HHs) to rely on unsafe or costly alternatives, with poorer HHs being especially vulnerable due to limited resources.[11,12] Peri-urbanisation is commonly understood as a result of low-income HHs seeking affordable living spaces near urban centres.[1] The fragmented jurisdictional arrangements and limited institutional capacities of local governments in peri-urban zones further constrain their ability to provide adequate infrastructure and services.[11,16–19] Bringing peri-urban areas under urban governance is frequently proposed as a viable solution to bridge service gaps in the water and sanitation sectors.[16,19–23] According to the Constitution of India, local governments in CTs and STs are responsible for managing essential services, including drinking water.[24] However, several studies note that local bodies in CTs often lack the capacity and resources needed to meet the demands of rapidly urbanising areas.[20,22,25–29] While some peri-urban CTs may eventually merge under adjoining STs or become STs and thus transition to urban governance, there is no conclusive evidence that this leads to improved amenities, including better water services. Some studies report that overall service delivery is poorer under rural governance frameworks,[20,26,30–32] whereas others find no significant difference in service provision between CTs and STs.[10] Additionally, rural residents often resist the shift to urban governance due to the absence of or minimal user fees, limited tax categories, and lower tax rates in rurally administered areas.[12,33] This resistance is further reinforced by the skewed allocation of central government grants, which tend to favour rural areas.[33] To date, there are no dedicated studies examining the specific impact of the transition from CTs to STs on the drinking water sector.

In the absence of conclusive evidence on better services in areas under urban governance, we hypothesise that there is no significant difference in water services available to HHs in towns under urban governance and those in fast-urbanising villages. By testing this hypothesis, the study seeks to generate evidence on whether the transition of fast-urbanising villages to urban governance leads to improved water service delivery. Additionally, the study examines the services available across different settlement types to identify those with inadequate provisions that require urgent attention.

2. Methods

To test the hypothesis, the study employed a structured household survey to collect data on multiple dimensions of water service provision in fast-urbanising villages, towns under urban governance, and various settlement types across two metropolitan regions in India. The data were then subjected to statistical analysis to assess whether significant differences in service levels existed between towns under rural administration and those governed by urban local bodies.

2.1 Dimensions for assessing water services

After reviewing several water service assessment frameworks, the dimensions in the service delivery assessment ladder framework developed by the IRC Water and Sanitation (IRC) in 2009[34,35] were chosen with a modification. The framework uses four dimensions of water services: quality, quantity, accessibility, and reliability. To better capture the continuity of supply, an additional dimension, regularity, was incorporated to reflect anticipated interruptions in service. These dimensions are broadly applicable across diverse contexts and facilitate consistent comparison. Except for water quality, data for all dimensions could be reliably collected with the resources available to this study. Owing to the practical and logistical challenges of testing household-level water quality[36,37] was not feasible. However perceived water quality of HHs can be estimated through the extent to which HHs rely on bottled water and undertake in-house treatment of supplied water.‡ As these practices also indicate how well the system performs relative to its intended service level, they were included as indicators of the reliability dimension. Table 1 outlines each dimension, its relevance, and the indicators selected for assessment.

‡ The literature on integrating water quality testing with household surveys emphasises the intensive training required for field surveyors to collect samples accurately, the need for sufficient practice in testing procedures, and the importance of access to functional laboratories, including collaboration with trained technicians.[36,37] In this study, household surveys capturing multiple dimensions of water services were implemented by an external agency engaged by the research team. Due to constraints of time and resources, it was not feasible to provide surveyors with the necessary technical training for water quality sampling. In addition, ensuring access to functional laboratories within or near all six study towns to enable timely testing posed further challenges. Consequently, the planned water quality parameter was replaced with the dimension of regularity. Nonetheless, the survey captured household perceptions of water quality as well as indirect indicators, including bottled water purchases, in-house water treatment practices, and reliance on alternative water sources along with the reasons for such reliance, the analysis of which is presented in this paper.

Table 1 Dimensions and indicators used for assessing water services

S. No	Dimension	Definition and significance	Indicator/s
1	Accessibility of source	Refers to the location of the principal water source. If the source lies outside the household premises, it is likely that less water will be collected, and may adversely affect the quality of water due to unsafe handling practices[35]	Whether the principal water source lies within the household premises (yes/no)
2	Regularity of supply	It measures the continuity of water supply. It captures the anticipated interruptions[35] in supply, for which HHs usually have a backup plan, like setting up storage tanks or accessing a supplementary source	(i) Number of hours water is available in a day (ii) number of days water is available in a week
3	Quantity of water available	The quantity of water to the household. It has a bearing on household hygiene and public health.[38] Identifying a suitable indicator to assess the quantity was a challenge as HHs with piped connections and household or community storage facilities were not aware of the quantity of water they used, unlike those fetching water from public standpipes who had a clear idea of the quantity of water they collect and use in a day	(i) If sufficient quantity of water is available to HHs to meet their daily needs (yes/no) (ii) if households get the required quantity of water whenever needed (yes/no) (The first indicator highlights a 'bare minimum scenario' which captures if adequate quantity of water is available for meeting the routine needs of the HHs. The second indicator of quantity, if required quantity of water is available to HHs whenever needed, captures the temporal factor along with adequacy, which reflects the 'most desirable scenario')
4	Reliability of supply	Reliability of water services is defined as the proportion of the time during which the system functions at its intended level of performance.[34] It captures the 'unanticipated interruptions' in supply that often force HHs to rely on less safe or expensive sources. Studies reveal that even a few days of disruption in the water supply can damage the benefits accrued from an improved system and pose a threat to public health[39]	(i) Number of breakdowns in water supply in a month (ii) Proportion of HHs relying on storage facilities (iii) Proportion of HHs relying on alternate sources (iv) Proportion of HHs relying on bottled water (v) Proportion of HHs relying on water treatment

2.2 Study setting

The research setting was metropolitan areas in India, which are areas with a population of one million or more, surrounding large cities in India, comprising cities, towns, and villages, that can spread across several districts, the extent of which is determined by respective state governments.[40] This study was conducted in two metropolitan regions: the Mumbai metropolitan region (MMR), which surrounds Mumbai, the second-largest city in India, and the Chennai metropolitan area (CMA), which surrounds Chennai, the fourth-largest city in the country. These regions are part of the states of Maharashtra and Tamil Nadu, respectively.

Three types of towns in close proximity were selected in each region to examine the impact of transitioning from rural to urban administration on water services. The first is a CT identified as such in 2001, representing an advanced stage of rural-to-urban transition; this is referred to as an 'old CT' in the study. The second is a CT that was classified as a CT only in 2011 in the last census, indicating a more recent transition; this is referred to as a 'young CT'. The third is a ST, a town under urban governance, near the selected CTs.

2.2.1 Study area in the Mumbai metropolitan region. Bhiwandi is a satellite city of Mumbai and is part of the MMR. It has been a leading cotton cloth producer and supplier since colonial times, and the transport network cutting across Bhiwandi city and the surrounding villages makes it a major logistic hub in the country.[41] Recognising its growing significance, the state government notified an area of 144 square kilometres, spanning 60 villages around the Bhiwandi–Nizampur City Municipal Corporation, as the Bhiwandi surrounding notified area (BSNA).[42,43]

For this study, the Bhiwandi–Nizampur Municipal Corporation, hereafter referred to as Bhiwandi city, was selected as the ST. The 60 villages surrounding Bhiwandi city, collectively notified as the BSNA, include nine CTs: five old CTs and four young CTs. Using a random number generator, one CT from each category was selected. Karivali was chosen as the old CT, and Purne as the young CT (Fig. 1).

In CTs, water supply was managed by the Gram Panchayat, the local village government, whereas in the ST, it was overseen by the municipal corporation. All three towns had a public piped water supply, with the bulk water sourced from a private limited company[44] and the Mumbai Municipal Corporation. In addition, privately owned protected wells and boreholes were also used in the area.

2.2.2 Study area in Chennai metropolitan region. Chennai, a prominent port city on the eastern coast, touches the state's border with the neighbouring state in the north. The transport corridors and economic activities in the city's outskirts, especially information technology (IT) parks set up post-2000,[12,30,45,46] led to peri-urban growth.

The Chengalpattu sub-district of the erstwhile Kancheepuram district (now part of Chengalpattu district), which is home to several IT parks and is intersected by prominent transport corridors, formed the study area in Chennai. The towns chosen

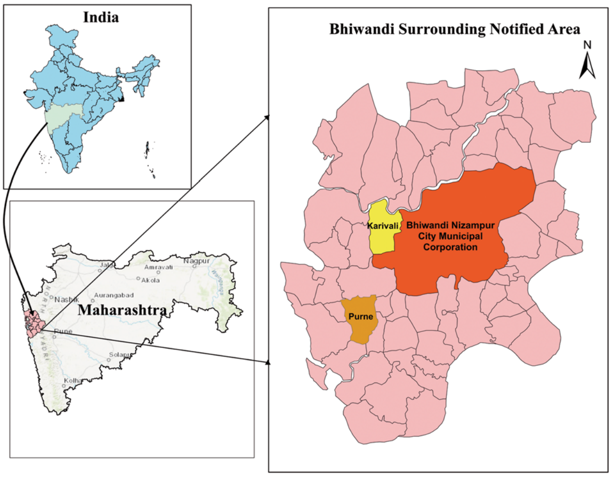

Fig. 1 Study area in Mumbai metropolitan region.

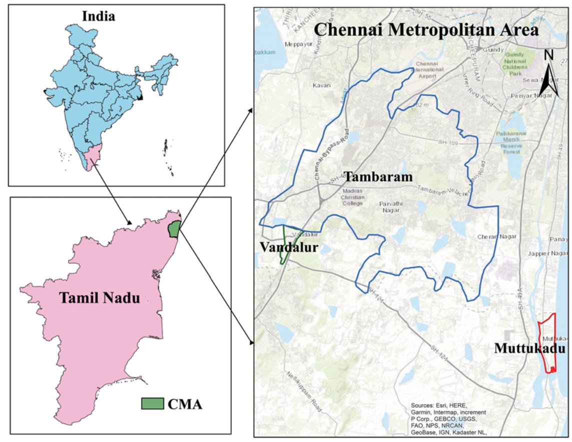

Fig. 2 Study area in Chennai region.

in the Chennai region include Vandalur, an old CT; Muttukadu, a young CT; and Tambaram Municipal Corporation, a ST adjoining them (Fig. 2), and were randomly selected using a random number generator technique.

Like the Mumbai region, in Chennai, too, local governments in the towns were responsible for public water supply. The public water supply system in STs relied on the bulk water supply from statutory boards set up by the state government or had its own groundwater-based systems, which ended in either household connections or public fountains dispersed throughout the town. In CTs, the public water system consisted of several groundwater-based decentralised systems with a borehole, an elevated storage tank, and a distribution network. Self-supply based on boreholes and protected wells were also common in the HHs in these three towns.

2.3 Selection criteria for settlements

Peri-urban studies, both globally and regionally,[12] have raised concerns about equity in resource allocation and sharing among different resident groups. Qualitative studies conducted by the researcher in these towns prior to the quantitative analysis identified three types of settlements: (i) settlements dominated by long-term residents, (ii) low-income settlements, and (iii) apartments.

Residents who have lived in the town for several generations, often referred to as 'early settlers', are classified in this study as 'long-term residents'. Settlements where long-term residents form the majority are termed 'long-term resident settlements'. Low-income settlements refer to areas inhabited by low-income HHs, typically characterised by overcrowding and poorly constructed housing. These settlements are often occupied by migrants who have relocated from rural areas in search of better livelihood opportunities. They may also include caste-based settlements occupied by individuals from marginalised castes, where caste refers to social groups within India's classification system that are assigned by birth. The third category, apartments, represents a distinct feature of urban and peri-urban areas and includes multi-storeyed residential buildings or 'gated communities', as they are commonly known. These communities are generally occupied by middle- or high-income residents, most of whom are migrants from nearby districts or other states.

2.4 Sampling strategies and selection of HHs

The population residing in the towns selected from the MMR and the CMA constituted the target population for this study. The unit of analysis was the household. A cluster sampling method was employed, drawing samples from long-term resident settlements, apartments, and low-income settlements within each town. This approach provided insights into the performance of water services within each settlement type while offering a comprehensive understanding of water service delivery at the town level.

2.4.1 Sampling plan. The minimum sample size was determined using a power analysis technique,[47] assuming a statistical power of 80% and a significance threshold of 0.05, which indicated a minimum sample size of 60 HHs in each town. Considering available resources and time constraints, a total of 360 HHs were targeted for survey in each metropolitan region, resulting in a combined sample of 720 HHs across the two metropolitan regions. Sampling was planned in such a manner that at least 60 HHs were selected from each town and each settlement type within a metropolitan region. Household distribution data in the towns studied from the most recent census is provided in Appendix A-1 (All appendices are part of supplementary material). Since the number of HHs in STs was significantly higher than in CTs, it was decided to allocate half of the metropolitan region's total sample, that is, 180 HHs, to STs. Furthermore, as the number of HHs in old CTs was nearly twice that in young CTs in both metropolitan regions (Appendix A-1), 120 HHs were sampled from old CTs and 60 HHs were recruited from young CTs. The exact distribution of HHs surveyed by town and settlement type in the Chennai and Mumbai regions is provided in Table 2.

Table 2 Town-wise number of HHs surveyed in Mumbai and Chennai

Chennai region				
Type of settlement	Apartments	Long-term resident settlements	Low-income settlements	Total
Type of town	HHs surveyed	HHs surveyed	HHs surveyed	HHs surveyed
Young CT	20	20	20	60
Old CT	40	40	40	120
ST	60	60	63	183
Total	120	120	123	363
Mumbai region				
Young CT	19	22	21	62
Old CT	—	70	66	136
ST	60	63	65	188
Total	79	155	152	386

2.4.2 Selecting the HHs for the sample. With support from community leaders, elected representatives, and local government officials in the study towns, wards (or zones in the case of STs) and streets with the highest concentration of long-term resident settlements, apartments, and low-income settlements were identified using a pre-designed format (Appendix A-2 in supplementary material). This information was compiled for each settlement type. Using a random number generator, two wards per settlement type were selected in the CTs, and three wards per settlement type were selected in the STs, given their larger geographic area. From each selected ward, two streets were randomly chosen. From each chosen street, five HHs were sampled in the young CT (resulting in 60 HHs total), and ten HHs were sampled in each street in the old CT and ST (resulting in 120 and 180 HHs, respectively). An illustration of sampling plan in towns is appended as Appendix A-3 in supplementary material.

The survey began at the first house on the right side of the street, which was willing to participate. From there, it proceeded systematically, selecting every fifth house while alternating between the right and left sides of the street until the required sample size was achieved – 10 HHs per street in old CTs and STs, and 5 HHs per street in young CTs.

The criteria used to categorise settlements were not uniform. Low-income settlements and apartments were identified based on physical housing characteristics and the income levels of residents, both of which had clearly distinguishable features. In contrast, long-term resident settlements lacked such visible identifiers and were defined solely through the information provided by key informants. To ensure that the sample accurately represented the intended population, settlement types were coded for enumerators prior to data collection. Appendix A-4 in supplementary material elaborates the codes used to identify the three types of settlements studied and also defines town types.

2.5 Household survey questionnaire for collecting data

Data were collected using a structured questionnaire (Appendix A-5 in supplementary material). The draft version of the questionnaire was reviewed in consultation with supervisors, key stakeholders, and the research support team from the partner organisations. The researcher conducted several rounds of pretesting with dummy real-life respondents, during which minor linguistic modifications were made to ensure clarity and contextual relevance. The finalised household survey questionnaire was then digitised using Qualtrics software (Qualtrics, Provo, UT).

2.6 Data collection process

Household surveys were carried out by a commercial agency that deployed trained enumerators. The researcher conducted training sessions for the enumerators, explaining the research context, objectives, and the translated version of the survey tool. Data collection was carried out in two phases during the summer of 2024: from 21st to 28th March in Chennai, and from 17th to 22nd April in Mumbai. To ensure data quality, the researcher conducted spot checks in the field and continuously monitored entries using the Qualtrics platform, which enabled real-time tracking. Any discrepancies, such as missing or non-feasible data, were promptly flagged and communicated to the enumerators for immediate corrective action. In addition, daily feedback was exchanged between the enumerators and the researcher, facilitating timely rectifications such as discarding erroneous entries and surveying additional HHs to compensate for data loss.

2.7 Data cleaning and data harmonising

The data collected through the e-survey platform was exported into MS Excel spreadsheets for further processing. It was then examined for inconsistencies, incompleteness, and outliers. If inconsistencies were found in individual variables or if contradictory entries appeared across variables within a household, the data from that household was excluded from the analysis. During sense-checking, some apparent outliers were verified as valid and were therefore retained for analysis.

2.8 Data analysis–statistical tests

Descriptive statistics, including frequencies, measures of central tendency, and dispersion, were used to summarise the data. Hypothesis testing was employed for four key

Table 3 Hypotheses tested

Indicator	Null hypothesis: Across towns	Null hypothesis: Across settlements
Whether the principal water source lies within the household premises	There is no association between the type of town and the availability of water source within the premises in HHs in these towns	There is no association between the type of settlements and the availability of water source within the premises in HHs in these settlements
If sufficient quantity of water is available to HHs to meet their daily needs	There is no association between the town type and the availability of sufficient quantity of water to meet the daily needs in HHs in these towns	There is no association between the settlement type and the availability of sufficient quantity of water to meet the daily needs in HHs in these settlements
If households get the required quantity of water whenever needed	There is no association between the town type and the availability of required quantity of water whenever needed in HHs in these towns	There is no association between the settlement type and the availability of required quantity of water whenever needed in HHs in these settlements
Number of breakdowns in water supply in a month	There is no difference between the statutory town, old census town and young census town with respect to the number of breakdowns in water supply in a month in HHs in these towns	There is no difference between the low-income settlements, apartments and long-term resident settlements with respect to number of breakdowns in water supply in a month in HHs in settlements
Number of days water is available in a week	There is no difference between the statutory town, old census town and young census town with respect to the number of days water is available in a week to HHs in these towns	There is no difference between the low-income settlements, apartments and long-term resident settlements with respect to number of days water is available in a week to HHs in these settlements
Number of hours water is available in a day	There is no difference between the statutory town, old census town and young census town with respect to the number of hours water is available in a day to HHs in these towns	There is no difference between the low-income settlements, apartments and long-term resident settlements with respect to number of hours water is available in a day to HHs in these settlements

dimensions to assess whether town type or settlement type had a significant effect on these dimensions.

The independent Kruskal–Wallis test, the non-parametric equivalent of ANOVA, was used to compare medians[48,49] since the distribution of the quantitative variables across towns did not meet the assumptions of parametric tests. When the test indicated statistically significant differences, a *post hoc* Dun–Bonferroni test[50] was conducted to identify the specific town or settlement types that differed from one another.

For categorical variables such as accessibility and quantity, a chi-square test was employed to examine associations between town types or settlement types, as it evaluates the relationship between two nominal variables.[51]§ The strength of the association was further assessed using Cramér's V value.[51]

The hypotheses tested are summarised in Table 3.

The research used IBM Corp. (2022) IBM SPSS Statistics for Mac (Version 29.0), a quantitative data analysis software. The study was approved by the Research Ethics Board of Cranfield University, *vide* Approval No. CURES/21020/2023. All participants provided informed consent prior to participation.

3. Findings

3.1 Accessibility of water sources

The different water supply systems accessed by HHs in towns within the Chennai and Mumbai regions are summarised in Fig. 3. A public piped water supply with house connections and public standpipes constitute the primary sources across towns and settlements in the Mumbai region. As shown in Fig. 3, the statutory town (ST) in the Mumbai region reported better public water supply coverage compared to the other two towns. In Mumbai and Chennai STs, 89% and 81% of HHs, respectively, relied on a single source, which is piped water supply within premises in Mumbai and borehole with motorised pumps within premises in Chennai. In contrast, this proportion was markedly lower in the old CTs – 59% in Mumbai and 61% in Chennai. In the remaining 41% of HHs in Mumbai's old CT, 14.5% accessed boreholes with motorised pumps within their premises, 9.9% used boreholes with motorised pumps located outside, 13.7% depended on public standpipes, and 2.3% obtained piped water from neighbouring HHs. A comparable pattern was evident in Chennai's old CT, where 39% of HHs depended on six distinct primary sources. Similarly, as illustrated in Fig. 3, young CTs in both regions also displayed considerable diversity, underscoring the diverse water sources in CTs compared to STs.

In contrast to Mumbai, the predominant water source in Chennai was boreholes with motorised pumps, primarily developed through private initiatives. This trend can be attributed to the high groundwater table in the areas studied within the Chennai region, which makes borewell drilling relatively inexpensive. The second most common source in Chennai was piped water supply provided by local governments.

Across settlement types, a key finding in both regions is the greater variety of water sources accessed by HHs in low-income and long-term resident settlements, as opposed to apartments, which are primarily occupied by middle- and high-income HHs (Fig. 4).

§ In situations where the chi-square test assumption was violated due to expected cell counts falling below five, which could compromise the reliability of the results, the likelihood ratio chi-square test, being less sensitive to small, expected counts, was employed instead. The likelihood ratio chi-square test is generally considered more reliable than Pearson's chi-square test when expected frequencies are small, as it relies on maximum likelihood estimation rather than direct frequency counts.[51]

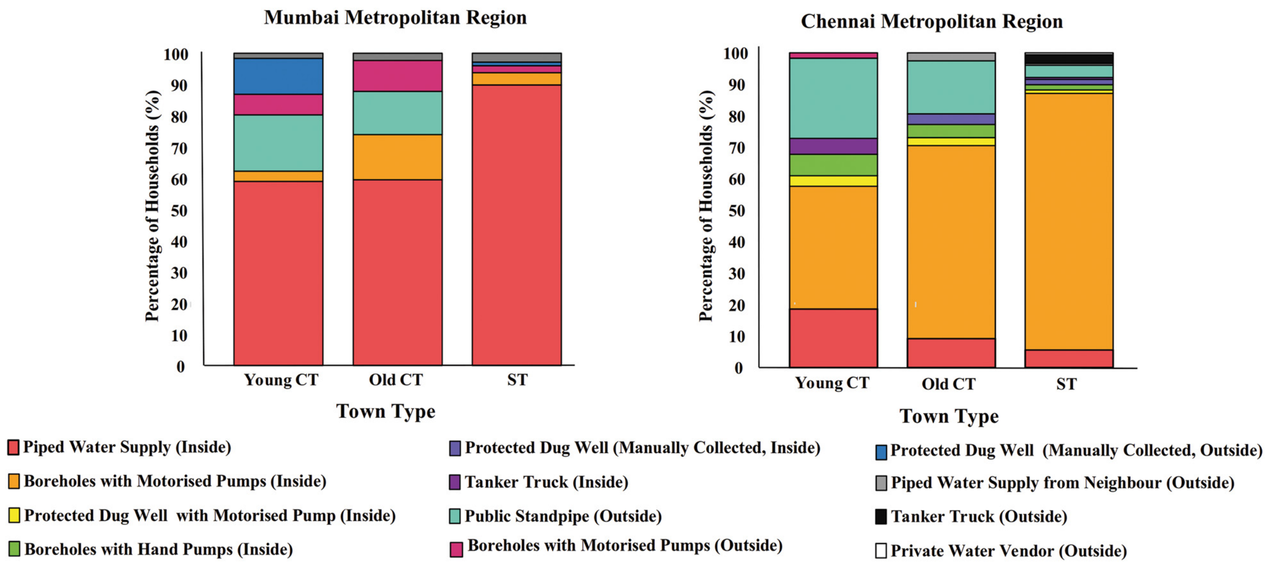

Fig. 3 Diversity of water sources accessed by HHs in Mumbai and Chennai metropolitan regions across towns.

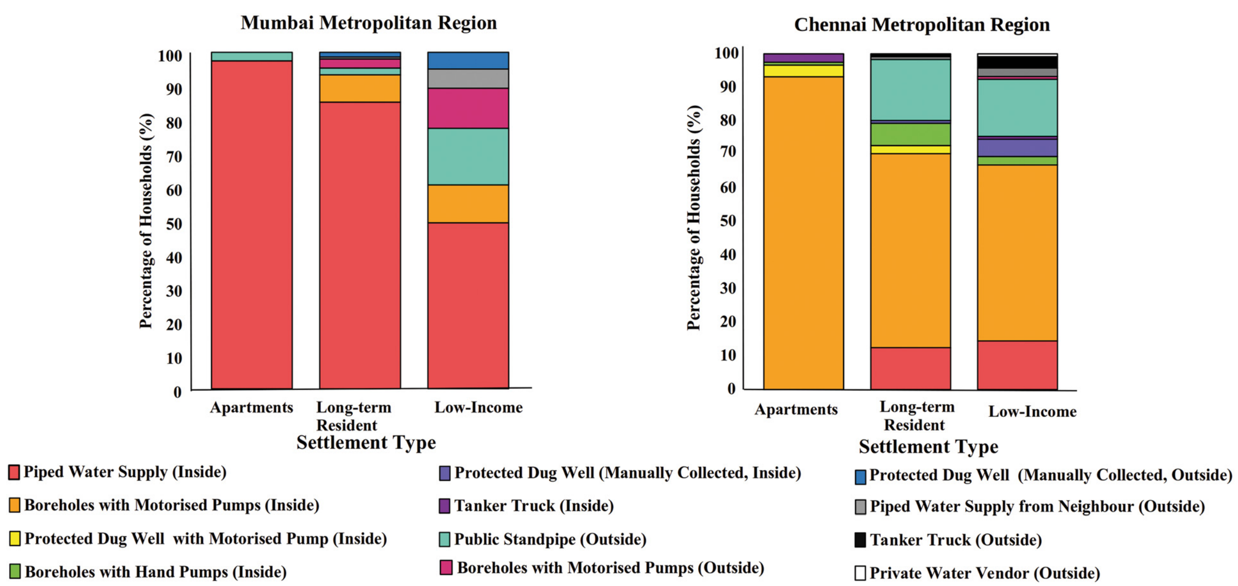

Fig. 4 Diversity of water sources accessed by HHs in Mumbai and Chennai metropolitan regions across settlements.

3.1.1 Effect of town types on accessibility. Fig. 5 highlights variations across town types in both regions. In Mumbai, approximately 62.3% of HHs in the young census town (CT), that is, 38 out of 61 HHs, reported accessing a water source within their premises. This figure increases to 73.8% (96 out of 130 HHs) in the old CT and 93.8% (166 out of 177 HHs) in the ST. Similarly, in Chennai, 72.9% of HHs in the young CT (43 out of 59 HHs) reported sources within the premises, compared to 80.7% (96 out of 119 HHs) in the old CT and 92.7% (165 out of 178 HHs) in the ST. These findings indicate a clear trend: the proportion of HHs accessing water sources within their premises increases as towns progress further along the rural-to-urban transition.

The chi-square test conducted to examine the association between accessibility and town types yielded a p-value of <0.5 in both regions, indicating a statistically significant relationship (Table 4). As a result, the null hypothesis was rejected. Cramér's V values were 0.32 for Mumbai and 0.22 for Chennai, suggesting a weak association. Cross-tabulation tables for all three nominal variables, including observed and expected frequencies (*i.e.*, the number of HHs expected in each category under the assumption of no association), are provided in Appendix A-6 and A-7 in supplementary material. For the dimension of 'accessibility', the analysis shows that in both Mumbai and Chennai, more HHs in CTs than expected accessed sources located outside their premises. In

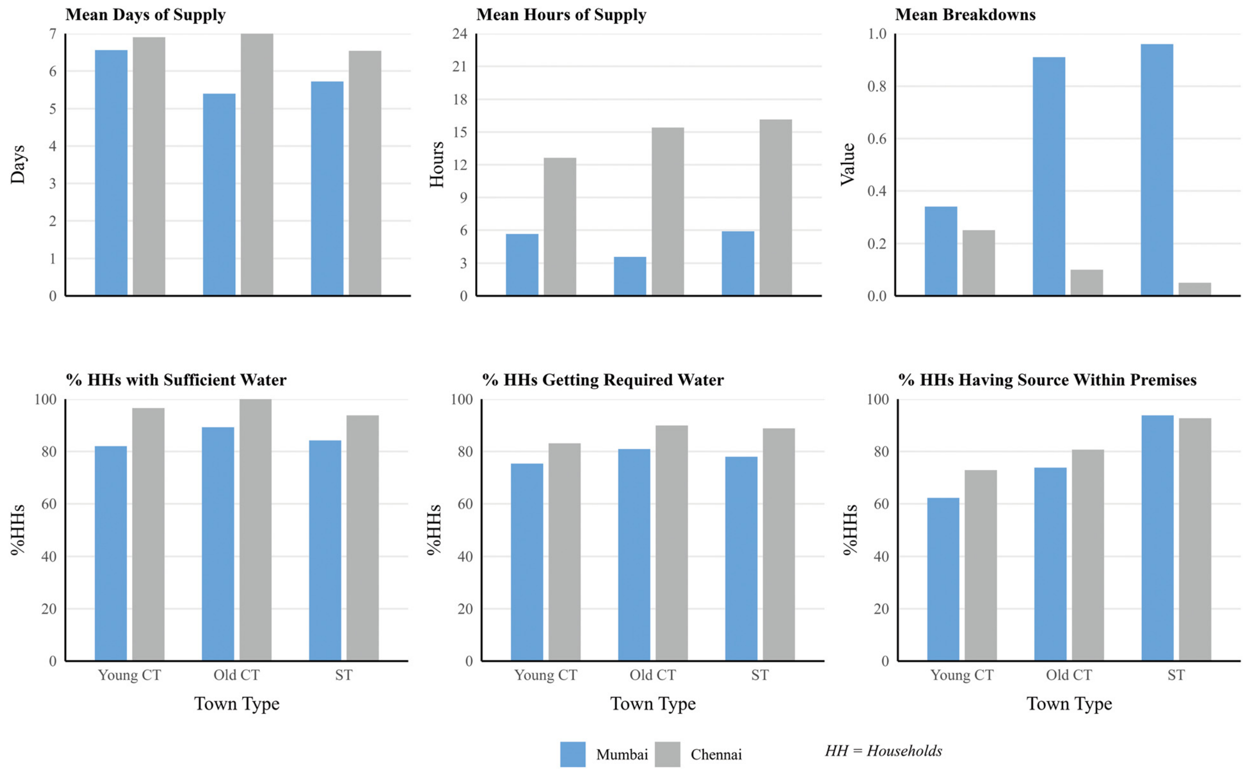

Fig. 5 Water services across towns in Mumbai and Chennai regions.

contrast, in STs, fewer HHs than expected accessed water sources outside the premises, indicating a better scenario in STs (Appendix A-6 and A-7).

3.1.2 Effect of settlement types on accessibility. All 120 apartment HHs in the Chennai region and 97.4% (76 out of 78) of apartment HHs in Mumbai reported having a source within their premises (Fig. 6). However, in low-income settlements, only 76.3% (90 out of 118) of HHs in Chennai and 60.7% (86 out of 142) in Mumbai reported access to a water source within the premises. In the Chennai region, the level of accessibility among HHs in long-term resident settlements, 80.2% accessing a source within premises, was comparable to that in low-income settlements. In contrast, long-term resident HHs in the Mumbai region had better access, similar to that of apartment dwellers.

A chi-square test with a p-value <0.05 confirmed that differences in accessibility across settlement types in both Mumbai and Chennai were statistically significant (Table 5). The Cramér's V value of 0.29 in Chennai indicated a moderately strong association, while a value of 0.43 in Mumbai reflected a stronger association. Low-income settlements reported the poorest accessibility in both regions (Appendix A-8 and A-9 in supplementary material). As seen in the cross-tabulation table (Appendix A-8), in Chennai, more HHs in long-term resident settlements than expected reported accessing sources outside the premises, indicating an undesirable scenario. In contrast, apartments in both regions consistently exhibited better access.

3.2 Quantity of water available to HHs

In this study, quantity was assessed using two complementary indicators: (i) the percentage of HHs reporting that they receive sufficient water to meet their daily needs and (ii) the percentage of HHs stating that they obtain the required quantity of water whenever needed. Together, these indicators capture both the overall adequacy of water availability and HHs' ability to access water at the moment of demand, thereby providing a more comprehensive understanding of quantity-related service performance. In addition to these two measures, HHs' dependence on supplementary water sources, reliance on storage facilities, and the use of booster pumps to extract water from public distribution networks also provide insights into the sufficiency. These three indicators are discussed in detail under section 3.4, which examines the reliability of water services.

3.2.1 Effect of town types on quantity. The bare minimum scenario in terms of quantity available to HHs was assessed by examining whether HHs received a sufficient quantity of water to meet their daily needs. In the Mumbai region, the proportion of HHs that responded 'yes' was 82.0% in the young CT (50 out of 61 HHs), 89.3% in the old CT (117 out of 131 HHs), and 84.2% in the ST (149 out of 177 HHs). In Chennai, all HHs in the old CT reported that they received sufficient water, while the corresponding figures for the ST and young CT were 93.8% and 96.6%, respectively (Table 4). The association between town type and availability of sufficient water was found to be statistically significant only in Chennai, with a p-value <0.05 (Table 4), leading to the

Table 4 Effect of town types on dimensions of water services across Mumbai and Chennai regions

Dimension	Mumbai region			Chennai region		
	Young CT ($n = 62$)	Old CT ($n = 36$)	ST ($n = 188$)	Young CT ($n = 60$)	Old CT ($n = 20$)	ST ($n = 183$)
Mean days of supply in a week	6.6	5.4	5.7	6.9	7	6.5
Mean hours of supply in a day	5.7	3.6	5.9	12.6	15.4	16.2
Mean breakdowns in a month	0.34	0.91	0.96	0.25	0.10	0.05
% of HHs with sufficient water for meeting HH needs	82.0	89.3	84.2	96.6	100	**93.8**
% of HHs getting required quantity of water whenever needed	75.4	80.9	78	83.1	89.9	88.8
% of HHs accessing source within HH premises	**62.3**	**73.8**	93.8	**72.9**	**80.7**	92.7

Significant difference across towns on hypothesis testing (p-value <0.05)

No Significant difference across towns on hypothesis testing (p-value >0.05)

Indicates pair of town types which differ significantly for a dimension, identified by conducting a *post hoc* test

Bold font indicates that in the chi-square test, less than expected percentage of HHs in that town type reported that they were getting sufficient water/required water whenever needed/had sources outside the premises, which reflects an undesirable scenario

While testing the association between town type and the proportion of households reporting sufficient water to meet their daily needs, two cells had expected frequencies below the minimum threshold of 5 in Chennai region. Therefore, the likelihood ratio chi-square test was employed in place of the Pearson chi-square test, as it provides a more reliable estimate under such conditions

rejection of the null hypothesis. Here, two cells had an expected count of less than 5, so the maximum likelihood ratio chi-square test was employed. The strength of this association, as indicated by a Cramér's V value of 0.15, was weak.

Notably, more HHs than expected in the ST reported insufficient water, reflecting an undesirable scenario. In the young CT, the number of HHs reporting insufficient water was approximately equal to the expected count (Appendix A-6).

The best-case scenario was assessed by examining whether HHs received the required quantity of water whenever needed. In the Mumbai region, 80.9% of HHs in the old CT (106 out of 131) responded 'yes,' compared to 78.0% in the ST (138 out of 177) and 75.4% in the young CT (46 out of 61). In Chennai, 83.1%, 89.9%, and 88.8% of HHs in the young CT, old CT, and ST, respectively, reported receiving the required water whenever needed. However, chi-square test yielded a p-value >0.05 for Chennai and Mumbai, indicating no statistically significant association between town type and this variable in either region. Accordingly, the null hypothesis of no association was retained.

3.2.2 Effect of settlement types on quantity. In Chennai, 99% of HHs in both apartments and long-term resident settlements reported receiving sufficient water to meet their household needs. In comparison, 90% of HHs in low-income settlements reported the same (Table 5). In Mumbai, long-term resident settlements performed best, with 91.3% of HHs receiving sufficient water, followed by apartments at 89.7% and low-income settlements at 77.5% (Table 5).

In Chennai's apartments, there was little difference between the best-case and bare minimum scenarios, with 98.2% of HHs reporting that they received the required quantity of water whenever needed. However, among long-term resident and low-income settlements, the figures were 86.8% and 79.7%, respectively, indicating a notable gap between the two scenarios. In Mumbai as well, all apartment HHs who reported receiving sufficient water also stated that they received water whenever required. In contrast, only 83.2% of HHs in long-term resident settlements and 67.6% in low-income settlements in Mumbai affirmed receiving the required quantity of water whenever needed, again highlighting a significant gap between the bare minimum and best-case scenarios.

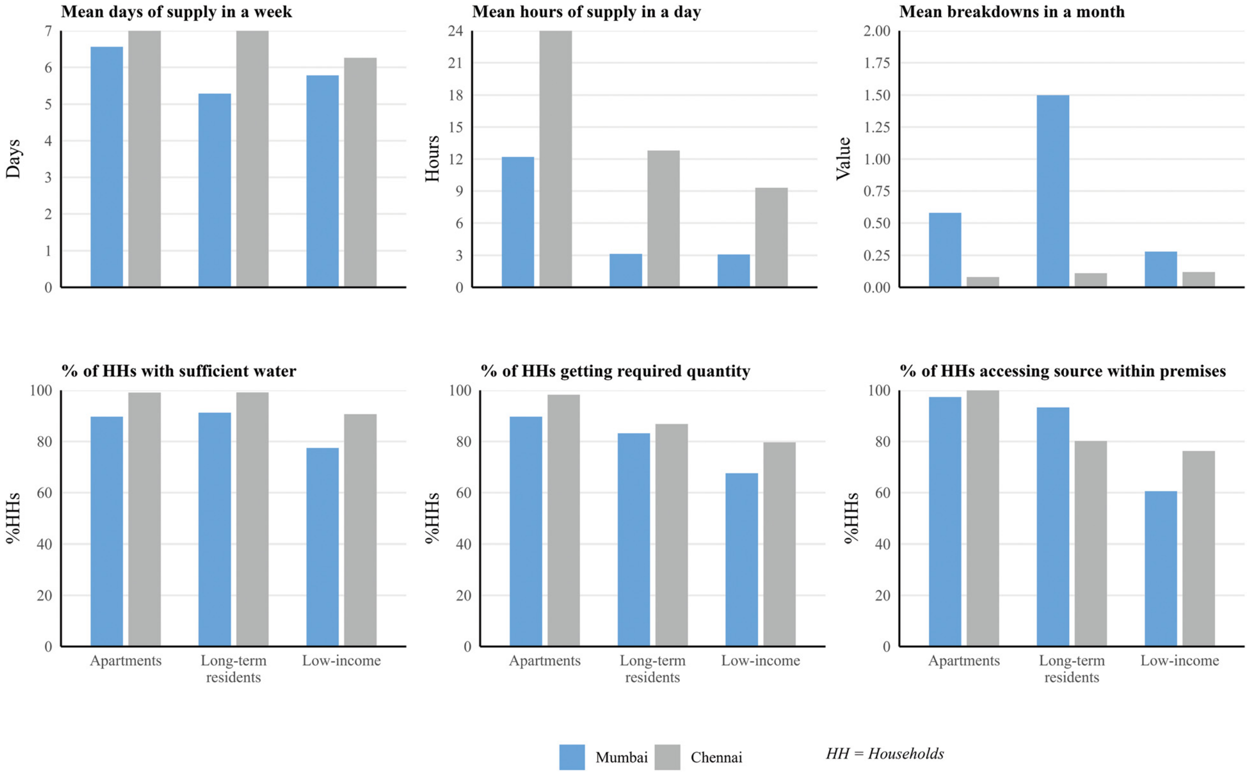

Fig. 6 Water services across settlements in Mumbai and Chennai regions.

Chi-square tests yielded a p-value <0.05 which confirmed a statistically significant association between settlement type and both variables: availability of sufficient quantity of water and availability of required quantity of water whenever needed (Table 5). In Chennai, the analysis of the variable, availability of sufficient quantity of water, resulted in three expected cell counts below 5, violating the assumptions of the Pearson chi-square test. Consequently, the maximum likelihood ratio chi-square test was used. In Chennai, the Cramér's V values for these two variables were 0.21 and 0.24, respectively, indicating moderately strong associations. In Mumbai, the association between settlement type and availability of sufficient water was weak (Cramér's $V = 0.19$), while the association with the variable 'availability of required quantity whenever needed' was moderately strong (Cramér's $V = 0.22$).

3.3 Regularity of supply

Regularity of supply was assessed using two indicators: the number of days in a week that water is available and the number of hours of supply per day. HHs frequently rely on storage facilities to manage intermittent or unpredictable supply, and the prevalence of such facilities provides an additional, indirect indication of service regularity and reliability. The role of storage, along with other reliability-related indicators, is examined in detail in section 3.4. The present section focuses specifically on the two regularity indicators – number of supply days per week and number of supply hours per day.

3.3.1 Effect of town types on regularity. In Mumbai, the average number of days that water is available per week was highest in the young CT compared to the old CT and ST. In contrast, in Chennai, the old CT reported water availability on all seven days of the week (Fig. 5). In both regions, STs reported the highest number of supply hours per day, followed by old CTs.

A Kruskal–Wallis test conducted at a 5% significance level revealed a statistically significant difference between town types with respect to the number of days water was available per week, with a p-value <0.05 in both regions (Table 4). Consequently, the null hypothesis was rejected. *Post hoc* analysis using the Dunn–Bonferroni test indicated statistically significant differences between the old CT and the young CT as well as between the ST and the young CT, in Mumbai, where the young CT had the highest number of supply days per week (Table 4). In Chennai, the difference between the ST and the old CT was found to be statistically significant, with the old CT reporting daily water availability.

With regard to the number of hours water was available per day, statistically significant differences across town types were observed only in the Mumbai region (p-value <0.05). Pairwise comparisons using the Dunn–Bonferroni *post hoc* test revealed a significant difference between the ST and young CT, with HHs in the ST receiving more hours of water supply per day than those in the young CT (Fig. 5).

3.3.2 Effect of settlement types on regularity. Apartments in both regions reported the highest number of water supply hours per day as well as the highest number of supply days per

Table 5 Effect of settlement types on dimensions of water services across Mumbai and Chennai regions

Dimension	**Mumbai region**			**Chennai region**		
	Apartments ($n = 79$)	Long-term residents ($n = 155$)	Low-income ($n = 152$)	Apartments ($n = 120$)	Long-term residents ($n = (120)$)	Low-income ($n = 123$)
Mean days of supply in a week	6.7	5.3	5.8	7	7	6.3
Mean hours of supply in a day	12.2	3.14	3.08	24	12.8	9.3
Mean breakdowns in a month	0.58	1.50	0.28	0.08	0.11	0.12
% of HHs with sufficient water for meeting HH needs	89.7	91.3	**77.5**	99.1	99.2	**90.7**
% of HHs getting required quantity of water whenever needed	89.7	83.2	**67.6**	98.3	**86.8**	**79.7**
% of HHs accessing source within HH premises	97.4	93.3	**60.6**	100	**80.2**	**76.3**

Significant difference across settlements on hypothesis testing (p-value <0.05)

No significant difference across settlements on hypothesis testing (p-value <0.05)

Indicates pair of settlement types which differ significantly for a dimension, identified by conducting a *post hoc* test

Bold font indicates that in the chi-square test, less than expected percentage of HHs in that settlement type reported that they were getting sufficient water/required water whenever needed/had sources outside the premises, which reflects an undesirable scenario

While testing the association between settlement type and the proportion of households reporting sufficient water to meet their daily needs, three cells had expected frequencies below the minimum threshold of 5 in Chennai region. Therefore, the likelihood ratio chi-square test was employed in place of the Pearson chi-square test, as it provides a more reliable estimate under such conditions

week. In Mumbai, long-term resident HHs had the lowest average number of supply days per week, whereas in Chennai, HHs in low-income settlements reported the fewest supply days (Fig. 6). Across both regions, low-income HHs consistently recorded the lowest number of daily supply hours.

The results of the Kruskal–Wallis test, conducted at a 5% significance level, revealed statistically significant differences across settlement types with respect to the number of days water was available per week, with a p-value <0.05 (Table 5) in both the regions. Accordingly, the null hypothesis was rejected. *Post hoc* analysis using the Dunn test with Bonferroni correction indicated statistically significant differences in mean supply hours across all three settlement types.

With regard to the number of supply days per week, significant differences were found between low-income and long-term resident settlements in both regions. However, differences between apartments and low-income settlements were statistically significant only in Chennai, while differences between apartments and long-term resident settlements were significant only in Mumbai (Table 5).

3.4 Reliability of supply

Reliability of water services, defined as the proportion of time during which the system functions at its intended level of performance, can be assessed using several indicators. These include the frequency of supply breakdowns; the extent to which HHs depend on storage facilities or supplementary water sources; and the proportion of HHs purchasing bottled water or adopting in-house treatment measures. In addition, although applicable only to HHs relying on the public water supply, the extent to which HHs use boosting pumps to extract water from the distribution network also provides an indication of whether the system is delivering water at the

Table 6 Percentage of HHs accessing a supplementary source across towns and settlements in Chennai and Mumbai region

Region	Settlement type	Young CT	Old CT	ST
Chennai	Apartments	47.4	28.2	35.6
	Long-term resident	55	25	44.3
	Low-income	0	15	82.8
Mumbai	Apartments	47.4	—	64.4
	Long-term resident	14.3	29.2	22.2
	Low-income	14.3	45.5	25.5

expected pressure. However, for the purpose of analysing whether significant differences exist between town types and settlement types, the indicator 'number of supply breakdowns' was selected, as it is the only reliability measure that is consistently observed across all contexts and thus enables methodologically robust comparison.

3.4.1 Dependence of supplementary sources. Reliance on a supplementary water source, in addition to the primary supply, serves as an indicator of issues related to supply reliability, water sufficiency, and perceived water quality. HHs reported turning to supplementary sources due to inadequate quantity, irregular supply, concerns over quality, and the unaffordability of the primary source. As shown in Table 6, an increasing dependence on supplementary sources was observed across settlements in STs in both regions. This ranged from 22% of long-term resident settlements HHs in Mumbai to as high as 82% of low-income HHs in Chennai. Nearly half the HHs in apartments in young CTs across both regions also accessed a supplementary source. In Mumbai, when all such HHs in young CT cited inadequate quantity as the primary reason, in Chennai, the use of additional sources was driven by poor quality, insufficient quantity, and affordability concerns. A substantial proportion of HHs in low-income settlements in Chennai STs and in Mumbai's old CTs also reported reliance on supplementary sources. Notably, while only 22% of HHs in long-term resident settlements in Mumbai used supplementary sources, nearly double that proportion did so in the corresponding settlement in Chennai.

3.4.2 Storage facilities in HHs. The prevalence of household-level water storage facilities offers insights into the regularity and reliability of water supply in a given area. In the study locations, such facilities ranged from small plastic drums with a capacity of 100–500 litres to reinforced cement concrete rooftop tanks (Fig. 7). In the case of multi-storeyed apartment complexes, it was common to find large, shared underground and rooftop storage tanks with capacities reaching several hundred thousand litres. As shown in Table 7, across towns and settlements in the Mumbai region, nearly all HHs reported the presence of storage facilities, with the exception of a few HHs in long-term resident settlements in the old CT and low-income settlements in the young CT. A similar pattern was observed in Chennai, where at least three-quarters of the surveyed HHs reported having water storage facilities.

3.4.3 Quality of water perceived by HHs. The data indicate that HHs employed a variety of water treatment methods for cooking and drinking purposes, including filtering, settling, boiling, and using household water purification units. In addition, some HHs opted to purchase bottled water as an alternative.

As illustrated in Fig. 8, HHs in CTs in Chennai reported higher rates of bottled water consumption, with long-term residents relying more heavily on bottled water than residents of other settlement types. In contrast, the proportion of HHs purchasing bottled water in the Mumbai region was generally lower than in Chennai, except in apartments located within the young CT (Fig. 8). In Mumbai, HHs in STs and apartments showed a greater preference for in-home water treatment over bottled water. In Mumbai, the purchase of bottled water was predominantly seasonal, occurring mostly during the monsoon period. In contrast, Chennai HHs reported purchasing bottled water throughout

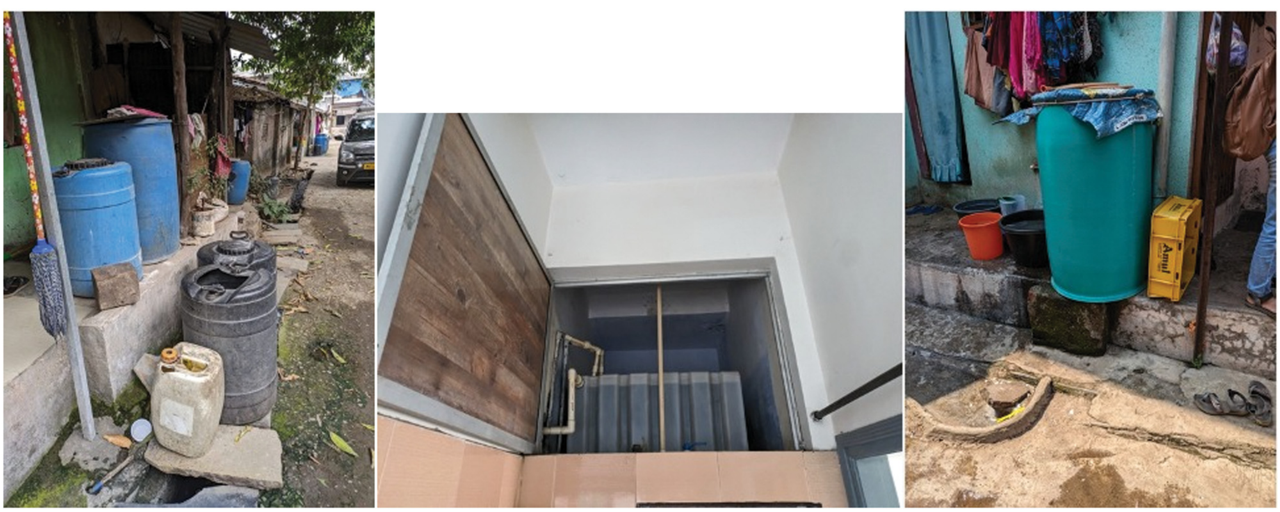

Fig. 7 Household storage structures in Mumbai.

Table 7 Percentage of HHs with storage facility across towns and settlements in Chennai and Mumbai regions

Region	Settlement type	Young CT	Old CT	ST
Chennai	Apartments	100[a]	100[a]	100[a]
	Long-term resident	90	90	85.3
	Low-income	95	77.5	89.7
Mumbai	Apartments	100[a]	—	100[a]
	Long-term resident	100	92.3	100
	Low-income	95.2	100	100

[a] Common storage facilities. — No apartments in old CT.

the year. Commonly adopted treatment practices included boiling, filtering (using cloth or filtration devices), and chlorination.

3.4.4 Use of booster pumps. Qualitative studies conducted in the Mumbai region (Haridasan *et al.*, in preparation) revealed that in many areas within towns, elevated storage reservoirs, intended to maintain pressure in the distribution system, were either defunct and bypassed or entirely absent. The resulting drop in pressure deprived HHs located near the end of the distribution network of adequate water supply. In all towns, the public water supply system operated on a rotational basis, limiting supply to a few hours per day or to specific days of the week using valve-based regulation. To address the drop in pressure, HHs dependent on the public water supply often used motorised pumps to extract the maximum amount of water within the limited supply period. Data on motorised pump usage indicate that all 220 HHs in the ST, 67 out of 78 HHs in the old CT, and 34 out of 36 HHs in the young CT, dependent on public water supply, reported using motorised pumps in the Mumbai region. In contrast, this practice was not prevalent in Chennai towns, likely due to the presence of several decentralised supply systems distributed across the settlements. The dispersed infrastructure setup helped to eliminate the household-level pressure-boosting mechanisms in the Chennai region.

3.4.5 Effect of town types on breakdowns in a month. In Mumbai, the old CT and ST reported nearly one breakdown per month, while the fewest breakdowns were observed in the young CT. In contrast, the pattern was reversed in Chennai, where the young CT experienced the highest number of breakdowns, and the ST reported the least. Results from the Kruskal–Wallis test indicated that the differences in water supply breakdowns across town types were statistically significant only in Chennai (p-value <0.05). Subsequent pairwise comparisons revealed a statistically significant difference between the ST and young CT in terms of the frequency of breakdowns. As shown in Fig. 6, HHs in the ST reported the fewest breakdowns among the three town types.

3.4.6 Effect of settlement types on breakdowns in a month. As illustrated in Fig. 6, long-term resident settlements, followed by apartments, reported the highest number of breakdowns in Mumbai. In contrast, in Chennai, low-income settlements experienced the most breakdowns, followed by long-term resident settlements. However, the Kruskal–Wallis test yielded p-values >0.05, indicating that the observed differences were not statistically significant. Thus, no meaningful variation in the frequency of breakdowns across settlement types was found in either region.

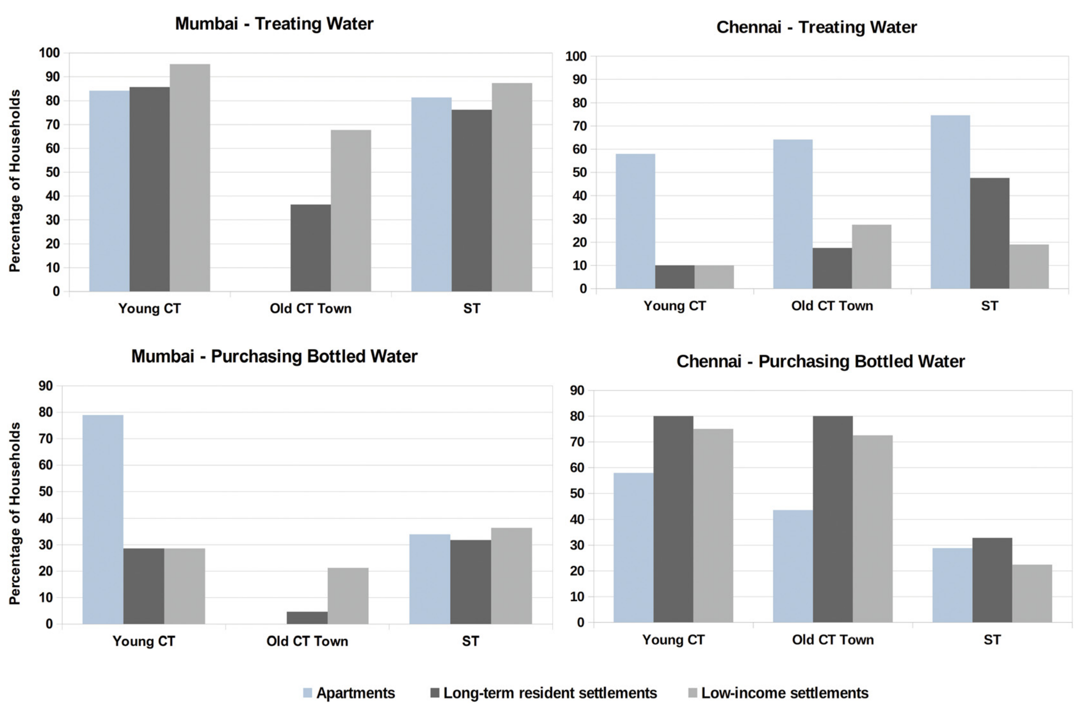

Fig. 8 Trends in treatment of water and purchase of bottled water across settlements in various town types in Mumbai and Chennai.

Table 8 Indicators of reliability of water services across towns and settlements in Mumbai and Chennai region

Region	Settlement type	% of HHs relying on supplementary sources			% of HHs with storage facility			% of HHs purchasing bottled water			% of HHs treating water		
		Y CT	O CT	ST	Y CT	O CT	ST	Y CT	O CT	ST	Y CT	O CT	ST
Chennai	A	47.4	28.2	35.6	100*	100*	100*	**57.9**	43.6	28.8	57.9	64.1	74.6
	L-T	55	25	44.3	90	90	85.3	**80**	80	32.8	10	17.5	47.6
	L-I	**0**	**15**	**82.8**	**95**	**77.5**	**89.7**	**75**	**72.5**	**22.4**	**10**	**27.5**	**18.9**
Mumbai	A	47.4	—	64.4	100*	—	100*	78.9	—	33.9	**84.2**	—	**81.4**
	L-T	14.3	29.2	22.2	100	92.3	100	28.6	4.6	31.8	**85.7**	36.4	**76.2**
	L-I	**14.3**	**45.5**	**25.5**	**95.2**	**100**	**100**	**28.6**	**21.2**	**36.4**	**95.2**	**67.7**	**87.3**

Y CT – young CT, O CT – old CT, A – apartments, L-T – long term resident settlements, L-I – low-income settlements.

3.4.7 Summary of reliability indicators. Table 8 summarises the indicators of reliability dimension. Young CTs in both regions report high dependence on coping mechanisms – if Chennai households purchase bottled water, households in Mumbai treat water. STs in Chennai show the most severe stress, with low-income areas showing exceptionally high use of supplementary sources. As explained in section 3.4.4, Mumbai towns rely heavily on booster pumps, indicating persistent low-pressure issues even in formal urban systems in STs. Water treatment measures were more prominent in Mumbai, raising water quality concerns.

Low-income settlements demonstrate the most variability, reflecting vulnerabilities and uneven service access during rapid urbanisation. In contrast, apartment settlements with predominantly middle- and high-income residents tend to demonstrate stronger coping capacity through better access to alternative sources, more reliable storage facilities, and more systematic treatment strategies.

4. Discussion

A comparison of water services available to HHs in towns under rural administration, those that have only recently begun urbanising (young CTs) and those that have been urbanising over a longer period (old CTs) with towns that have transitioned to urban governance (STs) revealed no consistent pattern in service outcomes. Statistically significant differences across town types were observed in only two variables in both regions: the number of days of water supply per week and the availability of a source within household premises. Differences in mean breakdowns and the availability of sufficient water were statistically significant only in the Chennai region, while mean daily supply hours were significantly different only in the Mumbai region. In cases where the differences were statistically significant, STs performed better with respect to accessibility, average supply hours per day, and frequency of breakdowns. In the Mumbai region, young CTs reported more days of water supply per week than other town types. In Chennai, old CTs, where HHs reported daily water supply, outperformed both young CTs and STs. Regarding the availability of sufficient water, old CT again performed better than both ST and young CT. Of the six service variables analysed, three showed better outcomes in towns under urban governance, while the remaining three performed better in rurally administered towns. These findings suggest the absence of a uniform pattern across town types or regions and that a shift to urban governance alone does not guarantee better water services in fast-urbanising villages.

These findings diverge from existing literature on rapidly transitioning peri-urban areas which reports better services in urban areas.[13–15,20,23,32,52] Among the two indicators of quantity, the differences across towns in the measure 'whether HHs receive the required quantity of water whenever needed' were not statistically significant in either region. Table 4 shows that, across all towns, including those under urban governance, the number of HHs reporting that they receive adequate water when needed was lower than those reporting that they receive sufficient overall quantity. Previous studies demonstrate that continuous water availability throughout the day and on all days leads to higher water use and associated health gains.[38] These results indicate that water programmes and policies must move beyond ensuring sufficiency and instead prioritise achieving continuous supply in both rapidly urbanising villages and urban-governed areas.

In contrast, significant differences were observed across towns in the second quantity indicator, availability of sufficient water in the Chennai region. A higher-than-expected proportion of HHs in the ST reported 'No'. It is notable that the ST in Chennai was constituted only in November 2021 through the merger of several small, contiguous STs acknowledging their rapid urbanisation and the need for infrastructure upgrades, including drinking water services. The creation of a larger municipal corporation was intended to support improved administration, resource mobilisation, and integrated planning.[53] Qualitative work undertaken by the researcher, including interviews and focus group discussions with officials and elected representatives, also highlighted that major drinking water projects are currently under preparation.

Many studies that report superior water service delivery in STs typically attribute these outcomes to more advanced infrastructure networks, which are generally absent in CTs or rurally administered areas.[15,22,28,54] However, in the present study, all towns examined, regardless of their administrative classification, possessed extensive piped water supply networks. Moreover, notable similarities were observed in the design, age, and condition of water supply infrastructure across the three types of towns within a metropolitan region. For instance, in the Mumbai region, in all three towns studied, public piped water supply was the major source and stakeholders interviewed by the researcher raised the problems associated with the aged infrastructure. In the Chennai region, the public water supply infrastructure in all three towns comprised several small-scale systems dispersed throughout the town. Further, in all three towns in Chennai, private boreholes with motorised pumps or hand pumps within premises were the predominant water sources (Fig. 3). These observed infrastructural similarities across town types within each metropolitan region also explain the absence of significant variation in service levels, despite having different governance arrangements.

Additionally, most studies that find poorer services in peri-urban areas attribute these shortcomings to the limited capacity of the local village governments.[17–19,26,28,32,55,56] It is important to recognise that in a hierarchical administrative system, while the mandate to provide basic services to local governments is granted centrally, the actual devolution of powers and allocation of resources lies with the regional governments.[16,57] A World Bank study in India comparing basic services between towns under rural and urban governance while concluding that there is no clear evidence of superior services in STs, assign the poor service delivery therein to the understaffing in municipal bodies.[29] A similar study examining the criteria for officially classifying a settlement as urban in India also highlights the ambiguity regarding the effectiveness of urban governance in terms of service delivery.[58] It argues that service efficiency often depends on the level of support available to municipal towns. For instance, in a research study focusing on the patterns in the emergence of CTs, services in CTs were found to be comparable to or slightly better than those in small towns under municipal administration,[59] and the study attributes this to the better federal funding mechanisms available to rural governments. As discussed earlier, evidence exists on the resistance from citizens in rurally administered areas against shifting to urban governance owing to increased central funding in rural areas in comparison to municipal areas.[12,33] Moreover, research highlights significant funding shortfalls in municipal bodies, stemming from inadequate financial transfers by state governments, limited tax revenue generation capacity, and challenges in securing investment.[60] These constraints adversely impact the quality of service delivery across income groups. A recent study in Belu Regency, an urban area in Indonesia, underscores that constraints in financial, human, social, and cultural resources significantly hinder effective drinking water management.[61] Similarly, a comparative analysis of meso-institutions involved in urban water provision across seven Asian cities found that these entities often face resource shortages, particularly a lack of skilled personnel, which impairs their capacity to fulfil their mandates.[62] Thus, it is evident that lack of capacity and resource scarcity are not endemic to rurally administered towns.

A census data-based inquiry in India on the administrative status and access to basic services, including water and sanitation, also found that STs do not necessarily fare better than CTs[63] and argued that service outcomes are shaped by the extent of decentralisation and the degree to which powers are devolved to urban local bodies (ULBs) by the states. It further says that the institutional arrangements adopted by state governments significantly influence the ability of municipal governments to participate in decision-making processes at the state level. Urban development in India remains a highly centralised process, predominantly controlled by state governments, with ULBs, except the ones in metropolitan cities, having limited or no role.[60,63,64] As Bhagat says, "state governments continue to take decisions on such matters as rates of user charges, property tax, octroi,¶ role of parastatals in water supply and sanitation services, *etc.*, with little reference to ULBs that are affected by these decisions".[30] A study on decentralized governance and water service delivery in Adama City, Ethiopia, reveals a mismatch in authority: while urban local governments are responsible for delivering water services, the regional state governments retain control over structural design, funding, and staffing.[57] This centralisation also affects how ULBs engage with state-level decision-making institutions, leaving them with little agency to improve service delivery.[63] As Ghosh and Das[65] caution in their conclusion on whether the statutory status makes a difference in CTs, governance transitions must be context-sensitive, taking into account not only governance structures but also other broader determinants, including the perspectives of residents.

As the Global South continues to urbanise at an unprecedented rate, rural–urban transition zones will increasingly emerge, necessitating a long-term institutional response beyond the shift in governance. Allen acknowledges the inadequacy of the 'centrifugal view' inherent in urban planning to solve the problems of peri-urban areas and argues that for addressing both the immediate needs and long-term sustainability challenges in transition zones there is a need to establish dedicated fora tailored to these regions,[66] a recommendation echoed by an IRC thematic paper on small-town water services.[67] This paper highlights the demographic, geographic, governance, and economic complexities of small towns, emphasising the need for diverse service delivery models in such zones. It also advocates for the creation of a specialised unit within the national government to focus on peri-urban water issues. Similarly, a study on institutional realignment for water service provision in small towns in Africa also proposes two such institutional options: establishing a dedicated department within the national WASH agency or creating a peri-urban unit within the urban utility to manage these transitioning small towns.[68] A viable solution lies in establishing dedicated units within state-level water

¶ Octroi is a tax to be paid to the local bodies when goods enter the area under jurisdiction of local bodies.

departments, equipped with adequate technical expertise and contextual understanding, to support local governments in planning, implementing, maintaining, and monitoring water projects in rapidly urbanising small towns.

The settlement type was found to have an effect on all dimensions studied except the reliability of water supply in both regions. Further, consistent with existing literature, services were found to be poor in low-income settlements.[12,69] The long-term resident settlements were only marginally better than low-income settlements. These long-term resident settlements, mostly occupying the central core of cities and towns, are plagued by aged infrastructure and space constraints, offering little room for additional infrastructure. The new water projects, which are generally located in city peripheries, tend to benefit peripheral areas more than the core. Apartments occupied by middle- and high-income residents had better coping mechanisms, and these settlements unsurprisingly reported better services, resonating what Allen points out on the high-income-driven coping mechanisms differentiating water-poor low-income and water-poor high-income HHs in peri-urban localities.[69]

4.1 Positionality

The lead researcher previously worked in the national government's Department of Drinking Water in India, responsible for rural water supply, prior to undertaking this research. As the current study is based on quantitative data analysis, this prior professional background has limited potential to influence the empirical results. Nonetheless, it is acknowledged that the researcher's professional experience and prior knowledge may have shaped the interpretation of findings.

5. Limitations of the study

A key limitation affecting external validity is that household surveys in both regions were conducted during the summer season. Water service dimensions such as regularity, quantity, and reliability are strongly influenced by seasonal variations, particularly in a monsoon-dependent country like India. As a result, generalisations to other seasons or to peri-urban contexts with different climatic patterns should be made with caution.

6. Conclusion

The comparative analysis of water services across different types of towns under rural administration, namely, newly urbanising areas (young CTs) and those with a longer history of urbanisation (old CTs), and towns that have transitioned to statutory urban governance (STs), revealed no consistent pattern. Among the six water service parameters studied, only two showed statistically significant differences between town types in both the Mumbai and the Chennai metropolitan regions. STs outperformed CTs only in terms of accessibility, average hours of water supply per day, and frequency of service breakdowns. These findings question the widely held assumption that transitioning to urban governance inherently leads to improved water services in rapidly urbanising villages. Instead, they echo insights from previous research, which attributes continued service deficiencies in areas under urban governance due to partial decentralisation and the incomplete devolution of financial and administrative powers by state governments, factors that constrain local governance capacity. Evidently, a mere administrative shift to urban status does not ensure water service improvements.

Regarding the influence of settlement types on water service outcomes, the results align with existing literature: low-income settlements consistently reported poorer service levels. Long-term resident settlements fared only marginally better than low-income settlements. In contrast, apartments, typically inhabited by middle- and high-income HHs, exhibited stronger coping mechanisms and consequently reported better service conditions.

In light of these findings, it is imperative that policy responses to water-related challenges in fast-urbanising villages should go beyond simply bringing such areas under urban governance. Alongside infrastructure upgradation, programme implementers must prioritise capacity-building efforts for both rural and urban local bodies within large metropolitan regions and ensure timely and adequate transfer of financial and human resources. Moreover, inclusive institutional mechanisms must be established to meaningfully engage both STs and CTs in participatory urban development planning concerning their area. Further, governments must also plan for setting up specialised peri-urban units within the national and state water departments, which can serve as agencies responsible for supporting the planning and implementation of water projects in peri-urban areas. The unique constraints faced by long-term resident settlements necessitate innovative engineering and technical interventions tailored to their specific conditions. Meanwhile, in low-income settlements, where service delivery remains particularly poor, equity-focused drinking water programmes are to be designed. Civil society organisations have a critical role to play in informal low-income contexts, especially given the reluctance of public agencies to intervene until such areas are officially 'formalised'.

Ultimately, these findings challenge the dominant narrative in peri-urban research that equates the transition from rural to urban governance with improved service delivery. Rather than treating urban governance as a universal solution, policymakers and practitioners must prioritise the institutional strengthening of local governments, ensure their active participation in urban development planning, and adopt inclusive, stakeholder-driven approaches when considering shifts in governance.

Author contributions

RMH: conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualisation, writing – original draft. AP: conceptualization (supporting), formal analysis (supporting), funding acquisition, methodology (supporting), project administration (supporting), resources, supervision, validation (supporting), visualisation (support), writing review and editing. MS: conceptualization (supporting), formal analysis (supporting), funding acquisition, methodology (supporting), project administration (supporting), resources, supervision, validation (supporting), visualisation (supporting), writing review and editing.

Conflicts of interest

There are no conflicts to declare.

Data availability

The data used in this study are available in the Cranfield University repository and the sharing of the same will be guided by CC-BY, Creative Commons license https://doi.org/10.57996/cran.ceres-2783.

Supplementary information (SI): all annexures. See DOI: https://doi.org/10.1039/d5ew00935a.

Acknowledgements

This work was supported by the Engineering and Physical Sciences Research Council, UKRI [grant number EP/S022066/1]. We are grateful to Sanitation First India and the Citizen Association for Child Rights (CACR) for helping us conduct the fieldwork in the Chennai and Mumbai regions, respectively. Special thanks are extended to Ms. Farida Sayyed Nabi (CACR, Mumbai) and Ms. Vanitha Deivamani (Sanitation First India, Chennai) for their invaluable support in data collection. We would like to particularly thank Dr. Sophia J. D., Sanitation First India, for providing valuable inputs on designing the survey methodology and for reviewing the survey schedule. The authors wish to thank Dr. Ana Casas Garcia for reviewing the sampling plan and statistical methods. Thanks are due to Dr. James Bartram, Jamie Myers, Virginia Roaf, Megan Mcconochie, Claire Grisaffi, Elizabeth Cullen, V. R. Raman, and Spurthi Kolipaka for their helpful comments on the manuscript during its development. We are grateful to Arya Devi for her assistance with GIS in creating the maps. The authors also acknowledge the contribution of DevInsights Pvt Ltd, the agency that conducted the household surveys for data collection. Lastly, we also acknowledge the use of Generative AI Chat GPT4o (OpenAI. (2025). ChatGPT (June 11 version) [Large language model]. https://chat.openai.com) for proofreading this document.

Notes and references

1 United Nations Human Settlements Programme (UN-Habitat), *World Cities Report 2020: The Value of Sustainable Urbanization [Internet]*, Nairobi, Kenya, 2020, Available from: https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization.
2 United Nations, *World Urbanization Prospects 2018 Highlights [Internet]*, [cited 2023 May 15], Available from: https://population.un.org/wup/publications/Files/WUP2018-Highlights.pdf.
3 Census of India, *Rural-Urban Classification for Census 2021*, Circular No-02 - Ref. No. 9/26/2018-CD, Office of Registrar General of India, New Delhi, India, Government of India, 2018.
4 A. Mitra and R. Kumar, New Patterns in Indian Urbanization, *Environ. Urban. ASIA*, 2015, **6**(1), 18–27.
5 Government of India, *Census Tables [Internet]*, 2011, [cited 2022 Aug 26], Available from: https://censusindia.gov.in/census.website/data/census-tables.
6 K. C. Pradhan, *Unacknowledged Urbanisation: The New Census Towns of India [Internet]*, 2013, Available from: http://mpra.ub.uni-muenchen.de/41035/.
7 K. Farrell and H. Westlund, China's rapid urban ascent: an examination into the components of urban growth, *Asian Geogr.*, 2018, **35**(1), 85–106.
8 W. Avis, *Urban Expansion in Nigeria*, K4D Helpdesk Report 692, Brighton, 2019.
9 S. Nath Roy and K. C. Pradhan, Predicting the Future of Census Towns, *Econ. Polit. Wkly.*, 2018, **53**(49), 70–79, Available from: https://www.researchgate.net/publication/329915966.
10 S. N. Roy and K. C. Pradhan, *Census towns in India-current patterns and future discourses [Internet]*, New Delhi, 2018, May, Available from: https://www.researchgate.net/publication/325284041.
11 A. Allen, Neither Rural nor Urban: Service Delivery Options That Work for the Peri-urban Poor, in *Peri-urban Water and Sanitation Services*, Springer Netherlands, Dordrecht, 2010, pp. 27–61.
12 A. Allen, J. Davila and P. Hofman, *Governance of water and sanitation services for the peri-urban poor: a framework for understanding and action in Metropolitan regions*, University College London, Development Planning Unit, 2006.
13 S. Maryati and A. N. S. Humaira, Water supply provision characteristics in peri-urban area, in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, 2018.
14 S. J. Marks, G. Clair-Caliot, L. Taing, J. T. Bamwenda, C. Kanyesigye and N. E. Rwendeire, *et al.*, Water supply and sanitation services in small towns in rural–urban transition zones: The case of Bushenyi-Ishaka Municipality, Uganda, *NPJ Clean Water*, 2020, **3**(1), 21.
15 L. M. S. N. Sanchez, J. S. Kemerink-Seyoum, D. W. Batega and R. Paul, Caught in the middle? Access to water in the rural to urban transformation of Bushenyi-Ishaka municipality, Uganda, *Water Policy*, 2020, **22**(4), 670–685.
16 D. Guin, Contemporary perspectives of small towns in India: A review, *Habitat Int.*, 2019, **86**, 19–27.
17 A. Duarte Vera, J. Vanhulst and E. A. Letelier Araya, Peri-urban territories and rural water community governance in Chile, *Int. J. Soc. Econ.*, 2022, **49**(1), 59–72.
18 F. H. Mardiansjah, D. Rukmana and M. Fadjar Hari, Urban Population Growth and the Growth of Towns and Cities in Indonesia: the Challenge of Non-statutory Town Development, in *The 55th ISOCARP World Planning Congress*

Jakarta-Bogor, Indonesia [Internet], ISOCARP, 2019, Available from: https://www.researchgate.net/publication/351160462.

19 J. Woltjer, A global review on peri-urban development and planning, *J. Reg. City Plan.*, 2014, **25**(1), 1–16, Available from: http://journals.itb.ac.id/index.php/jpwk/article/view/1273.

20 A. Rumi, *India's Peri-Urban Regions: The Need for Policy and the Challenges of Governance [Internet]*, Observer Research Foundation, 2019, Available from: https://www.orfonline.org/series/urbanisation-and-its-discontents/.

21 A. Shaw, Peri-Urban Interface of Indian Cities: Growth, Governance and Local Initiatives, *Econ. Polit. Wkly.*, 2005, **40**(2), 129–136.

22 J. Chandiramani, S. Tripathi, G. Patil, S. B. Misra and A. Shende, How to transform census towns into economic growth engines: an Indian (Pune) perspective, *Asia-Pac. J. Reg. Sci.*, 2025, **9**(1), 129–157.

23 D. Kundu, Slowdown in Urban Growth, *Econ. Polit. Wkly.*, 2013, **6**(27), 5–9.

24 Government of India, *Constitution of India [Internet]*, 2024, [cited 2024 Nov 12], Available from: https://cdnbbsr.s3waas.gov.in/s380537a945c7aaa788ccfcdf1b99b5d8f/uploads/2024/07/20240716890312078.pdf.

25 M. Jain and A. Korzhenevych, Urbanisation as the rise of census towns in India: An outcome of traditional master planning?, *Cities*, 2020, **99**, 102627.

26 M. Jain, Contemporary urbanization as unregulated growth in India: The story of census towns, *Cities*, 2018, **73**, 117–127.

27 G. Samanta, The Politics of Classification and the Complexity of Governance in Census Towns, *Econ. Polit. Wkly.*, 2014, **49**(22), 55–62.

28 S. Tripathi and A. Mitra, Shedding light on unnoticed gems in India: A small town's growth perspective, *Land use policy*, 2022, **120**, 106239.

29 P. Mukhopadhyay, M. H. Zérah, G. Samanta and A. Maria, *Understanding India's Urban Frontier What Is behind the Emergence of Census Towns in India? [Internet]*, Washington, DC, 2016, Report No.: No. 2923, Available from: https://openknowledge.worldbank.org/entities/publication/890381b6-c9c8-5b53-a1de-151c121aaa0a.

30 P. Tiwari, Dynamics of Peri Urban areas of Indian Cities, *Int. J. Sci. Eng. Res.*, 2019, **10**(4), 131–141, Available from: https://www.researchgate.net/publication/332410187_Dynamics_of_Peri_Urban_areas_of_Indian_Cities.

31 P. K. Ghosh and S. Khatun, Statutory vs census towns: modelling the differences of urban development using statistical approach in India: a micro level case analysis, *Model Earth Syst. Env.*, 2022, **8**(1), 435–448.

32 G. Samanta, Urban Territories Rural Governance, *Econ. Polit. Wkly.*, 2013, **27**(6), 36–38.

33 R. B. Bhagat, Rural-Urban Classification and Municipal Governance in India, *Singap. J. Trop. Geogr.*, 2005, **26**(1), 61–73, DOI: 10.1111/j.0129-7619.2005.00204.x.

34 P. Moriarty, C. Batchelor, C. Fonseca, A. Klutse, A. Naafs and K. Nyarko, *Ladders for assessing and costing water service delivery [Internet]*, 2011, Nov. Report No.: 2, Available from: https://www.washcost.info.

35 G. L. Kayser, P. Moriarty, C. Fonseca and J. Bartram, Domestic water service delivery indicators and frameworks for monitoring, evaluation, policy and planning: A review, *Int. J. Environ. Res. Public Health*, 2013, **10**, 4812–4835.

36 A. K. Biswas and C. Tortajada, Water quality management: a globally neglected issue, *Int. J. Water Resour. Dev.*, 2019, **35**, 913–916.

37 UNICEF and WHO, *Integrating water quality testing into household surveys [Internet]*, New York, 2020, Available from: https://washdata.org/sites/default/files/2020-10/JMP-2020-water-quality-testing-household-surveys.pdf.

38 G. Howard, J. Bartram, A. Williams, A. Overbo, D. Fuente and J. A. Geere, *Domestic water quantity, service level and health*, Geneva, 2nd edn, 2020.

39 P. R. Hunter, D. Zmirou-Navier and P. Hartemann, Estimating the impact on health of poor reliability of drinking water interventions in developing countries, *Sci. Total Environ.*, 2009, **407**(8), 2621–2624.

40 Government of India, *The Constitution (Seventy-fourth Amendment) Act, 1992 [Internet]*, 1992, [cited 2023 Dec 10].

41 Mumbai Metropolitan Region Planning Board, *Official Website of MMRDA [Internet]*, [cited 2023 Dec 5], Available from: https://mmrda.maharashtra.gov.in/about-us/about-mmr.

42 Government of Maharashtra, *Notification-Mumbai Metropolitan Region Development Authority Act, 1974 [Internet]*, Maharashtra Government Gazette, No. MRD.3318/CR-108/UD-7, India, Sep 9, 2019.

43 Government of Maharashtra, *Notification-Mumbai Metropolitan Region Development Authority Act, 1974*, Maharashtra Government Gazette, TPS.1206/330/CR-230/06/UD-12, India, Mar 17, 2007.

44 STEM, *Stem Water Distribution And Infrastructure Company Private Limited [Internet]*, [cited 2024 Nov 5], Available from: Stem Water Distribution And Infrastructure Company Private Limited.

45 S. P. Sekar and S. Kanchanamala, An Analysis of Growth Dynamics in Chennai Metropolitan Area, Institute of Town Planners, *India J.*, 2011, **8**(4), 31–57, Available from: https://www.itpi.org.in/uploads/journalfiles/oct3_11.pdf.

46 V. Narain, P. Anand and P. Banerjee, *Periurbanization in India: A review of the literature and evidence*, 2013, Available from: https://saciwaters.org/uploads/documents/1694775858_status_paper_on_periurbanisation_in_india(3).pdf.

47 A. Casteel and N. L. Bridier, Describing populations and samples in doctoral student research, *Int. J. Dr. Stud.*, 2021, **16**, 339–362.

48 *Laerd Statistics [Internet]*, 2024, [cited 2025 Aug 28], Available from: https://statistics.laerd.com/spss-tutorials.

49 S. Guo, S. Zhong and A. Zhang, Privacy-preserving Kruskal-Wallis test, *Comput. Methods Programs Biomed.*, 2013, **112**(1), 135–145.

50 A. Dinno, Nonparametric pairwise multiple comparisons in independent groups using Dunn's test, *Stata J.*, 2015, **15**(1), 292–300.

51 M. L. McHugh, The Chi-square test of independence, *Biochem. Med.*, 2013, **23**(2), 143–149.
52 E. Ingwani, M. Thynell, L. R. Gurure, N. G. A. Ekelund, T. Gumbo and P. Schubert, *et al.*, The Impacts of Peri-Urban Expansion on Municipal and Ecosystem Services: Experiences from Makhado Biaba Town, South Africa, *Urban Forum*, 2024, **35**(2), 297–327.
53 Government of Tamil Nadu, *A Bill to Provide for the Establishment of a Municipal Corporation for the City of Tambaram [Internet]*, Tamil Nadu Government Gazette Extraordinary, L.A. Bill No. 5 of 2022, India, Jan 6, 2022, Available from: https://prsindia.org/files/bills_acts/bills_states/tamil-nadu/2022/Bill%20No.%205%20of%202022%20Tamil%20Nadu.pdf.
54 P. Mukhopadhyay, M. H. Zerah, E. Denis and E. D. Subaltern, *India's Contemporary Urban Conundrum [Internet]*, India International Centre Quarterly, Urbanization Revisited. India International Centre Quarterly, 2017, vol. 43, Available from: https://shs.hal.science/halshs-01755990v1.
55 A. Follmann, L. Kennedy, K. Pfeffer and F. Wu, Peri-urban transformation in the Global South: a comparative socio-spatial analytics approach, *Reg. Stud.*, 2023, **57**(3), 447–461.
56 U. Grant, *Spatial inequality and urban poverty traps [Internet]*, 2010, Available from: https://media.odi.org/documents/5502.pdf.
57 K. W. Debela, Decentralized Urban Governance and Water Supply Service Delivery in Ethiopia: The Case of Adama City, *Am. J. Manage. Sci. Eng.*, 2021, **6**(3), 63.
58 K. C. Pradhan and B. Joshi, *Officiating Urbanisation What makes a settlement officially urban in India? [Internet]*, 2018, Available from: https://www.researchgate.net/publication/337674244.
59 S. N. Roy, K. C. Pradhan and N. R. Shamindra, *Census Towns In India: Current Patterns and Future Discourses*, 2018, available at https://cprindia.org/census-towns-in-india-current-patterns-and-future/.
60 K. Sharma, Transition towns, *Econ. Polit. Wkly.*, 2013, **27**(6), 25–28.
61 M. L. B. Mau, S. Sriyana, H. Purnaweni and D. Lituhayu, The importance of institutional capacity in drinking water supply system governance: A policy evaluation from border area, *Edelweiss Appl. Sci. Technol.*, 2024, **8**(4), 1448–1461.
62 O. Jensen and C. Ménard, Understanding the roles of meso-institutions: a comparative approach to urban water provision in seven Asian cities, *J. Institutional Econ.*, 2024, **20**, e36.
63 P. Mukhopadhyay, in *Subaltern Urbanisation in India: An Introduction to the Dynamics of Ordinary Towns*, ed. E. Denis and M. H. Zerah, Springer, Delhi, 2017.
64 Government of India, *Reforms in Urban Planning Capacity in India [Internet]*, New Delhi, 2021, Sep [cited 2025 Aug 28], Available from: https://www.niti.gov.in/sites/default/files/2021-09/UrbanPlanningCapacity-in-India-16092021.pdf.
65 S. Ghosh and D. N. Das, Does Statutory Status Make Any Difference to the Governance of Census Towns?, *Urban India*, 2021, **41**(1), 36–48.
66 A. Allen, *Environmental planning and management of the peri-urban interface: perspectives on an emerging field [Internet]*, 2003, Available from: https://www.researchgate.net/publication/32893598_Allen_A_Environmental_planning_and_management_of_the_periurban_interface_Perspectives_on_an_emerging_field_Environment_and_Urbanization_15-_httpdxdoiorg101177095624780301500103.
67 M. Adank, *Small town water services Trends, challenges and models [Internet]*, 2013, Available from: https://www.ircwash.org/sites/default/files/small_towns_top27.pdf?__cf_chl_tk=_TSJES9_hyyRYHpbe3BAmbEPJyduEtq.kdfvGsJujSY-1771777694-1.0.1.1-67yERm1y9tdctX03A43O_Wd_tsqX9.MiKE0POtJsFS4.
68 J. Nedjoh, A case for governance and institutional re-alignment for small towns piped water services in Africa, in *Ensuring availability and sustainable management of water and sanitation for all. Kumasi, Ghana: 39th WDEC International Conference*, 2016.
69 A. Allen, J. D. Dávila and P. Hofmann, The peri-urban water poor: Citizens or consumers?, *Environ. Urban.*, 2006, **18**, 333–351.