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Contextualizing urban water consumption theories: Reconceptualizing demand drivers in the context of Gurugram

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Abstract

Nowadays, most theories regarding water consumption are related to the cities' development. However, there is a phenomenon that modern scientific communities try to analyze as it appears in the developing countries. The existing theory of water consumption was developed on a relationship between the horizontal urban structure, macroeconomic factors such as GDP, and stable population rates. Meanwhile, there exist skyscraper structures, usually associated with high business development and unstable population rates, and areas unfit for human existence due to severe ecological issues. The purpose of this paper is to provide a critical analysis of fourteen various studies of water consumption rates among global cities. The studies performed for Nigeria, India, China, Japan, Malaysia, Portugal, Sri Lanka, and OECD countries allow the analysis to establish some crucial discrepancies in water consumption theories used for the territories with vast horizontal structures and high business development. By studying the water consumption theory in these countries, one understands why Gurugram was chosen as the best practice example to demonstrate the relationship between innovative concepts and local peculiarities. Hence, this paper emphasizes the necessity to adapt water consumption theories for areas similar to the Gurugram region. Thus, the paper suggests several concepts that can be used for further research in areas with skyscraper structures. It should be noted that the paper is based on the critical analysis of the existing sources rather than an empirical study.

Keywords: Contextualization, urban water theories, demand drivers, water scarcity, urban metamorphosis, gurugram

Introduction

The theories surrounding domestic water consumption have so far been based on the well-established "inverted U" curves predicting peaks of consumption (Du *et al.*, 2022) ^[1], and the enduse breakdown peculiar to the horizontal society (Sadr *et al.*, 2015) ^[2]. However, with the advent of new phenomena, such a theory either is refuted or rethought.

To start with, the urban environment of the Global South has changed dramatically in recent decades. In India, Gurugram is now a city of contrasts regarding water consumption: it has emerged as one of India's fastest-growing service economies (Zacarias-Farah & Geyer-Allely, 2003) ^[3], the hyper-modern Asian megalopolis's vertical sprawl (Bandari *et al.*, 2023) ^[4], and the localized, capital-driven aquifer depletion of the dry global south (Fashae *et al.*, 2024) ^[5]. Therefore, when the theories derived from the analysis of global consumption trends are superimposed on such a territory, they either predict paradoxes or miss new phenomena entirely. In other words, if a theory worked for a stable horizontal neighborhood, it has limited success in an expanding vertical township with private tanker services.

In this paper, the term hyper-verticality refers to the concentration of high-rise residential and commercial developments that substantially alter water demand through centralized infrastructure and shared amenities.

Objective of the Study

This study aims to reconceptualize traditional water theories through Gurugram's hyper-vertical reality, proposing a new framework for modern megacities.

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Contextualizing Supply-side Theories: From Geological Constraints to Capital-Induced Depletion

Within the literature on water access, the discussion of physical availability and the existing infrastructure is a natural starting point. However, in developing countries, the supply-side theories and hypotheses are intrinsically linked with the narrative of deprivation and inequity. Fashae *et al.* (2024)^[5] describe the situation in Ibadan, Nigeria, where the rocky geology renders digging unviable and makes community boreholes seasonal. Similarly, Maina *et al.* (2024)^[6] discuss the insufficiency of the infrastructure in Gombe, Nigeria, which makes residents turn to private water vendors.

Within the supply-side theories, there is a growing body of literature that seeks to establish a link between access to water and social conflagration. Neo-Malthusian theories popular in the 19th century were refuted by Böhmelt *et al.* (2014)^[7], who analyzed the propensity for water-related violence in the context of 35 countries, managing to establish a conceptual framework about the causes of water conflicts. Thus, according to Böhmelt *et al.* (2014), water conflicts are demand-driven, with supply-side dynamics being “restraint” factors and predictors of conflagration, such as democratic regimes, lowering the likelihood of conflagration.

Gurugram’s Supply-Side Paradox

With the supply-side theories, both physically and socially informed, discussed, it becomes apparent that applying them to a context such as Gurugram township would produce paradoxes. On the one hand, the Nigerian studies are a warning about the limitations of natural infrastructure (Fashae *et al.*, 2024; Maina *et al.*, 2024)^[5, 6]. However, in Gurugram, fertile alluvial sediment replaces the unreliable boreholes of Ibadan and Gombe. On the other, the municipal well is depleted to the point of capital-driven aquifer shrinkage, a phenomenon not discussed in the Nigerian literature. Fashae *et al.* (2024)^[5] and Maina *et al.* (2024)^[6] discuss the limitations of geology, but not the reverse phenomenon, which is the capital-driven shrinkage of natural water resources. Finally, according to Böhmelt *et al.* (2014)^[7], it is the democratic, middle-class Resident Welfare Association (RWA) neighborhoods of Gurugram that are factors driving the local natural capital to the brink through private tanker services.

Reassessing Economic Predictors: How the ‘Inverted U’ Curves Meet Microeconomics of a Dead Aquifer

When the task is to discuss consumption trends in societies experiencing rapid urbanization, it is impossible to ignore debates surrounding the theoretical patterns concerning the so-called ‘inverted U’ and ‘inverted V star’. Having reviewed the supply-side theories and hypotheses, it becomes necessary to proceed to water-demand theories and models that may help understand the water imprint of a dynamic economy like Gurugram. Indeed, Du *et al.* (2022)^[1] engage in an analysis that applies to several theories attempting to predict China’s water footprint in developed economies. Using ordinary least squares regression, the authors examined the associations between water consumption *per capita* and China’s GDP *per capita* as well as its urbanization rate, thus testing the predictive capacity of these theories. The results of the study contribute to the general understanding of water-consumption trends, as an application of the theories to China helps extrapolate the conclusions to similar developing urban centers like Gurugram. In particular, the authors identified an ‘inverted U’ curve for

water-consumption associations with GDP *per capita* and an ‘inverted V’ curve for water-consumption associations with urbanization rate (Du *et al.*, 2022)^[1]. According to the findings, increases in the size of the economy and the process of urbanization lead to rises in water-consumption until the 70–80% level of urbanization, after which consumption begins to decrease due to the adoption of water-saving technologies.

When it comes to applying demand theories to Gurugram, the discussion should begin with the general macro-trends. In that regard, the findings of Du *et al.* (2022)^[1] can be supplemented and expanded upon by drawing from the analysis of the rebound effect by Zacarias-Farah and Geyer-Allely (2003)^[3]. Indeed, the latter study is one of the comprehensive pieces of research that examined the phenomena in the context of the Organization of Economic Cooperation and Development (OECD) countries (Zacarias-Farah & Geyer-Allely, 2003)^[3]. Specifically, as applied to water, Zacarias-Farah and Geyer-Allely (2003)^[3] argue that every single technology, by its very nature, offsets itself by enabling the consumption of more of other goods due to the fact that water is an essential input in the production process of every good and service. Therefore, it is logical to state that unless consumption of other goods decreases, the rising water-consumption trends will remain a major concern for global sustainability and environmental conservation.

It is in the rebound-effect analysis that it becomes possible to proceed to a discussion of water-consumption theories at a micro level. Indeed, Narmilan *et al.* (2021)^[8] examine the relationship between water use and income in the context of rapidly developing countries such as India. Later, the study is adapted to analyze the trends in Sri Lanka. As a result, the authors find a strong linear association (.968) between the water-consumption patterns of RWA and residents’ income levels (Narmilan *et al.*, 2021)^[8]. According to the study, the income effect accounts for every additional liter consumed for every additional dollar earned as a result of the acquisition of more electric appliances by citizens.

Questioning Spatial Norms: Why Do Urban Households in Gurugram Consume More Water than their Rural Counterparts?

When the objective is to identify the patterns of water-consumption by urban and rural households, it is logical to begin once again with a discussion of theoretical foundations. In particular, the literature review section of the present paper demonstrates that there is a considerable body of literature that recognizes the link between residents’ consumption habits and the gradation of their urbanization. For example, when analyzing the water-consumption patterns of households in Northern Portugal, Gonçalves *et al.* (2018)^[9] applied ordinal logistic regression to examine the link between the level of urbanization and consumption trends. In particular, the authors’ findings demonstrate that the water-use of urban households was predicted to be 30% higher than that of their rural counterparts (Gonçalves *et al.*, 2018)^[9].

The findings of Gonçalves *et al.* (2018)^[9] can be supported by elaborating on the findings of Bandari *et al.* (2023)^[4], who examine the consumption patterns of Vijayawada’s residents. In particular, Bandari *et al.* (2023)^[4] apply multiple linear regression to predict water-consumption based on neighborhoods’ characteristics, including their planning status. According to the authors, residents of organic and planned neighborhoods were predicted to consume the highest amount of water (150.14 lpcd), compared to unplanned slums (136.46

lpcd). Moreover, in Bandari *et al.* (2023) ^[4], it is the building height and the year of its construction that show significant contributions to the regression model. Specifically, the authors find that, for their sample, the increase in height and the age of a building negatively predict potable water consumption *per capita*. It is possible to argue that it is the result of domestic water consumption being offset by the water-intensity of airconditioning in high-rise buildings. Finally, Bandari *et al.* (2023) ^[4] can be supplemented by Narmilan *et al.* (2020) ^[10], who explore the association between residents' water-consumption and the level of urbanization in Sri Lanka. According to Narmilan *et al.* (2020) ^[10], the likelihood of having high-flow faucets and water-saving showerheads increases with the level of urbanization.

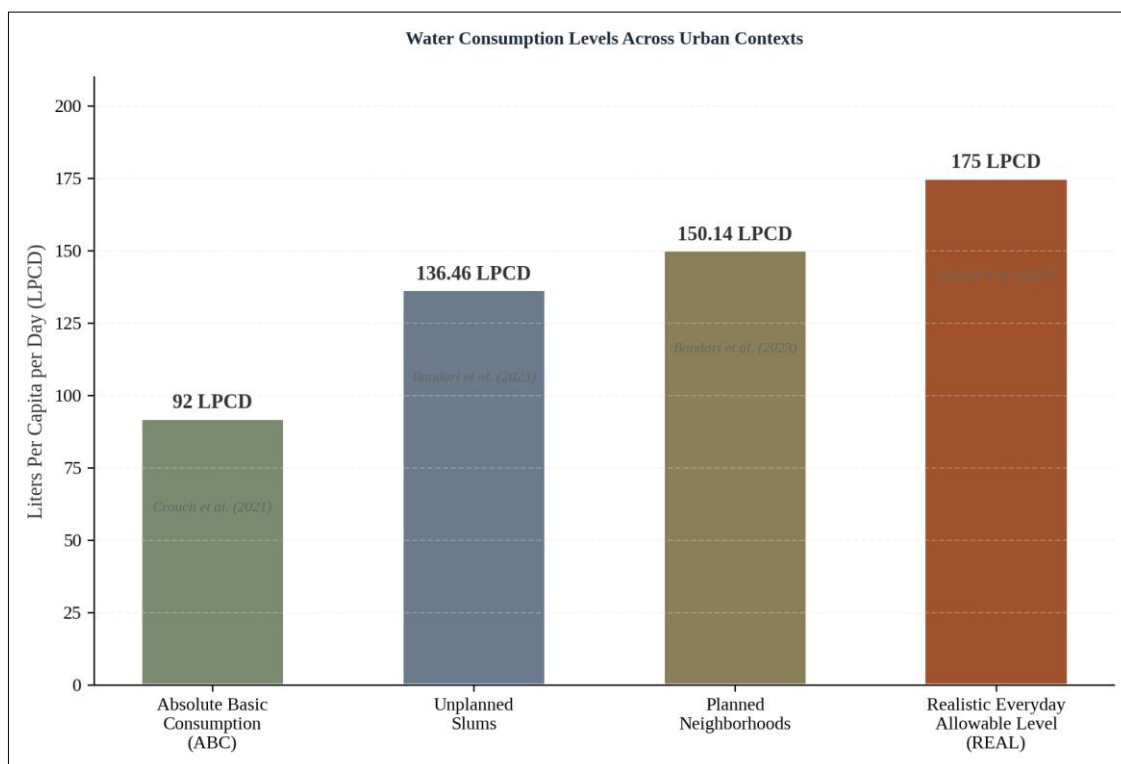
The Fallacy of Horizontal Models

As stated in the preliminary paragraphs, when the objective is to discuss consumption theories in the context of rapidly urbanizing societies, the discussion should begin with theories that address the consumption peculiar to vertical sprawl. However, as demonstrated by the findings of Bandari *et al.* (2023) ^[4] and Gonçalves *et al.* (2018) ^[9], not a single study examined the implications of hyperverticality. Indeed, Bandari *et al.* (2023) ^[4] document the trends of water-intensity, yet they only address horizontal neighborhoods. In other words, the authors overlook the fact that, in Gurugram, high-rise buildings replaced low-rise ones. Similarly, Gonçalves *et al.* (2018) fail to address the question of whether or not, in a 30-story high-rise township, water-intensity will be predicted to increase exponentially. Finally, according to Bandari *et al.* (2023) ^[4], building height negatively predicts potable water consumption *per capita*, whereas in Gurugram, verticality is a major predictor of ultra-luxury consumption: spatial theories should be rethought in the context of hyperverticality to account for the non-linear drivers of extreme consumption.

Contextualizing Micro-component Theories: Communal Luxury vs. Absolute Basic Needs

As far as physical micro-component studies are concerned, it is only natural to begin with the work of Sadr *et al.* (2015 ^[2]; 2016). Indeed, the authors pioneered the analysis of water consumption in the context of Jaipur, India. Using survey-based research, Sadr *et al.* (2015; 2016) ^[2] identified the largest areas of consumption, finding bathroom and toilet flushing to account for the majority of it. Moreover, the authors find that family size is a negative predictor of water-consumption *per capita*, suggesting that small families are ill-adapted in terms of consumption. Other findings relate to the cultural specifics of the region, including the prevalence of bucket bathing over showers and toploading washing machines.

It is interesting to note that, in order to operationalize the concepts of absolute necessities, Crouch *et al.* (2021) ^[11] developed a theoretical model around Maslow's hierarchy of needs. In particular, in their article, the authors discuss the concept of Absolute Basic Consumption (ABC), which is defined as the most deprived and barely sufficient level of consumption, which satisfies only the most primal needs. According to Crouch *et al.* (2021) ^[11], it is ABC that underlies the 'Realistic Everyday Allowable Level' (REAL), which refers to a comfortable, but non-frugal level of living, wherein waste is minimized. As stated by the authors, REAL constitutes 175 LPCD, whereas ABC only comprises 92 LPCD. Finally, another approach to conceptualizing basic needs is discussed by Narmilan *et al.* (2020) ^[10]. In their study, the authors operationalized the term by identifying the number of taps as a theoretical micro-component that influences consumption. According to Narmilan *et al.* (2020) ^[10], the number of taps significantly predicts water-consumption, independent of people's ability to conserve due to the differences in pipework and high-flow showerheads.



Source: Compiled by the authors based on Crouch *et al.* (2021) ^[11] and Bandari *et al.* (2023) ^[4]

Fig 1: Water Consumption Levels Across Urban Contexts

Beyond the Household Tap: Contextualizing the Micro-components

As can be inferred from the discussion presented above, the primary theoretical limitation in the context of Gurugram lies in the definition of ‘needs’, or, rather, the complete absence of ‘communal luxury’. In this paper, communal luxury refers to water consumed through shared residential amenities such as swimming pools, landscaped areas, centralized cooling systems, and other common facilities within gated communities. Indeed, while Sadr *et al.* (2016) ^[12] only account for micro-components used for personal hygiene, such as bathing or cooking, it is reasonable to assume that, in ultra-luxury RWAs the communal amenities are at the forefront of residents expenditure on water. In other words, RWAs’ swimming pools, lawn maintenance, and car washes are examples of communal luxury that significantly offset the consumption of water by households. In that regard, it is logical to argue that RWAs’ residents’ expenditures on communal facilities challenge the concepts of ABC (Crouch *et al.*, 2021) ^[11] or, at very least, significantly expand them. On the other hand, according to Narmilan *et al.* (2020) ^[10], in a hyper-vertical RWA the theoretical micro-component that should be considered is the number of taps: in reality, they are replaced by centralized pumping stations of RWAs, reverse osmosis water purification plants, and air conditioning systems.

Contextualizing Behavioral and Temporal Theories: The Transience Variable

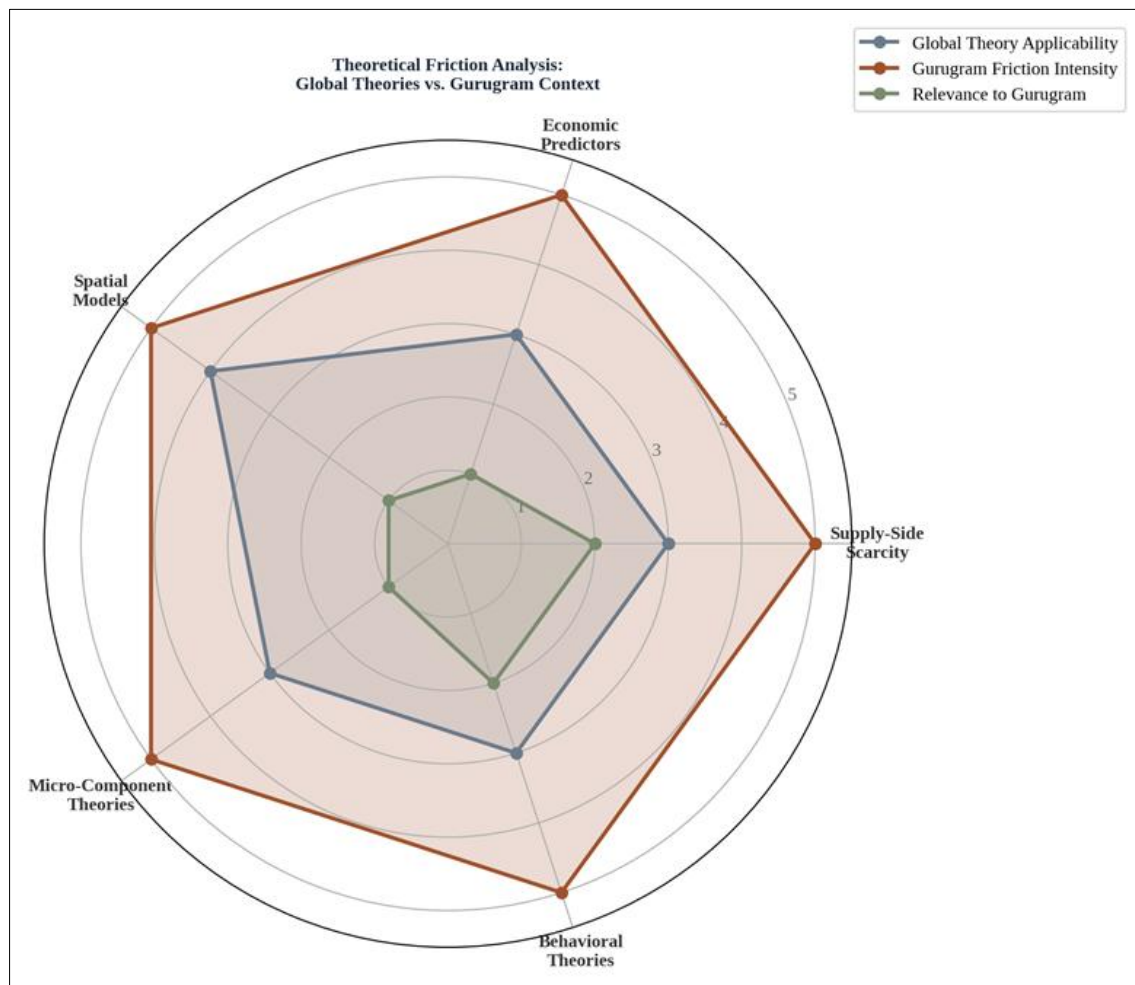
Finally, when it comes to consuming water in accordance with human behavior, the analysis conducted by Ahmad *et al.* (2024) ^[13] offer rather intriguing insights. In particular, the authors applied the Theory of Planned Behavior (TPB) to operationalize sustainable water consumption behavior (SWCB). According to Ahmad *et al.* (2024) ^[13], behavior intention played a mediational role, and attitudes were identified as the strongest predictor of water consumption. In addition, the authors identified socio-demographic variables as significant moderators. Obaid *et al.* (2024) ^[14], in their turn, examined human behavior in connection to water with a focus on temporal variables in the context of urban households in Japan. In particular, Obaid *et al.* (2024) ^[14] utilized water consumption data provided by high-resolution water meters, thus analyzing consumption patterns of ‘worker households. According to Obaid *et al.* (2024) ^[14], ‘worker households’ demonstrate bi-modal consumption, peaking at 8:00 AM and 8:00 PM. At the same time, households

with absent spouses demonstrated delayed and flattened consumption throughout the day. In other words, temporal patterns of consumption were entirely dictated by the behavior of the residents. However, Obaid *et al.* (2024) ^[14] and Ahmad *et al.* (2024) ^[13] failed to account for the fact that theoretical awareness rarely translates into practical necessity; in fact, Narmilan *et al.* (2021) ^[8] document the residents of high RWAs in Colombo, Sri Lanka, being remarkably unaware of the value of water in terms of currency despite the environment of extreme luxury (73.3% of respondents were completely oblivious).

The Transience Factor: Why Short-Term Residents Do Not Conserve Water

It is only rational to begin this section by stating that Ahmad *et al.* (2024) ^[13] and Obaid *et al.* (2024) ^[14] only account for the stability of residents in RWA townships. However, as mentioned in passing earlier, it is a rare occurrence for IT professionals to stay in the same company for longer than 6- 18 months, with many advancing both their professional careers and/or receiving an opportunity to pursue post-graduation. Similarly, migrant laborers from Bihar, Jharkhand, and West Bengal only stay in Gurugram for 12-24 months before returning home. As can be inferred from this information, there is a behavioral disposition among the residents of Gurugram, which must be taken into account.

Firstly, it is common sense that a transient household is not going to renovate the rented accommodation, thus rendering Obaid *et al.*’s (2024) ^[14] conclusion about behavioral intention invalid. Secondly, although it is fair to assume that most migrant workers and IT employees prefer to live in a nuclear family, it is only going to be a matter of months or even weeks. Therefore, it is possible to argue that if we use the SWCB framework proposed by Ahmad *et al.* (2024) ^[13], the bachelor living in a flat with another two worker friends, who have a shift-based duty-rotating system, do not fit the mold of “worker household” described by Obaid *et al.* (2024) ^[14]. In reality, the water consumption pattern of a “worker household” with a family of four, whose offspring commute to their respective colleges in separate cars, cannot be any different from the pattern of a migrant laborer family that lives in a rented apartment and pays for water separately. Overall, any behavioral intention suggested by Ahmad *et al.* (2024) ^[13] is utterly meaningless to the Gurugram residents who intend to stay for a maximum of 24 months.



Source: Developed by the authors based on the reviewed literature

Fig 2: Conceptual Comparison of Global Theories and the Gurugram Context

[Note: The scores [1-5] are conceptual and illustrative. They do not represent statistical measurements but summarize the comparative interpretation of the reviewed literature.]

Figure 2 summarizes the conceptual differences between existing water consumption theories and the Gurugram context. It highlights the areas where conventional theories require

contextual adaptation. These observations are further synthesized in Table 1.

Table 1: Theoretical Friction Points—Global Theories vs. Gurugram's Reality

Theoretical Domain	Established Global Theory/Assumption	Key Literature Support	Gurugram's Reality (The Friction Point)
Supply-Side	Scarcity is driven by physical/geological constraints or state infrastructural deficit.	Fashae <i>et al.</i> (2024) ^[5] ; Maina <i>et al.</i> (2024) ^[6]	Wealth-Induced Scarcity: Scarcity is driven by unregulated capital extraction by wealthy RWAs on alluvial plains, not by rocky terrain.
Economic	"Inverted U" curve & "Rebound effect" assume reliance on the public grid with standard price elasticity.	Du <i>et al.</i> (2022) ^[11] ;Zacarias-Farah & Geyer-Allely(2003) ^[13] ;Narmilan <i>et al.</i> (2021) ^[8]	Off-Grid Privatization: Extreme wealth bypasses grid failures entirely by purchasing private tanker water, severing the public utility feedback loop.
Spatial	Horizontal urbanization drives demand; building height/age shows negative correlation with per capita use.	Gonçalves <i>et al.</i> (2018);Bandari <i>et al.</i> (2023) ^[4]	Hyper-Verticality: Height equals hyper-luxury. Ultra-modern high-rises with centralized cooling towers create exponential, nonlinear demand.
Micro-Component	Demand is calculated via individual household fixtures (taps, showers) capped at a "REAL" limit (~175 LPCD).	Sadr <i>et al.</i> (2016) ^[12] ; Crouch <i>et al.</i> (2021) ^[11] ;Narmilan <i>et al.</i> (2020) ^[10]	Communal Luxury: Water use defies individual fixture metrics, driven instead by centralized RWA amenities (pools, landscaping, RO plants).
Behavioral	Behavior is modeled on stable residents with territorial attachment and predictable temporal routines.	Ahmad <i>et al.</i> (2024) ^[13] ; Obaid <i>et al.</i> (2024) ^[14]	Transience & Tenant Apathy: Short-term renters lack Perceived Behavioral Control, distorting temporal peaks and negating long-term conservation attitudes.

Source: Developed by the authors based on the reviewed literature.

Table 1 above presents the significant theoretical friction points emerged from the provided literature review in relation to the

case of Gurugram. The comparison allows for concluding on the applicability of the reviewed theories to the patterns of

domestic water consumption in the region. The analysis indicates that while the general trends can be related to the theoretical foundations, the specifics of the case, including the tendencies toward hyper-vertical development, groundwater

depletion, shared infrastructure, and transience, need to be taken into account. Thus, it is necessary to interpret the theories through the prism of the peculiarities of the urban environment.

Table 2: Proposed Paradigm Shift in Water Demand Drivers for Corporate Megacities

Traditional Demand Driver	Limitation in 21st-Century Hubs	Proposed Context-Specific Driver (The Gurugram Model)
Physical Geology	Ignores capital's ability to destroy naturally abundant water bases.	Capital-Induced Aquifer Depletion (Measuring extraction power vs. natural recharge).
Household Income Level	Assumes public grid reliance and standard price elasticity.	Off-Grid Privatization Capacity (Measuring ability to purchase private water logistics).
Horizontal Urbanization Rate	Fails to capture vertical amenity loads and shared infrastructure.	Hyper-Vertical Density & Centralized Luxury (Measuring centralized cooling/amenity water loads).
Number of Household Taps/Fixtures	Misses shared infrastructure in gated communities.	RWA-Level Infrastructural Demand (Shifting the analytical unit from the kitchen to the cooling tower).
Long-Term Resident Attitudes	Assumes control over property and stable behavioral norms.	Population Transience & Tenant Apathy (Factoring in rental tenure length and lack of territorial control).

Source: Developed by the authors based on the reviewed literature.

Conclusion

A critical analysis of these fourteen foundational studies leads to partially positive conclusions about the application of global theories for the study of demand. The theories adequately describe demand in horizontal, stable, and historically justified systems. However, they fail to meet when it comes to the contextualization of results within a vertical, highly-GDP, and transient system. In fact, Gurugram is the ultimate context for reinventing the theories that describe the forces driving demand. First, it is the ultimate source of GDP to counterbalance the OECD rebound effect (Zacarias-Farah & Geyer-Allely, 2003) ^[3]. Second, it is the ultimate vertical for testing the spatial height model (Bandari *et al.*, 2023) ^[4]. Third, it can provide the ultimate opportunity to interact with a transient workforce for pioneering behavioral models (Obaid *et al.*, 2024) ^[14]. Fourth, it is the ultimate capital to discuss the creation of supply-independent scarcity (Fashae *et al.*, 2024) ^[5]. Fifth, it can offer ultimate luxury assets to deconstruct the need-based micro-component approach (Crouch *et al.*, 2021) ^[11]. Therefore, conducting a primary study in Gurugram is a must because it is the only chance to converge the divergent theories and pioneer a modern understanding of the forces that drive demand. Specifically, according to Table 2, there is a need to conceptualize the drivers of demand anew.

The proposed framework is merely conceptual and aims to provide guidelines for further empirical research. As discussed above, the current water crisis in Gurugram is mainly caused by the housing real estate sector through groundwater extraction, making the analysis purely economic. Traditional approaches are inefficient in addressing municipal consumption, given the significant consumption gap between urban and rural areas. In the case of Gurugram, such a divide can no longer be applied, given the tremendous rise of high-rises in favor of low-rises. This fact allows concluding that when estimating consumption, attention should be paid to luxury developments, swimming pools, and other infrastructure in the researched area. Last but not least, a considerable number of people only reside in the city temporarily, which is vital information about the consumption to be taken into account. Ultimately, the research will allow analyzing consumption beyond the traditional aspects and introduce alternative approaches, better understanding the forces that contribute to water consumption in the twenty-first century. The limitation of this study is that it only relies on published data, meaning that it is mostly conceptual and

requires further empirical research to identify the actual drivers of demand.

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