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A Framework for Archive Demand Management Strategies: A Pilot Study on Water Use in a Low-Income Brazilian Area

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Abstract: This study presents a pilot study in suburban households in Salvador, Brazil, inserted in the context of a framework developed to aid water demand management strategies. The framework aims to understand the barrier of subjectivity while identifying consumption habit patterns in households. Six key sets of components create the framework architecture: (1) characterization of the area based on: context, climate, population/area, population growth rate, and water management challenges; (2) a survey to obtain socio-demographic and physical property data of the sample; (3) smart metering and data processing systems to monitor sample water end use; (4) determining daily consumption patterns; (5) analyzing qualitative data through theoretical consumption models to identify relevant variables for the next step; and (6) construction of representative mathematical models of consumption for each daily practice (this item was not included on pilot). It provides a starting point to understand how water demand management strategies can be supported at the user and decision-making level. As a result, improvements to the interview guides used in the pilot were suggested. Furthermore, customized measures to promote rational water consumption were identified in the study area, and policies could be proposed.

Keywords: water conservation; rational water consumption; low-income water end use; water consumption patterns and habits

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1. Introduction

Given the projected global urban growth in the coming years [1], even at current consumption levels, an increase in residential water demand is expected. This rise is consistent with trends in pollution and scarcity of quality water sources, particularly in developing countries [2], as well as projections of increases in extreme events such as droughts and increased temperatures caused by climate change [3,4]. Given the importance of making better use of available natural resources, it is critical to study human practices in depth and find ways to incorporate natural resource rationalization into this evolution.

Low-income people, who naturally consume less water because they have fewer consumption points at home, do not have financial access to activities that consume large amounts of water (e.g., irrigation of large gardens, use of swimming pools, and bathtubs) and continue to face problems due to a lack of basic food rights (e.g., lack of food security). Nonetheless, this population, like the high-income population, must adapt to the reality of climate change and resource scarcity. Under these conditions, one approach to achieving universal access is through the management of demand, which includes rational use as one of its fundamental principles.

Due to its subjectivity, rational water use is one of the demand management strategies that is difficult to implement and measure. The rational distribution of consumer goods is defined as a distribution that maximizes ownership of the goods produced, which entails not only purchasing a good but also learning how to interact with it [5]. Rational consumption is also associated with consciously meeting needs with minimal environmental impact. The basic needs are physiological, safety, love, esteem, and self-actualization [6]. Thus, the use of water or other consumer goods that meet basic needs can satisfy not only physiological needs such as drinking but also love needs, when, for example, getting wet in the garden with a hose brings back affective childhood memories. The goal of encouraging rational consumption is to avoid or delay the need for rationing measures. Rational consumption depends on a personal decision that is distinct from consumption to meet rationing targets, which means reducing consumption to the bare minimum due to external impositions such as governmental measures.

A detailed study of residential water consumption was conducted in four low-income households in Salvador, Bahia, Brazil. This city was chosen because it is where the research group's headquarters are located and may be a representative area of interest to describe similar water management challenges in developing coastal regions of the world with a tropical humid climate and considerable population growth. The Plataforma neighborhood's suburban region was chosen because, despite its reputation as a hotbed of police and criminal activity, it was feasible to study because contacts based on personal relationships between team members facilitated entry. This income level was chosen because it is representative of a considerable portion of the Bahia population; approximately 40% [7] of the Bahia population live with less than two minimum wages, which, in 2010 (year of last census), was equivalent to $567 dollars; therefore, it is considered a low-income population. The data, drawn from the Brazilian National Household Sample Survey (PNAD) [8] of the labor force, show that from 2012 to 2020, the unemployment rate increased, causing the proportion of the population in low-income levels to also increase. The economic crisis caused by the pandemic aggravated the situation. Additionally, understanding consumption in low-income areas aims to support ways to ensure that the minimum amount of water for this population's hygiene and health conditions is guaranteed as a fundamental human right. Four common activities were evaluated using the developed framework to enable water demand management strategies in a pilot study that could be used in future studies with a larger number of residences to make it more representative. This goal is consistent with Goal 12 of the United Nations' Sustainable Development Goals, "Responsible Consumption and Production".

The application in pilot scale of part of the framework proposed enabled the creation of a methodology that could be used in future studies with a larger number of residences to make it more representative. The study of consumption in detail with the help of theoretical models to guide the analyses allows for a fresh perspective on routine activities and can help users and decision makers gain insights to improve water demand management strategies.

The remainder of this paper is organized as follows. Section 2 presents a review of the literature, focusing on theories that can aid in understanding the various aspects of water consumption. Section 3 examines the feasibility of comparing the obtained results with those in the literature. Section 4 contains information about the study area, monitoring period, and interviews with residents. The analysis is completed in Section 5, which is divided into three sections: (a) the qualitative assessment of indoor activities, (b) the assessment of measured water consumption, and (c) the examination of the validity of the comparison with the literature. Finally, in Section 6, we summarize the main conclusions drawn from our analysis.

2. Models for Understanding Consumption Motivations

To effectively promote rational water consumption or any other pro-environmental behavior in homes, it is necessary to know the motivations and factors that interfere with these behaviors, in order to seek the best strategies to achieve this goal.

There are approaches that seek to understand individualistic consumption motivations (which exclude, for example, technological aspects), as well as structuralist approaches (which take the focus off individual aspects). These more individualistic or structuralist models have been criticized for ignoring other relevant aspects, such as context. The first has been accused of implying that changes in consumption are heavily dependent on individual behavior; the second, of portraying technological or structural factors as protagonists. More holistic approaches that consider aspects of each of these strands, such as the social practices approach, are becoming increasingly important [9].

As each approach has relevant aspects that partially explain consumption motivations, we shall discuss some points that have been raised for each of these approaches.

According to the psychosocial approach, human rationality is constrained by certain cognitive characteristics and patterns, as well as the social context in which it is placed [10]. There are aspects relevant to the environmental theme in this approach, such as:

- It has been described that the human psychosocial tendency is to believe that by performing one pro-environmental action previously, one is "authorized" to commit actions that cause environmental damage [11].
- There is also a propensity to reduce rational use measures when natural resources are or become more abundant, as in Israel, where demand control restrictions were relaxed owing to the scale of desalination use [12]. This could also indicate suppressed demand.
- Psychosocial factors are also mentioned as one of the causes of the rebound effect that occurs when a product's efficiency improves, resulting in increased demand, canceling out the benefit gained. For example, it has been reported that increased car energy efficiency leads to increased car use, which results in increased congestion and greenhouse gas emissions [13].
- Hardin [14] described the "tragedy of the commons" in this context, which states that individual demand for finite resources leads to depletion of the resource. Corral-Verdugo et al. [15] developed a model based on questionnaires to measure the influence of the "tragedy of the commons" on the motivation for water conservation, identifying a trend of individual increases in consumption when individuals perceived that others wasted water.
- Steg [16] asserted that the personal values of individuals are the primary motivators of pro-environmental actions and that strategies that access and instigate these values through, for example, laws and regulations or technological instruments (such as a green light that turns on when consumption is low), or even feedback comparing consumption with that of neighbors, are the most effective.
- Ajzen and Cote [17] sought a method to assess attitudes, which are defined as the proclivity to evaluate a psychological object favorably or unfavorably and to relate these attitudes to the individual's manifest behavior. He also cites the theory of planned behavior, which describes human behavior as being determined by three major factors: how the behavior is assessed (attitude toward the behavior), perception of social pressure on behavior (subjective norm), and the ability to perform the behavior (perceived behavioral control).

Another approach is rational economics, which proposes that personal choices are based on the rational calculation of the costs and benefits of a given action, as well as decision-making that maximizes its net benefit; therefore, access to information is critical for decisions. However, this approach has been criticized for neglecting issues such as the non-linear way in which costs and benefits change over time, and people do not always behave in a way that maximizes the cost–benefit ratio [10]. This approach is also considered an individualistic approach [9].

Diekmann and Preisendörfer [18] empirically confirmed within the rational economics and psychosocial approaches that when there are very high costs (financial or otherwise) to carrying out a certain pro-environmental behavior, and the importance given to the environmental issue tends to decrease; this does not happen when the cost is low.

In the context of water consumption, the tariff could be said to be an important factor in determining reductions or increases in consumption; however, given the essential nature of water, the question of its cost is part of a broader discussion. Furthermore, according to Steg [16], strategies that include financial incentives for pro-environmental behavior can make individuals with more selfish values believe they have purchased the right to spend more.

Stancu et al. [19] discussed the motivations that drive pro-environmental behavior in the food and clothing industries. He noted that what often drives pro-environmental behavior is not necessarily an environmental concern or cost concern but personal issues such as health promotion, the pursuit of the best taste in food, or personal affirmation by purchasing unique pieces from a thrift store in terms of clothing.

The systemic and infrastructure approach uses the dynamics of technological and infrastructure factors to explain individual environmental behavior. This is a structuralist approach in which individual factors are minimized [9]. One example of this approach would be to believe that installing new energy-saving devices would necessarily result in a reduction in consumption. However, studies conducted in Australia [20,21] proved otherwise. Devices were installed in showers so that when users reached a certain water volume limit in the bath, an alarm sounded. The annoyance generated by the alarm caused a reduction in water consumption at the beginning, but after four months, users had apparently become used to the sound, and the reduction achieved was lost. This result indicates that psychosocial factors should also be considered relevant factors.

2.1. The Social Practices Approach

The social practices approach, according to Mylan [22] and Liu et al. [9], is the most comprehensive approach to understanding consumption in general today. This approach, which includes both individual actions and structural aspects, uses daily practices or activities as measurement units. According to Watson [23], any sociotechnical transition must first occur in practice, and it is thus critical to understand how the dynamics of the formation and transformation of these practices influence consumption. The main criticisms of the social practices approach are that it appears difficult to account for change and that it has limited scope (local actions) [23].

The concept underlying the theory of practices or the social practices approach was first addressed by philosophers Ludwig Wittgenstein and Martin Heidegger [24]. One of the fundamental ideas of this theory, which was later adopted by Giddens, was that there would be a comparison between social rules and mathematics, in the sense of being a generalizable process [25].

Practices emerge from the interaction of three variables in the social practices approach: (a) meanings: ideas and aspirations that lead to that practice; (b) materials: structural and technological configurations that influence practice; and (c) competencies: user skills and expertise related to practice. As the links between these variables are formed and broken, practices emerge, persist, and disappear [24].

By analyzing the emergence and disappearance of practices, the elements that remain unchanged, and the obsolescence of other elements, we can discern how we arrived at certain behaviors and indications of how to change them, such as those that are less impactful from an environmental standpoint. As a result, the desired changes in society will not be found solely by educating people about the consequences of their actions or by promoting tariff incentives in favor of a specific action; they require understanding how structures of rules, meanings, and related infrastructure shape human activities and how these are reproduced in the flow of human action. As a result, individual practices can intervene at a collective level [24].

While the previous models considered important aspects but did not consider their interaction, the difference of the social practices approach is that it allows us to connect individual decisions with the necessary infrastructure for the activity, also connecting with Hardwig's [5] idea that it is necessary to know how to handle a resource to really possess it.

2.2. Conceptual Model of the Rationalization of Consumption

The conceptual model of the rationalization of consumption was developed in 2007 and has since been validated through practical application and several discussions in projects carried out at the research group of the Cleaner Technology Network of Bahia (Teclim-BA) of the Federal University of Bahia (UFBA) over a 15-year period [26,27].

Kiperstok and Kiperstok's [28] methodological conceptualization of the composition of water and energy consumption in buildings connects the elements of all approaches cited in the prior section. This model is called the conceptual model of the rationalization of consumption. Water consumption was described as follows: (a) control, (b) effective consumption, (c) waste, (d) leaks and losses in installations, and (e) environmental quality of the construction. Effective consumption can be classified as either necessary (when it meets physiological needs) or desired (beyond physiological needs, e.g., recreation). We recommend that, one more segment be added to model: (f) materials related directly or indirectly for use. It was inspired by the social practices approach and related to the term materials, which could be hygiene products or electricity that directly or indirectly intervene in water consumption.

Segment (a) is concerned with factors that influence water consumption. Tariffs, user perception (awareness and consciousness), and measurement all contribute to it in the original model. The user perception segment is concerned with the user's ability to control their own consumption through awareness. The measurement segment is concerned with its potential as a consumption control factor, because knowing one's own consumption allows one to quickly identify patterns of unusual consumption and take steps to correct them. The maintenance segment of the control focuses on the practice of system maintenance (preventive, predictive, and corrective maintenance), a practice that is complementary to the practice of water consumption. These three parts can also be interpreted as competencies, one of the parameters of the social practices approach model, because they are directly related to actions to be taken by users who require the competencies of being environmentally aware, such as reading and monitoring their consumption, and taking action to prevent and remedy leaks. The tariff, which is also a consumption-controlling factor, fits better into the meaning realm of the social practices approach model, because saving money on the water bill can be a motivator for lower consumption.

In the context of perception as a motivation for rational water use, Rahim et al. [29] observed that people are more likely to carry out conservation measures when they receive personalized feedback on their consumption. The experience of AGUAPURA, a water conservation program at the Federal University of Bahia and other public buildings, yields the same conclusion [26,27]. Similarly, Liu et al. [30] noted that providing detailed water consumption feedback to society is effective and can promote conservation at the individual and residential levels.

Meaning can also be used to frame the concepts of effective consumption (b) and waste (c). Effective consumption can be classified as either necessary (meeting physiological needs to maintain health conditions) or desired (when it meets needs beyond physiological needs, such as consumption for recreational purposes).

The installation loss portion (d) refers to the poor conservation conditions of the building's installations, which can result in, for example, water losses that are considered waste. The environmental quality of the building (e) is related to the good condition of the installations, which, in this case, has adequate maintenance and can also rely on solutions to improve resource use efficiency, such rainwater catchment systems, and water reuse. The new portion recommended of materials related directly or indirectly to use (f) is listed as both input materials used during use (for example, the type of soap used in washing clothes) and materials that influence use indirectly (for example, use dark floor colors to reduce cleaning frequency). The items d, e, and f can be classified as materials that are also present in the social practices approach.

Equation (1) represents the proposed relationship in this model; consumption is the sum of the effective consumption (b), waste (c), and installation loss (d). All three are functions of the control (a), the building's environmental quality (e), and the materials (f). The variables in the functions add a more specific aspect, so it would be ideal to create this equation customized for each family.

$$consumption = b(a, e, f) + c(a, e, f) + d(a, e, f) \tag{1}$$

This model, like the social practices approach, accepts the combined influence of human control and infrastructure. The difference here is that it introduces the concept of classifying an activity into what is essential, superfluous, and wasteful use; this encourages the assessment of the activity's quality and real need. Furthermore, this model incorporates critical elements such as measurement, tariffs (with elements of the rational economic model), and attention to facility quality. This model also has the advantage of being designed specifically for water and energy consumption, whereas the social practices approach is generic.

The models used to explain water consumption in the case studies adopted are those with a more holistic approach: the social practices approach and the conceptual model of rationalization of consumption. These models do not rule out the possibility of incorporating psychosocial, economic, rational, or structural considerations.

3. Comparison of Water Consumption Studies

A comparison of measured consumption and other relevant works, with the qualification of the consumption as a result, requires that they apply similar methodologies, so that the comparison does not lose its value due to contextual disparities. When comparing numerical residential water flow characteristics such as flow rate, average, duration, and volume consumed, it is important to consider factors such as climatic, cultural, architectural, and income ranges, as well as building facility characteristics. Personal and family habits are other relevant aspects of the comparison, but they might be very subjective.

For example, if a resident has a habit of using high flows, his/her consumption flow rate range will be high, but this does not always imply waste. It is possible for residents to use equipment quickly, thereby avoiding volume loss. Consequently, evaluating only the flow rate is not the best metric for assessing the quality of water use. Similarly, in terms of duration, long uses may indicate waste; however, if the flow rate is low, it is natural that the time invested in the activity is greater. Analogously, high volumes consumed for an activity may appear wasteful, but these volumes may meet the individual's basic needs and thus are not necessarily wasteful. As a result, when comparing the obtained values with references to evaluate water consumption, it is necessary to consider the entire context.

Even with all these caveats, comparisons are still important from a macro perspective to identify certain limits, identify disparities or similarities, and enable a critical evaluation of consumption. Furthermore, seeking reference values has practical applications, as in engineering projects where average values are established to reference the dimensioning of supply networks. However, it is important to consider whether a given interval can truly be considered a reference for drawing conclusions about the performance of a particular use and, as a result, lead decision-making.

For the two instances in this work, comparisons were made with earlier studies. First, studies that proposed a universal value of the minimum consumption for basic human needs were compared [31,32]. This comparison allowed us to assess the orders of magnitude of the values obtained in the current study and the previous studies, determining whether the values adopted in different realities would also make sense in this study.

Second, a comparison was made with works that only sought to characterize water consumption in the study areas, with no intention of establishing a consumption pattern [33–36]. This analysis shows differences in consumption between high-income and low-income locations, as well as locations with diametrically opposed weather patterns.

4. Residential End Use Case Study Information

4.1. Research Context

The dataset for our study was provided by the Cleaner Technology Network of Bahia (Teclim-BA) of the Federal University of Bahia (UFBA) as part of the network project "Rational Use of Water and Energy Efficiency in Housing of Social Interest" in which seven other Brazilian federal institutions of higher education participated. The study of UFBA was performed in the suburbs of Salvador, the capital of Bahia State, with the location highlighted in Figure 1.

Figure 1. Geographical location of the study area; adapted from google maps.

4.1.1. Salvador's Characterization

According to the 2010 census (the 2020 census was delayed due to the COVID-19 pandemic) from the database of the Brazilian Institute of Geography and Statistics (IBGE) [7] and projections for 2021, Salvador has an estimated population of 2,900,319, making it Brazil's fourth most populous city. The population growth rate is 0.73 percent (based on a mean between 2010 IBGE [7] and projections for 2021). The municipality has a total area of 693,453 km^2 (IBGE), resulting in a high population density of 4182.4 inhabitants per km^2. Approximately 20% of the population of the state of Bahia lives in Salvador.

According to IBGE [7], the percentage of the population that lives with less than two minimum wages and has declared a source of income is 45%. This number increases to 82% when we factor in people who declare they have no source of income.

High housing demand and steep land prices in urbanized areas have historically resulted in disorderly urban growth, with low-income residents occupying inappropriate areas such as hillsides and valleys. This disorderly occupation created several challenges, including a lack of adequate sanitation, particularly sewage treatment, which resulted in the degradation of most local water bodies. Environmental degradation and social exclusion are widespread issues in large Brazilian cities [37]. However, water pollution is not simply a local issue; according to OECD [38], 75% of the cities surveyed (including OECD and emerging countries) face water pollution as a challenge.

With twelve watersheds, nine natural drainage basins, underground water, and a high pluviometry index, Salvador, a coastal region with a tropical humid climate, has a significant amount of fresh water sources [37]. Despite this, the capital is supplied primarily (about 60%) by the Pedra do Cavalo dam on the Paraguaçu River, which is located approximately 120 km from Salvador and necessitates significant investments in infrastructure and electricity for transportation. This is consistent with the historical supply management policy but harms the demand management measures aimed at optimizing resource use.

Genz and Tanajura [39] analyzed the climate scenario GEE A1B based on a simulation model of Eta/CPTEC [40]. The annual precipitation for the period 1961–1990 was

1871 mm/year, and scenarios indicate that rainfall may reduce to approximately 1100 mm/year by 2040. The average annual temperature in the city, according to climatic norms, is 25.3 °C. The forecast for the late 2040 is an increase of 1.5 °C. Such changes impact resource availability and quality of life. Demand management measures are required to retard these effects.

The global understanding of urban rivers is changing; they are now valued as amenity-rich places for people-centric activities, rather than just a resource and a location for transporting and disposing effluents [41]. In contrast to the global trend, Salvador's administrators continue to cover the most degraded rivers (river canalization). River canalization also aims to solve drainage issues.

Another challenge is the issue of water loss, which is more severe in developing countries [42,43]. According to the 2019 National Sanitation Information System (SNIS) [44], Salvador reported 56.1% water distribution losses. There are few details about the losses before distribution or within the buildings, but they are also expected to be significant. In public buildings, where work was also done by Teclim, actions such as rapid detection of water loss events, preventive and corrective maintenance, and daily consumption monitoring were able to reduce the UFBA's consumption from 50 L/pessoa/day to 18 L/pessoa/day [45].

Given that residential water consumption accounts for most of the demand in urban areas, the purpose of this study is to aid demand management measures by expanding the knowledge of residential consumption.

4.1.2. Study Area Information

A low-income area was chosen for the study because this segment of the population constitutes a large segment of the population of Salvador. In addition, this population deserves special attention in terms of sanitation because it has historically been neglected by service providers.

In addition to being a low-income population, the study population was classified as living in a social interest residence. Social interest housing in Brazil is intended to serve people with monthly family incomes of up to three minimum wages. Investigating ways to reduce water consumption in homes of social interest can provide useful information for the future construction of this type of housing.

The Plataforma neighborhood was chosen because previous studies had already been carried out by the team in this location, which would enable the comparison of findings and facilitate the team's entry into the area. Furthermore, it was agreed among network-project researchers that localities inhabited for more than five years would be investigated, because after that time, it is assumed that behaviors and consumption patterns would have already been consolidated. There were 278 housing units in the housing complex.

The first stage of the research involved conducting a survey to investigate the family and residence characteristics. The survey questionnaire was developed in collaboration with network project members and included questions about (1) the interviewee's and family's profile, (2) housing characteristics, (3) water consumption, (4) energy consumption, and (5) interests. A survey was conducted with a sample of 111 households. The sample size was calculated using the appropriate equation for finite populations (Equation (2)).

$$n = \frac{z^2.p(1-p)N}{\varepsilon^2(N-1)+z^2.p(1-p)} \quad (2)$$

In Equation (2), represents the value of the standard normal distribution corresponding to the confidence level, represents the proportion of the main study characteristics, represents the total number of elements in the population, and represents the admitted margin of error for the results. Considering an 80 percent confidence level, a sampling error of 0.05, and p equal to 0.5, indicated by the lack of previous references, a sample of 107 households was reached; however, 111 families were interviewed in the field work, increasing the safety margin of the information obtained and allowing better generalization of the results to the population.

The questionnaires were administered personally by researchers and scientific initiation scholarship students, but they also had the support of five local residents, as indicated by the residents' association. The assistance of these residents was critical for the full progress of field activities because they already knew the location and other residents of the housing complex, allowing the technical team to access the homes.

The main results of the survey show that 80% of the families had minimum wages of up to 538 USD, 60% had no schooling or incomplete elementary schooling, and more than 70% had more than two years of debt related to water and sewage services. In this questionnaire, the participants were asked if they would be interested in participating in the second stage of the research, which consisted of longitudinal water consumption monitoring. Seven families agreed to have their consumption monitored.

4.2. Materials and Methods

4.2.1. Monitoring and Data Processing System

The water consumption of seven households was tracked for an average of 321 days, ranging from 230 to 412 days, during the pre-pandemic period. Water was distributed by gravity in all houses, which had upper reservoirs, and intelligent meters and optoelectronic data loggers were installed (after the reservoir) to store flow data to assess the total and sectorial water consumption of the houses. The brand and some characteristics of the installed equipment are listed in Table 1. Every 10 s, the data logger recorded the data emitted by the hydrometer.

Table 1. Smart meter and datalogger information per household.

Household	Hydrometer Brand	Factor	Nominal Flow of Hydrometer	Datalogger Brand and Model Datalogger Model
A, B, C e E	LAO®	K = 0.1 L/pulse	1.5 m^3/h	NOVUS®—FieldLogger
D, F, e G	LAO®	K = 0.1 L/pulse	1.5 m^3/h	NOVUS®—LogBox-DA-64k IP65

The generic K factor indicates that one pulse is emitted for every 100 mL of fluid. The ® symbol indicates that is a registered brand.

Trace Wizard® software was used to classify consumption events among residential hydraulic devices.

To recognize the end uses with Trace Wizard®, the following information had to be generated beforehand: a list of existing hydraulic equipment, peak flows, durations, volumes used, typical flows (mode), and minimum and maximum flows.

To gather this data, YF-S201 type flow sensors were installed in each house's fixture for approximately a week; this period was labeled the investigative week. The time, duration, and volume of each usage event were recorded using these sensors. The data from these sensors were compared to the data from the main monitoring system, allowing the identification of the usage patterns of each fixture for each family.

The need to connect it to the household's electrical system and the inconvenience to the residents limits the use of this type of measurement over long periods.

Table 2 summarizes important information from the overall monitoring process.

Table 2. Overall monitoring information.

House	Number of Inhabitants	Number of Fixtures	Number of Monitored Days	Number of Days in Investigative Week	Overdue Water Bills	Water Meter Situation
A	2	4	328	8	Yes	N
B	2	5	412	9	Yes	R
C	6	9	244	5	No	I
D	2	7	230	8	No	I
E	2	5	316	9	No	N
F	3	4	355	14	No	N
G	2	6	257	11	No	I

N, no water meter; R, regular meter situation; I, irregular meter situation.

The Trace Wizard® software was used to classify consumption events among residential hydraulic devices. This commercial software is a well-known and widely used research tool capable of dividing flow data into smaller time series that represent end uses. The decision tree is used to perform event classification; it computes the similarity between an unknown event and the listed equipment based on manually predefined parameters for each piece of equipment in the house (the process is described in Cominola et al. [46]). As previously stated, these values were gathered during the investigative week.

The characteristics of an unknown time series are compared to the parameters of predefined devices, and if there is compatibility, the time series is labeled by the corresponding fixture. This process is based on a list of devices in a given order, with the first device that matches being selected. This software's information can be found at https://aquacraft.com/ (accessed on 5 November 2021). As with any algorithm, it is unlikely to achieve a 100 percent trustworthy classification if different devices exhibit similar behaviors.

This software is heavily reliant on human interaction for input addition and manual validation for all outputs.

In this case, validation was performed using the data from the investigative week. There were two types of measurements at the time: a sensor per device and a hydrometer with a datalogger after the reservoir. The sensor indicated when the device was activated, making it easier to locate the corresponding time series in the flow data. The flow data (as measured by the hydrometer) were entered into the software, and the results were compared with the sensor's indication. In addition to the time check, the event features were compared with predefined parameters to assess behavior coherence. These two elements were used to validate the software. The trained team reviewed the results for the entire monitored period.

The work of Oliveira-Esquerre [47], who used the same database as the current work, characterized consumption from attributes distribution curves that, despite divergences between the curves with information from the flow sensor and information from the main monitoring system, most of the results show similarities in the characteristics of the different equipment. Nonetheless, despite some distortion, most outcomes could be trusted.

4.2.2. Semi-Structured Interviews

Semi-structured interviews were conducted with residents in four of the seven monitored homes to learn about their consumption habits. The interview was prepared and conducted by sociologist and master's student Kelly Fontoura (now PhD), with help from a student, the social assistance scholarship holder Mayara Castelano, both of whom were members of the project network team. During the interviews, the speech was recorded consensually (and later compiled faithfully to the audio), and the questions were asked with care to avoid inducing the interviewer's bias. Qualitative analyses of the speech were conducted, and the processes of washing clothes, cleaning, washing dishes, and bathing were detailed in these interviews. A script of questions to guide the interviews was created;

however, other questions could arise depending on the context of the conversation with the resident. On average, there were 16 questions, with Questions 1–5 focusing on the process of washing clothes, 6–7 on cleaning, 8–11 on washing dishes, 12–15 on bathing, and 16 on the toilet.

Because women are still primarily responsible for domestic services in Brazil, as observed in the residences studied, the homemaker was chosen to respond to the questionnaire. Speech analysis was intended to frame the ideas examined using the social practices approach and methodology concepts of Kiperstok and Kiperstok [28]. The effects of installation losses on each residence's consumption were also assessed.

The interviews were conducted in four residences (A, C, D, and E), which were part of a housing complex with two-story housing units measuring 21.37 m^2 on the lower floor and 21.80 m^2 on the upper floor. Figure 2 illustrates the appearance of the houses. The houses originally had five water consumption points (showers, kitchen faucets, bathroom faucets, external faucets, and toilets), but two of them (Houses C and D) had been renovated, increasing the number of consumption points. One more bathroom (bathroom faucet, toilet, and shower) and a kitchen sink were added to House C, and another bathroom was built in House D (bathroom faucet, toilet, and shower). Laundry faucets or external faucets were in a shared outdoor area; ceramic flooring was used in Houses C, D, and E, and rustic cement flooring in House A.

Figure 2. Illustration of the type of houses in the studied housing complex.

Figure 3 presents relevant information about the four residencies studied in interviews.

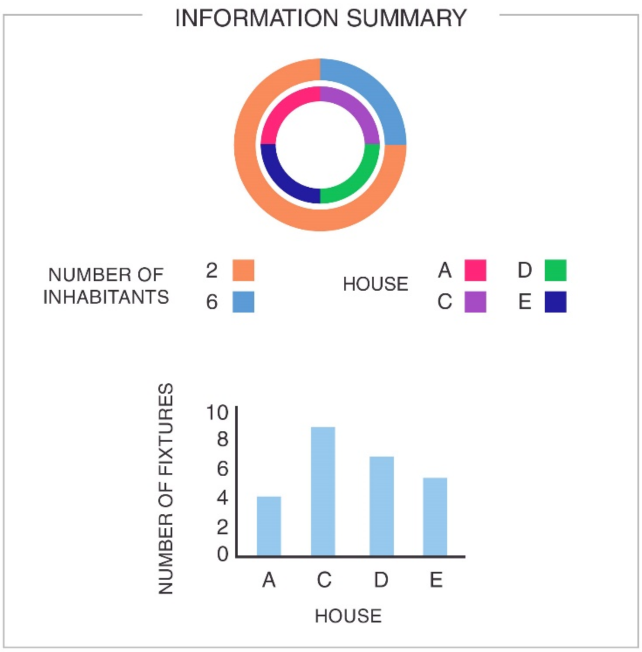

Figure 3. Information summary of the interviewed residences.

4.2.3. Procedure of the Pilot Study Analyses

The conceptual model of rationalization of consumption and the social approaches model were used to conduct qualitative analyses of the four households of the pilot study. Quantitative analyses were also performed for all seven monitored homes.

The qualitative analyses of the interviews aimed to understand the daily activities (of laundry, washing dishes, cleaning, and bathing) of the households and the evolution of these practices. This was studied from the perspective of the three pillars of the approach to social practices and the concepts of the rationalization of consumption model, as follows:

- The meaning of each activity, with the goal of understanding what constitutes a need, desire, or waste.
- Material used directly and indirectly in these activities.
- Competencies indirectly discovered through an examination of user habits and the evolution of practices.

Potential variables were chosen for each daily practice evaluated to build models that can predict consumption. Customized measures to promote rational consumption were proposed.

Quantitative analyses were performed to support the qualitative observations; additionally, these results were contextualized with other values in the literature.

5. Results

The results start with the qualitative analysis section using the models mentioned. Each one delves deeper into specific aspects of consumption, allowing for the assessment of intervention points in favor of the most appropriate consumption. As mentioned, the data came from interviews in four houses; they aid in identifying daily activities and how residents carry them out.

The quantitative data, which included the activities mentioned above, were then also analyzed to identify the devices with the greatest impact on water consumption, as well as the distribution of this consumption by end uses. Seven houses were investigated in this study. The data used in the analysis were obtained during the entire monitoring period. The final section aimed to compare the consumption values of houses and other works cited. However, due to the contextual differences between this work and those in the literature, the analyses were carried out with extreme caution.

5.1. Qualitative Analysis: Evaluation of Interviews under the Models

5.1.1. Interview Analysis Based on the Conceptual Model of Rationalization of Consumption

Laundry Practices

The laundry process begins with the perception of clothes as dirty, which varies from family to family. In some households, clothes are considered dirty if used only once; in others, clothes are used multiple times before they are washed.

The classification of clothes as "dirty" may be related to the method of washing and frequency of use. For families whose clothes are not too dirty, the manual washing method, for example, can influence the family to use the clothes more times before laundry to reduce work or save money on the water bill. In families where the clothes are dirtier, owing to work or personal characteristics (e.g., sweating), using clothes more than once can make the washing service even heavier, so families can choose to use the clothes only once, even when washing by hand; this held for House A. In the case of the mechanized washing method, if clothes do not get dirty easily, the same items of clothing can be used more than once to save water and energy, as in House D.

If more clothes are washed due to the greater or lesser ease of the washing method, or even the desire to save on the water and energy bill, this can be best considered desired effective consumption, as it does not meet a physiological need, but rather a desire to make work easier or save money. Furthermore, when washing frequency is motivated by a physiological demand, such as when clothes are washed more frequently due to personal characteristics such as excessive sweating, consumption can be defined as necessary effective because it is associated with hygiene and health. Otherwise, when motivated by a social convention, consumption can be defined as desired effective, limiting the possibility of suggestions for reducing consumption.

The next step in the laundry process is the accumulation of laundry and sorting by type. As shown in Figure 4, the process of accumulating clothes was performed in all homes. These clothes are separated into bed and bath linen and white and colored clothes, varying by family and reflecting the risk of staining or damaging the garments. Washing frequency varies from 0.5 times a week to twice a week. According to observations, the volume of clothes in each family (directly related to their size and purchasing power) and climate are the factors that influence clothing accumulation. When the weather is rainy, there is a greater accumulation of clothes, and when it is hotter and sweating increases, the clothes become dirtier faster (this applies to clothing, bed linen, and bath towels), requiring washing earlier.

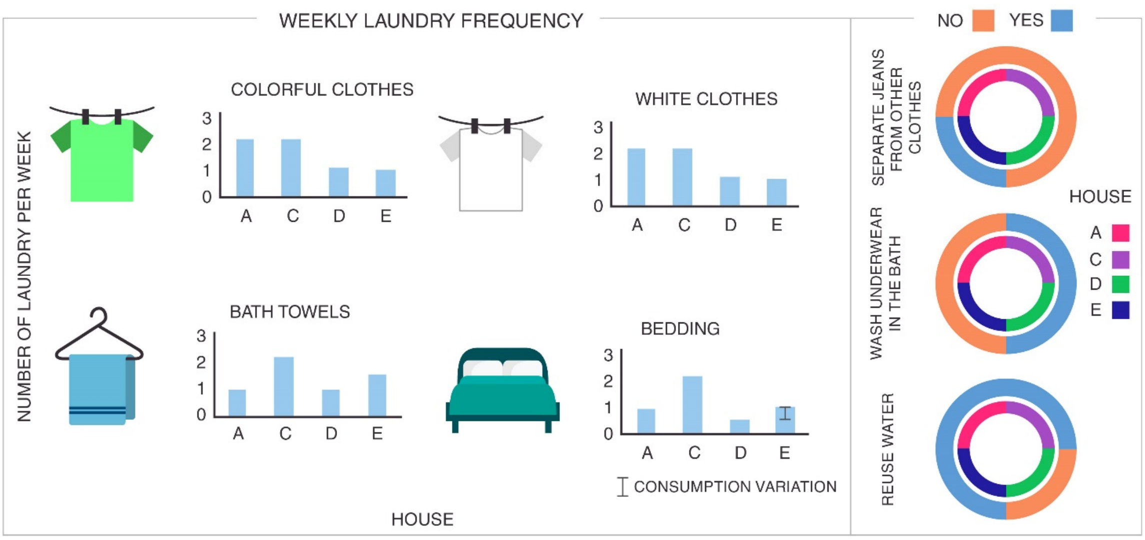

Figure 4. Laundry habits during the week.

If the washing method is mechanized, the process of accumulating clothes is also important, because most equipment has lower efficiency when operating at low loads, because the volume of water is the same but the number of clothes is lower. Separating clothes by color or type, on the other hand, responds to a desire to better conserve them, and thus becomes part of the desired consumption.

Figure 4 shows that House C had the highest overall frequency of washing clothes, most likely owing to having the most inhabitants (6). House D had the lowest washing frequency because residents had the habit of wearing clothes more than once before washing; it was also the only house with a washing machine.

The use of the shower to wash underwear during a bath was reported in Houses C and D; this was not a habit in Houses A and E. Washing underwear while bathing increases bath time, and because the shower is a high-flow device, this action can result in higher consumption than if the underwear was washed with a faucet. From the resident's perspective, this activity can be regarded as desired consumption because it optimizes time; however, depending on the dispersion of the shower jet and the manner in which the resident performs the action, this can be regarded as waste. House A washed all clothes, including underwear, in the shower, rather than in the bath. They used the shower in this manner because they did not have a washing machine or a semi-automatic device to wash clothes and did not use an external (community) faucet. Washing was performed in buckets. This prevents water loss, considering the water dispersion in the shower. However, it was discovered that this process was not ergonomic, which could lead to higher water costs. The uncomfortable position made it difficult to open and close the device. A suggestion for improvement would be to use a support to raise the bucket/basin level.

House A, the only house that washed clothes by hand, described the washing process, which begins with white clothes, where the bucket is filled with water, soap, and bleach. The clothes were soaked for a while, then rinsed, and in the case of white clothes, placed back into the soap. The colored clothes were soaked in the soap from the second cycle of white clothes and rinsed; no soap was added again. After soaking, the denim garments were brushed to remove excess dirt and then rinsed.

Based on the data from the investigation week, it was discovered that the volume used for manual washing in House A was approximately 66 L/wash, with much of this water being reused for other purposes. The volume per use in House D (which has a washing machine) is approximately 100 L/wash. Based on the frequency of use declared by the residents, the volume per wash, and the number of residents, it was determined that House A consumes 9.5 L/person/day and House D 10.8 L/person/day; the close values for these residences are approximately twice the minimum recommended value for this activity (5 L/person/day), as per Inocencio et al. [32]. This result also indicates that there is little difference in the volume used when washing clothes manually or in the washing machine by house, which may indicate that the predominant consumption for washing clothes in these houses is necessary consumption. During the investigative week, no use of an external faucet (used to fill the semi-automatic machine) was recorded in Houses C and E, but during the longer monitoring period, it was discovered that the use of the external faucet in House E was 12.4 L/person/day; there was no record for House C.

In general, the following suggestions were developed to make better use of water:

- House A: The external faucet in this house was shared, and it was defective during the measurement period. If the shower was used because of the defect, an alternative would be to repair the faucet; if the shower was used because the resident was uncomfortable sharing it with the neighbor, an alternative would be to install a faucet in the shower box at a height appropriate for the resident's habit of washing clothes and filling buckets.
- Houses C and D: Residents' care to reduce excess water consumption, such as turning off the shower while soaping and the use of a shower model with low dispersion, can improve the activity of washing underwear in the shower.

- House D: The final water discharged from the washing machine could be used for other purposes, such as toilet flushing and cleaning the outside area.

Cleaning the House

The reuse of water from other processes, such as using the water discharge from washing clothes as input to cleaning activities, presents an opportunity for rational consumption. In addition to reuse, rational consumption can be derived from residents' concern for keeping the environment clean, thereby avoiding high recurrence of the activity.

Although it is not a common practice in Brazil, taking off one's shoes before entering the house can reduce the need for cleaning; thus, the extra water needed to clean because of this issue can be considered a waste. Cleaning the house to attend to hygiene issues, on the other hand, can be considered a necessary effective consumption, and attending social conventions can be considered a desired effective consumption.

The main questions about this topic in the interview were about the frequency of cleaning and the type of cleaning, and some houses described the process in detail. Every household reported cleaning the bathroom with soap and water at least once every 15 days. Owing to the type of floor in House A (rustic cement), the house was swept in terms of cleaning. In House C, the cleaning process consisted of cleaning the surfaces, sweeping, and using a damp cloth; occasionally, water was poured on the floor of the house. The difference in House D is that it was not customary to throw water on the floor of the house.

Figure 5 depicts the frequency of house cleaning over the course of a week, as well as the different types of cleaning that are commonly performed in homes (mopping and washing the bathroom). The highest frequency of washing the bathroom was in House A, where the resident reused water from washing clothes to clean the bathroom. House C (with six residents) was cleaned once per week. Houses D and E, both with two residents each, had very different cleaning schedules. House D was cleaned every 15 days, whereas House E was cleaned with a floor cloth daily in the bathroom and twice a week in the rest of the house, and the bathroom was washed weekly. Despite having fewer residents than House C, residents in House E required more cleaning, but they reused water from other processes, resulting in more efficient consumption.

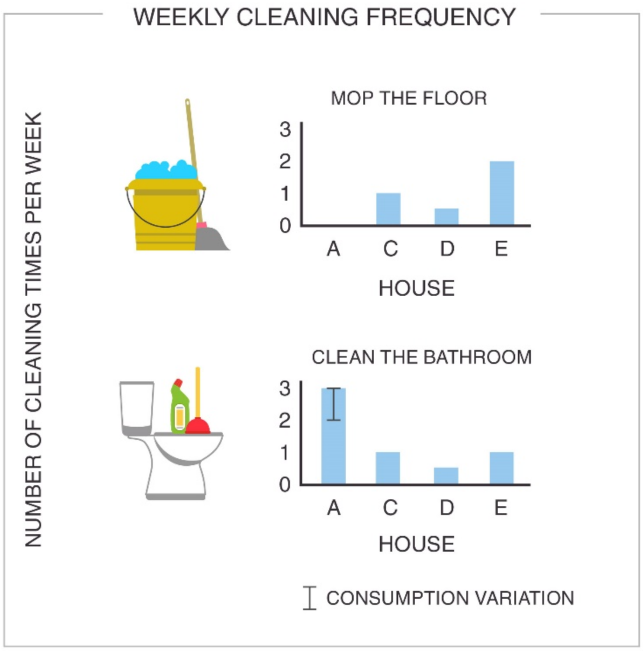

Figure 5. Systematization of house cleaning habits.

The cleaning process begins with the perception that the house is dirty; this perception may be related to the color and type of floor covering used (for example, lighter floors allow the perception of dirt to arise more quickly). Furthermore, the greater the number of people in the house, the greater the possibility of dirtying it, as increased circulation of people entails intensified dirt production. The dust from the public road was not too intense and could be ignored in this case as an intervening factor. All the houses were on paved streets, and there was not much traffic in the area.

In this case, the main rational practice suggested would be maintaining the house's cleanliness and adopting the custom of using specific footwear indoors, for example. In addition, residents continued to reuse water from laundry to clean the house.

Washing Dishes

The number of dirty dishes during meal preparation and after the meal, as well as the washing process, can reflect necessary/desired consumption and waste. Houses where food is cooked daily, which occurred in every interviewed home, use more water than houses where food is cooked weekly and stored in the refrigerator. On the other hand, daily cooking satisfies the desire to eat food prepared on the day, and thus is desired consumption. It is also difficult to recommend changes because it reflects the customs of the families.

The main questions in this topic were whether there was a habit of stacking dishes and turning off the faucet while soaping. Only House E described the entire dishwashing process, which began with the use of detergent and a sponge to soap the dishes. After this step, the dishes were placed in the sink when rinsing, and the resident reported that she sometimes closed the sink drain, allowing the water from the rinsing process to accumulate, which was used to remove excess soap from dishes placed inside the sink.

Figure 6 depicts some of the habits of the families interviewed. Only the family in House C accumulated dishes; the families in Houses C and D did not turn off the faucet when soaping, and in House D, it was turned off at least occasionally.

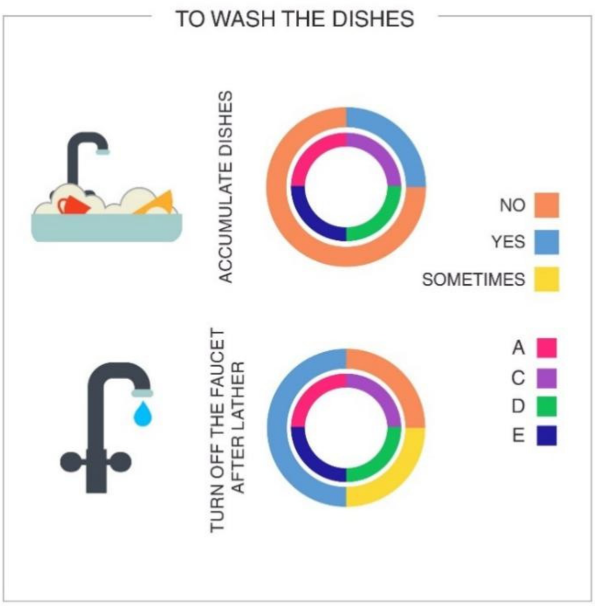

Figure 6. Systematization of household washing dishes habits.

The accumulation of dishes during the washing process can be an interesting measure to avoid higher water consumption. When it happens and while washing the items one by one, the water flowing into the sink helps to rinse other items inside the sink, making the process more efficient. However, if there is a desire to keep the sink clean, the highest consumption required is classified as the desired consumption.

Turning off the faucet while soaping the dishes is also a good practice. It is wasteful not to turn off the faucet because it does not fulfill a need or desire.

The amount of water consumed in the activity of washing dishes and cooking was calculated during the investigative week by averaging all kitchen sink uses added up on each monitored day (Figure 7). Because of the presence of the trigger sensor installed by the equipment, these values were calculated based on this period. As this device was not used for the longest period of time, it was not possible to separate the use of equipment with similar flow rates and durations, such as a kitchen sink and a washbasin.

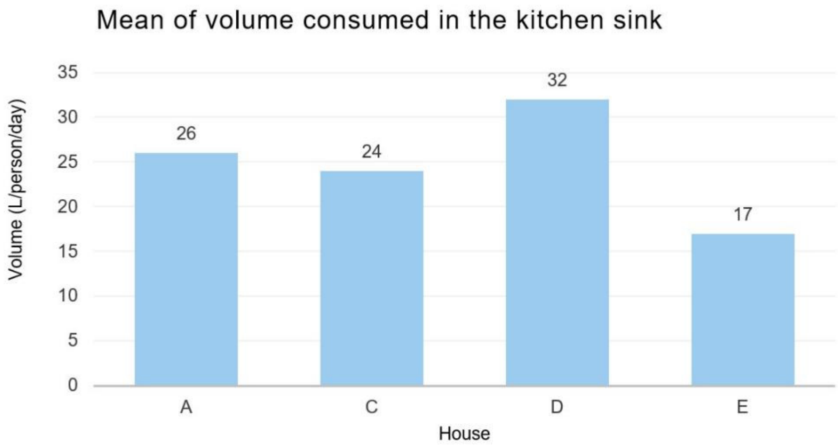

Figure 7. Water consumption for washing dishes during the investigative week.

Value analysis reveals that the houses with the highest consumption are A, C, and D, and this higher consumption was already anticipated in Houses C and D due to waste revealed in the interviews. The volume consumed in House E is very close to the [31] value of 15 L/person/day for the minimum volumes required to maintain health conditions, referring to the use of washing dishes, cooking, and drinking, indicating that the predominant consumption for this use is necessary.

The motivation for rational use in these houses included encouraging the closing of the faucet while the water was not needed, which Houses C and D did not do. Another recommendation for all households would be to always remove excess dirt from dishes before washing them, preferably with a washable bush. Another suggestion would be to accumulate the dishes and wash them a few times a day, placing them inside the sink with the drain closed, so that the sink is filled with rinsing water from the first washed dishes, and as the next dishes are washed, they meet the accumulated water, facilitating the washing process.

Bathing

A greater number of baths may be considered necessary or desired consumption depending on the reason: necessary when used solely for hygiene and desired if it serves other purposes such as relaxation.

Figure 8 shows the average number of showers per day for the person who completed the interview, as well as whether this person has the habit of closing the shower valve when soaping. Electric showers may lead to longer baths because they are more comfortable or shorter baths to avoid higher electricity costs, a relevant factor given the income range of the families studied. The fact that most of the houses interviewed did not have an electric shower may have contributed to the reduction in consumption. The only one with an electric shower was House D.

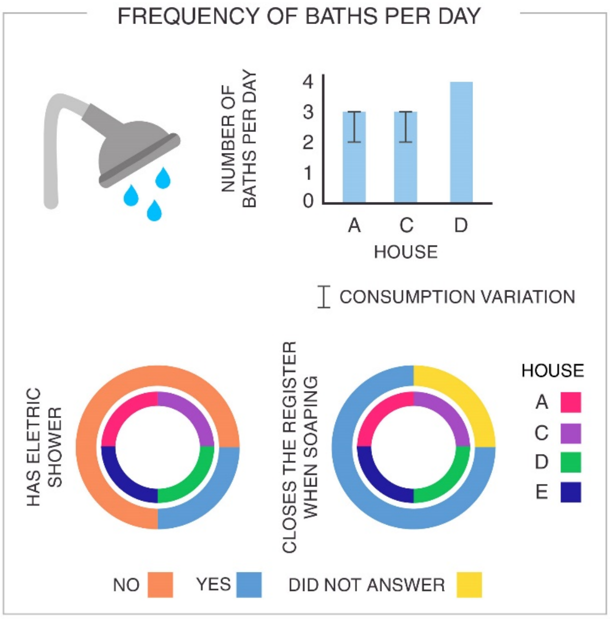

Figure 8. Systematization of bathing habits in homes.

The median volume of the bath in House A was 22.9 L/person/day (includes the amount of laundry); in House C, it was 9.1 L/person/day; in House D, it was 35.5 L/person/day; and in House E, it was 3.4 L/person/day, according to data from the investigative week.

The right side of Figure 9 shows which houses used the greatest volume of water per trigger; in this case, House D consumed the most, Houses C and E had similar medians, and House A consumed the least. By connecting the graphs on the right and left, it is possible to infer which houses used this equipment the most on a daily basis by comparing those that had similar volume per activation behavior. House C, for example, had a significantly higher daily consumption than House E, suggesting that the former triggered this device more frequently than the latter. This makes sense given that House C had six inhabitants. The lower value of House C's median per capita consumption is justified by the larger number of residents. Residents of House E appeared to have bathed only for hygiene and did not use this equipment for any other purpose.

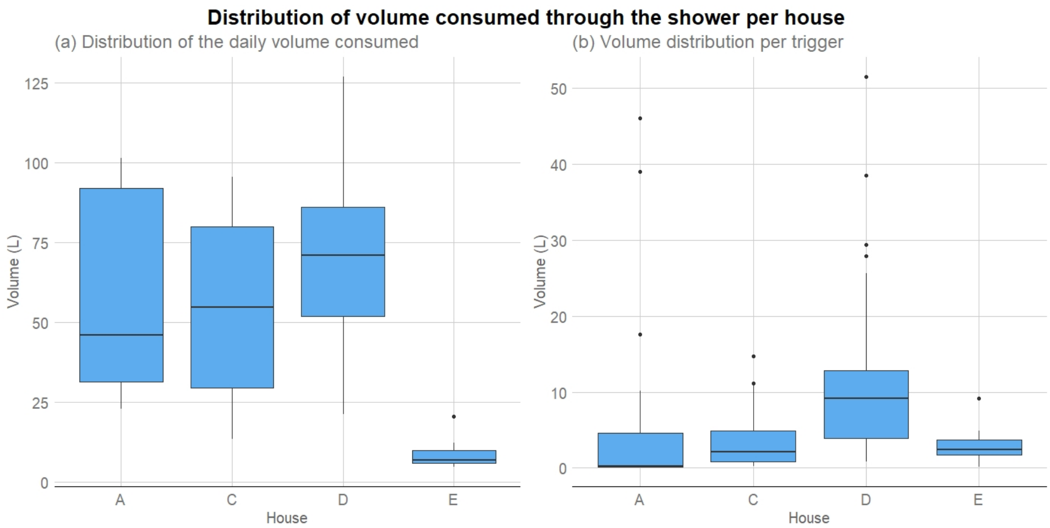

Figure 9. Distribution of volume consumed per house. The boxplot on the left side represents the daily distribution of consumed volume; the boxplot on the right side represents the distribution of consumed volume by trigger.

According to a survey by Gleick [31], the minimum recommended consumption for a bathroom is 15 L/person/day, with a range of 5 L/person/day to 70 L/person/day. Except for House E, where the value was slightly lower, all the values encountered were within this range. House C had one of the lowest per capita volumes; this lower consumption may be related to the number of people in this house (6), which has only two bathrooms, so there may be queues for the shower, resulting in shorter bath durations.

In terms of rational use, this device should be used exclusively for bathing. As mentioned previously, washing clothes in a device with high water dispersion leads to waste. If bathing is a relaxing activity (which seems to be the case in House D), residents should try to find other activities with the same purpose with a lower environmental impact.

Leaks

Proper building installation maintenance is a determining factor that enables the rational use of water. Periodic maintenance, carried out in a systematic manner, prevents leaks and allows the resident to regulate the flow rates to ideal levels, avoiding waste. In Brazil, the culture of building maintenance is still reactive, with problems resolved through corrective maintenance performed after the occurrence of malfunction or damage to the installation.

In all houses, the leaks or losses in the installation were mostly characterized by low volumes. The highest leakage frequencies were found primarily in Houses C and A. There was a leak in the shower valve in House A and in the toilet flush in House C, which reached large volumes; both were discovered and repaired during the search. House D, which has the highest per capita consumption (median 195 L/person/day) and has fewer leaks than Houses C and A. House E had no leaks and had the lowest per capita consumption (median 44 L/person/day). Figures 10–12 depict the distribution of leaks among the research houses.

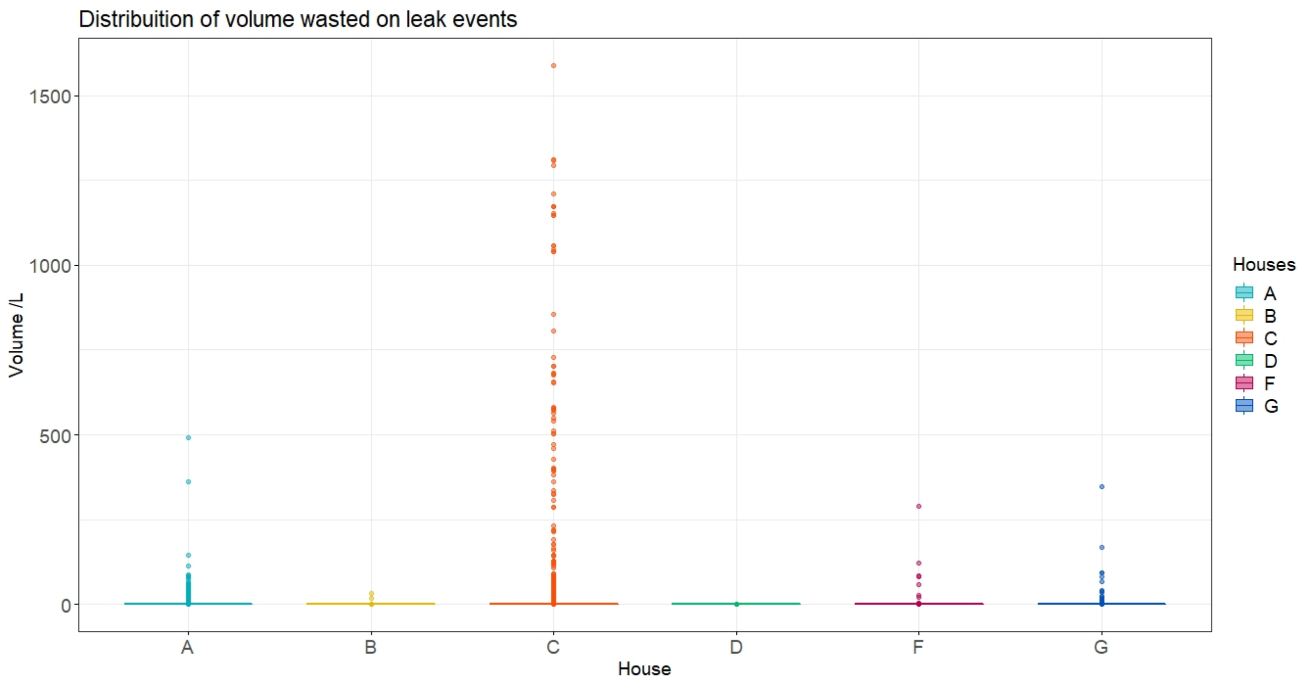

Figure 10. Boxplot of leak events volume by house.

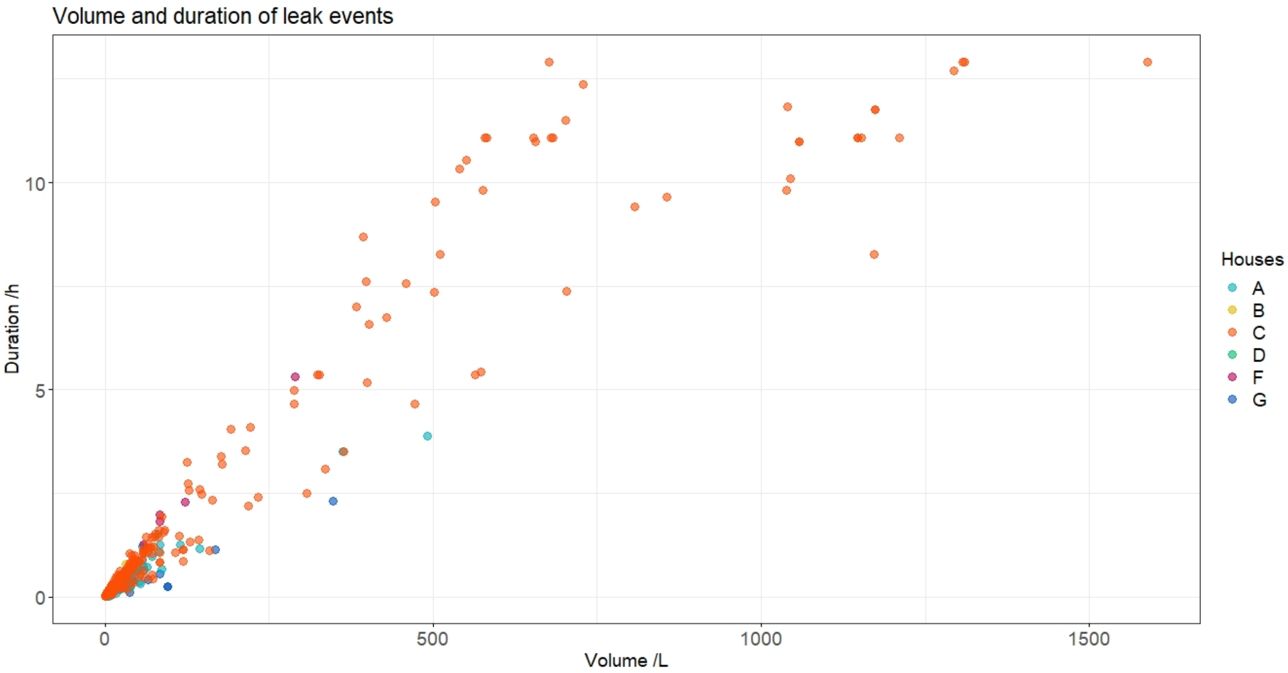

Figure 11. Scatter plot of leak events volume and duration.

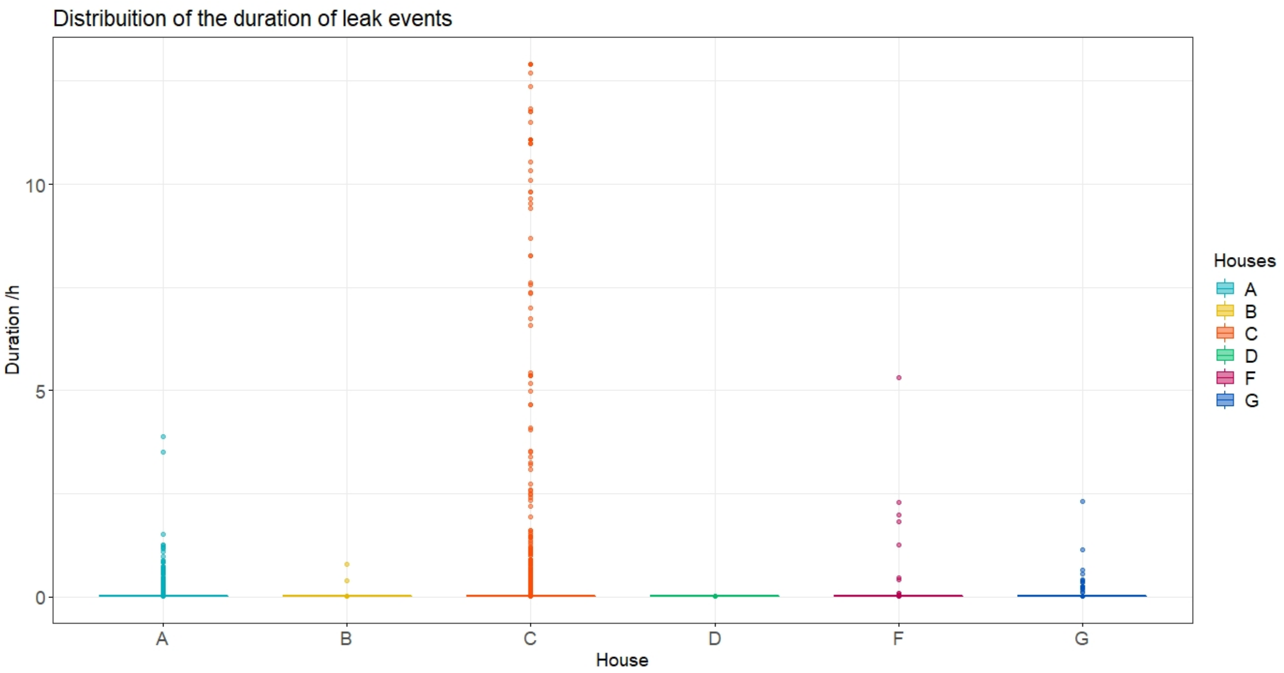

Figure 12. Boxplot of leak events duration by house.

The leaks or losses in the installation were mostly characterized by low volumes and durations in all houses, as shown in the boxplot graphs of duration and volume in Figures 10 and 12 and the scatter plot in Figure 11. The outliers in Figures 10 and 12 represent exceptional larger uses.

A suggestion for these residences would be for the residents to learn basic hydraulic skills to perform most of these maintenance activities, rather than relying on contracted services that are expensive, especially for low-income families. It is crucial to create a maintenance plan at set intervals (e.g., every six months) to perform preventive maintenance on every hydraulic installation in the house. This education can be provided by a water concessionaire.

The concessionaire is responsible for maintaining the facilities until it arrives at the residence. Within the residence, responsibility lies with the owner/tenant/real estate. In this way, the concessionaire could invest in a project to instruct the population to identify problems in their homes, which would consequently reduce losses.

Another suggestion, based on the work of Silva et al. [26], is that the user read his water meter daily and thus become familiar with his/her consumption pattern; thus, when consumption deviates from this pattern, the user quickly realizes that there is something wrong, such as a leak that could be repaired rapidly.

In "intelligent systems" [48], the process of obtaining information about anomalous water uses and performing maintenance would be even more streamlined. Intelligent systems are systems that perform autonomously from access to input data to generate output information. Information about water consumption, for example, would be transmitted almost in real time using these systems, greatly accelerating the process of repairing leaks.

5.1.2. Interview Results Considering the Social Practices Approach Conceptual Model

Figure 13 shows the evolution of the practice of cleaning and washing clothes and dishes in countries such as Brazil over time. These progressions are the result of changes in the level of skills required, materials used, and meaning to sustain the practice, all of which are elements of the social practices approach. The transformation trends in these three pillars of consumption must be observed to affect changes in the direction of rational consumption.

Figure 13 shows that the introduction of new "materials" was the main trend of evolution in these practices; this happened through the use of machines and devices that mechanized and automated the tasks. The goal of incorporating these new materials is to reduce physical effort and create the satisfaction of buying new home products.

In the context of the residences interviewed, it was observed that, in general, practices remained traditional, with no significant changes in terms of mechanization and automation. This is due to families' low purchasing power. However, there was complete automation in House D, which had a washing machine, and partial automation in Houses C and E, which had semi-automatic machines.

It has been observed that in the practice of cleaning, the use of water, which was previously high, tends to decrease with mechanization/automation and the use of cleaning equipment such as vacuum cleaners and mops. In terms of washing clothes, the number of functions and options for washing has increased with the most modern washing machines, which means that there are more ways to wash, such as separating by color, fabric, and temperature to be washed, resulting in an increase in the number of washes. Furthermore, even though the washing machine wastes a significant amount of water that can easily be collected and reused for other purposes, the water from the washing machine is generally not reused, but rather automatically directed to the sewage network, without directly involving the user's decision about what to do with this effluent. Thus, it appears that machine use influences the proclivity for reuse, which occurs more frequently when washing clothes by hand or with semi-automatic devices.

The habit of reusing washing water was prevalent in Houses A, C, and E, where the method of washing clothes was manual (A) or mechanized with a semi-automatic device (C and E). The water used to wash white clothes was reused to wash colored clothes, and the water remaining at the end of the process was used to clean the bathroom in House A. The water from the semi-automatic device, which was not automatically discharged into the sewer, was reused to flush the toilet in House C, and to clean the backyard, stairs, floor, and occasionally the toilet in House E.

Social Practices Approach *Elements*		Items	TASKS: CLEAN HOUSE → T	M	A	WASH CLOTHES → T	M	A	WASH DISHES → T	A
Competence	Physical efforts	To scrub	x			x			x	
		To rinse	x	x		x	x		x	
		To wring	x			x	x			
		To hang				x	x	x[0]		
		Remove food scraps							x	x
		To sweep /mop	x	x						
		Collect garbage	x							
		To soak				x				
		Put to dry				x	x		x	
	Intellectual efforts	Choose when do act	x	x	x	x	x	x	x	x
		Choose methods of action	x	x	x	x	x	x	x	x
		Choose quantities and types of inputs	x	x	x	x	x	x	x	x
		Choose what to do with the outputs	x	x	x	x	x	x[1]	x	x[1]
		Time and space management	x	x	x	x	x	x	x	x
Material (Inputs needed for the tasks)		Water	x	x	x	x	x	x	x	x
		Electrical energy		x	x		x	x		x
		Water and sewage installations	x	x		x	x	x	x	x
		Electric power installations		x	x		x	x		x
		Soap	x[2]	x[2]		x[3]	x[3]	x[3]	x[3]	x
		Disinfectant (chlorine or others)	x[4]	x[4]	x[4]	x[4]	x[4]	x[4]		
		Fabric conditioner				x[5]	x	x		
		Other cleaning materials	x[6]	x[6]	x	x	x	x	x	x[6]
		Clothesline and preachers				x	x	x[0]		
		Wire to dry dishes							x	
		Buckets	x	x		x				
		Baskets				x				
		Broom	x							
		Squeegee	x							
		Floor fabric	x							
		Dustpan	x							
		Dustbin								
		Vacuum Cleaner		x	x					
		Mop		x						
		Semi-automatic washing machine					x			
		Clothes washer						x		
		Dishwasher								x
Meaning		Health maintenance	x	x	x	x	x	x	x	x
		Social and individual conventions	x	x	x	x	x	x	x	x
		Buy free time			x			x		x
		Pleasure to buy new products		x	x		x	x		x

Figure 13. Evolution of the practice of cleaning and washing clothes and dishes over time from the point of view of the social practices approach method (skills, materials, and meanings influencing social practice). T—traditional, M—mechanization, and A—automation; the direction of the arrow corresponds to the direction of the evolution of practices. ([0] The most modern washing machines are also dryers, eliminating the need for hanging clothes and for clotheslines and clothespins, saving time. [1] Gray water is the effluent from washing machines and dishwashers, and it is typically directed instantly to household sewage without the need for human intervention, which does not occur in traditional and semi-automatic methods. [2] Soap is not always used in this case, because cleaning does not always consist of washing; it can only be done with a fabric dampened with a specific cleaning product. [3] For washing clothes and dishes, soap or traditional dishwashing detergent is not obligatory; people who are allergic to soap or are concerned about their environmental impact have been replacing this in washing clothes with products such as alcohol vinegar and sodium bicarbonate. Traditional dishwashing detergents can also be substituted with phosphor-free versions. [4] Chlorine-based products are the most used in homes for disinfection in house cleaning and laundry, but they can also be replaced by less aggressive products such as vinegar. [5] Fabric conditioner is not always used, particularly when clothes are washed by hand. [6] Other cleaning materials such as various types of perfumed disinfectants are used and mainly meet social or personal conventions of smell; there are also other specific products such as dishwashing dryer liquid that are not mandatory items but cater to social conventions such as brightness of dishes).

This demonstrates that these residents discovered useful ways of reusing water. The inconvenience of having to decide what to do with water makes users think and choose a more rational use of water in most cases. However, the automatic method does not support it directly. This kind of inconvenient situation can be used to encourage habit changes toward rational use.

Therefore, one alternative when washing clothes would be to encourage the inclusion of a reservoir for reuse water coming from the washing machine; the person could collect water through a water outlet hose. In addition, the reuse of this water would also be encouraged through educational campaigns. There are already washing machines on the market that have a water reuse function; one of them has a feature that, when activated, reminds the user via an audible reminder to position a container to collect the discarded water. Finding a location for the reservoir and knowing about the campaign could be enough motivation to cause the reflection reuse of water.

The most significant change in bath practice over time in the context of the social practices approach is the introduction of electric showers, which increased bathing comfort and, as a result, a proclivity for longer bathing times and higher water consumption. Electric showers, on the other hand, are an exception in low-income families, and even when they are available, bathing time is restricted to avoid high water and electricity bills. There has also been an increase in the variety of bath consumables available, such as different types of soaps, hair care products, and other personal cleaning products, which can lead to longer bathing times and higher water consumption.

To reduce bath consumption, shower models with a mechanism for activating water through the foot could be subsidized so that it is less expensive, and this activation device could be a little uncomfortable, for example, offering some resistance when pressed. As a result, an inconvenience that would lead to reflection would be present, which could lead to shorter showers, and the ease of simply taking your foot off when you wanted to turn off the faucet could encourage closing the device during intervals of use.

The impact of changes in habits can be quite significant; for example, studies have shown an increase in water consumption as a result of habit changes caused by the pandemic (due to extra hygiene measures such as hand washing, bathing, and cleaning of surfaces and an increase in time spent at home) [49,50].

The changes in consumption patterns observed prior to the pandemic were primarily due to the introduction of new technology made to simplify household tasks. The change observed following the pandemic was due to a significant shift in the meaning of water use, with health becoming a bigger concern. Thus, it can be concluded that a desirable shift in consumption habits would require a renewed understanding of the importance of conservation measures and the consequences of negligence. Additionally, the devices used in water consumption should be modified to achieve greater efficiency, from the most technologically advanced and complex (e.g., washing machines) to the most basic (e.g., the type of soap used or the material of the clothes).

5.1.3. Final Considerations

The rationalization model is useful for determining the importance of activities because it associates them with issues of physiological need, personal desire, and waste. It is especially important in low-income areas to look for ways to ensure that this population has a minimum amount of water as a right. The social practices approach model, by focusing on daily activities, encourages reflection and ideas toward the rational use of water, which is important even for socially vulnerable populations. Reflecting on these aspects can encourage conscious consumption by users. In the future, quantifying each of these portions can support the development of a "conscious" tariff system, focusing more heavily on the desired uses and waste, and subsidies of necessary consumption.

These suggestions aim to improve ergonomics, personal habits, and equipment used. This study found that when consumption is motivated by desire, it is more difficult to commit to behavioral changes. Waste occurred as a result of a lack of attention to the quality of the activity (leaving the faucet open even when not in use) and was also motivated by better time management (washing underwear while bathing). Waste-motivated consumption must be addressed through education and awareness.

5.1.4. Customized Measures to Promote Rational Water Consumption

The pilot study results, and literature analyses allowed us to identify certain key points where minor changes in habits could lead to reductions in consumption. The barriers to implementing the habits listed below are issues of social convention (meaning) and the need for residents to be environmentally conscious (competence). They are:

- Use clothes more times before washing;
- Do not wear worn shoes indoors;
- Do not use soapy water to clean the floor, but rather a damp cloth;
- Cook in larger quantities and store food in the refrigerator or freezer;
- Accumulate dishes to be washed all at once, reusing the washing water to “soften” the dirt on others.

Other identified habits listed below face obstacles to implementation due to the need for residents to be environmentally conscious (competence).

- Fill the washing machine to its maximum load;
- Avoid washing underwear in the shower;
- Reuse laundry water;
- Choose floors that are a little darker to avoid the quick perception of dirt;
- Turn off the taps at intervals of use;
- Remove excess dirt from dishes before washing;
- Prefer cold baths (applicable to places like Salvador, which has high temperatures most of the year);
- Use the shower only for hygiene; although, a longer bath can sometimes be a rational choice, for example, to satisfy a desire for relaxation. Individuals may have other relaxation options, and depending on the options, the longer bath may be the most environmentally friendly option.
- Provide preventative maintenance;
- Avoid activities that use water in non-ergonomic positions;
- Check the water meter periodically (preferably daily) [26];
- Check if the water pressure is too high or too low [51];
- Watering plants in the early morning and late evening [51]; despite the fact that gardens are uncommon in low-income neighborhoods.
- Check for any open water pipe before leaving the house [51].

Other observed habits, as listed below, face implementation challenges due to the need for residents to make financial investments (meaning) and the need for residents to be environmentally conscious (competence).

- Using collected rainwater to external uses [51] or other uses inside the home;
- Using reuse water for less prestigious uses (e.g., flushing the toilet);
- Invest in more efficient hydraulic devices.

Habits that involve changes in family customs and attending to social conventions are more difficult to implement and require a stronger meaning than those conventions and customs. Those that rely solely on their ability to be environmentally conscious can be cultivated through educational campaigns and higher waste disposal charges. Those that rely on financial investments are the most complex for low-income populations, and these types of measures should be subsidized for this group.

5.2. Quantitative Analysis: General Consumption of Studied Residences

Consumption measurements are important for determining the amount of water used in a concrete manner. Thus, the analysis begins with the volume consumed per capita per household through a boxplot (Figure 14).

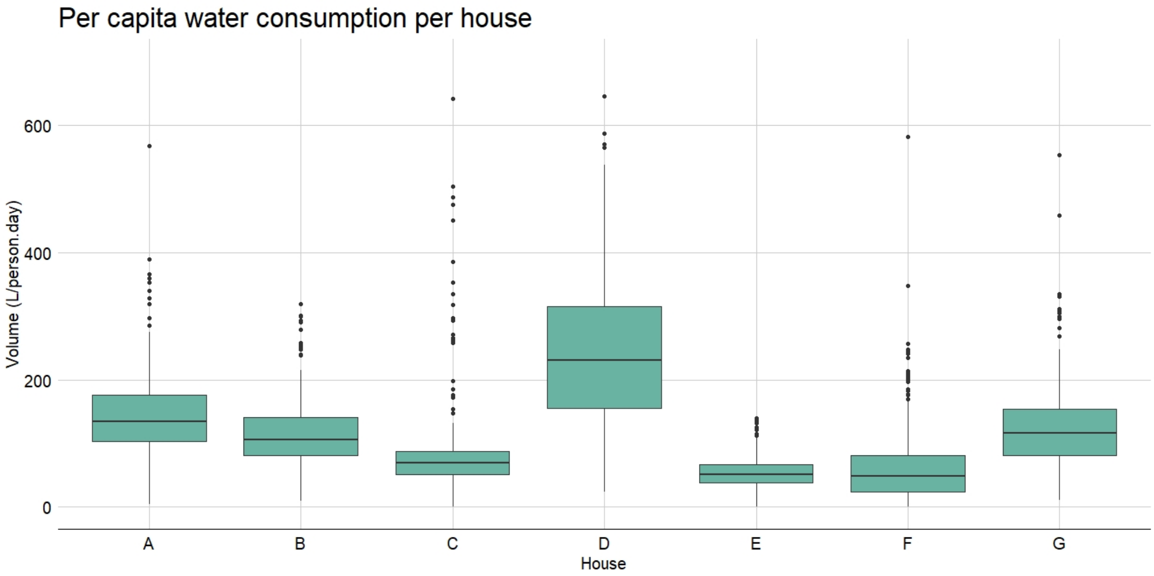

Figure 14. Distribution of the consumed volume per capita.

This demonstrates that the interquartile range for all ranges is between 30 and 350 L/person/day. Houses C and E had a narrow interquartile range, indicating almost constant behavior during this period, whereas House D had a wide interquartile range, indicating large consumption variations. House D had the highest median consumption (~231 L/person/day), and the third quartile of all the other houses were near or below the first quartile of this house, showing that the residents had a high consumption behavior (in comparison), and that it may be prone to waste or losses. Houses E and F had the lowest median and nearly the same values (~50 L/person/day). Figure 15 depicts a summary of the main information gleaned from the interviews; using this information, it is possible to identify reasons for the high values in House D. They did not reuse water or accumulate dishes and left the faucet open while cleaning the dishes. They cooked daily and had the highest average water consumption in the bath. House E, on the other hand, had similar aspects to House D, differing in the reuse of water, cooking frequency, and low volume consumption for the bath, among other factors that could not be evaluated.

Summary of the main characteristics related to the water consumption of the studied houses

House	Number of residents	Laundry						Cleaning		Dishwashing			Bath	Irregularities	
		Washing method	Washing frequency (weekly)	Accumulation	Shower/underwear	Consumption in liters per inhab. (External faucet)	Water reuse for other activities	Mop floor frequency	Bathroom washing frequency	Accumulation of dishes	Closing the faucet at intervals during cleaning	Cooking (every day)	Average volume (L/person.day)	By-pass connections	Overdue bills
A	2	manual	6	Yes	No	9.5	Yes	-	3	No	Yes	Yes	28.8	No	Yes
C	6	semi automatic	8	Yes	Yes	-	Yes	1	1	Yes	No	Yes	9.1	No	No
D	2	automatic	3.5	Yes	Yes	10.8	No	0.5	0.5	No	No	Yes	35.7	Yes	No
E	2	semi automatic	4.5	Yes	No	12.4	Yes	2	1	No	Sometimes	Yes	4.5	No	No

Figure 15. Summary of information on consumption habits by household by activity.

Some families in this income range frequently struggle to pay for the water they use. Households may delay their payment of bills, as illustrated in Figure 15 (House A). Subterfuges, such as diverting the water connection or altering the meter (interrupting the functioning of the meter pointers), are used in other houses to consume more without paying for the respective volume (Houses D and G). As shown in Figure 16, House D, which performs the water diversion, has the highest consumption. Despite the diversion, consumption in House G was similar to that in other houses.

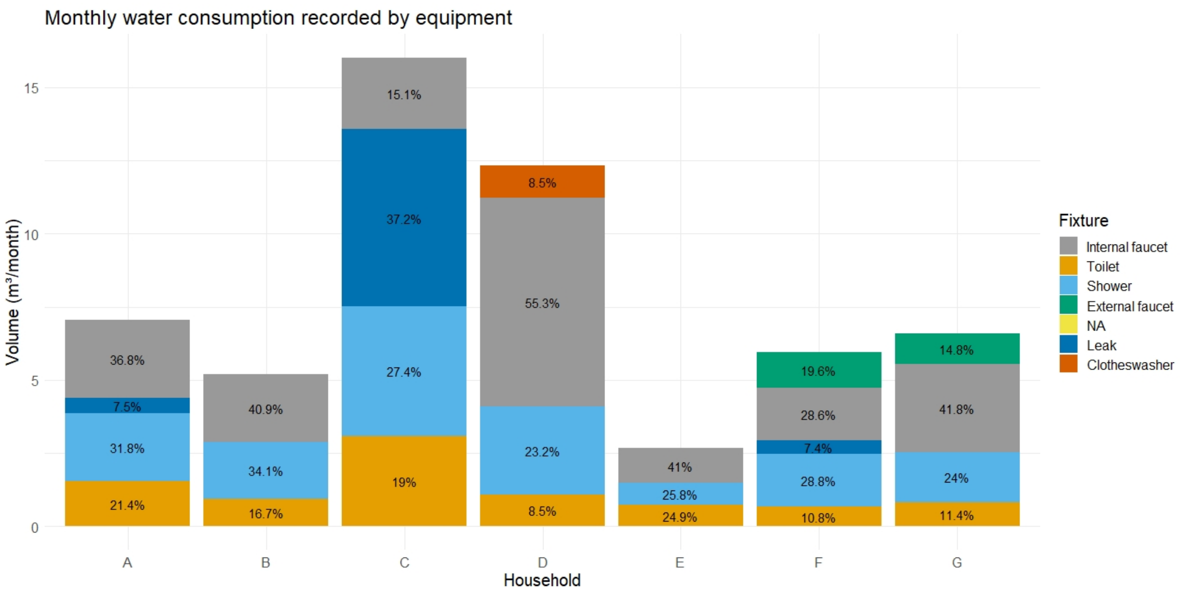

Figure 16. Total consumption of the period per house, including the percentage related to activated devices.

Figure 16 presents the total consumption per month and the volume percentage of each hydraulic device activated. In addition, Figure 17 shows the total activations in the period and the percentage for each hydraulic device activated. In both images, fixtures with percentages below 5% were omitted to improve the data visualization.

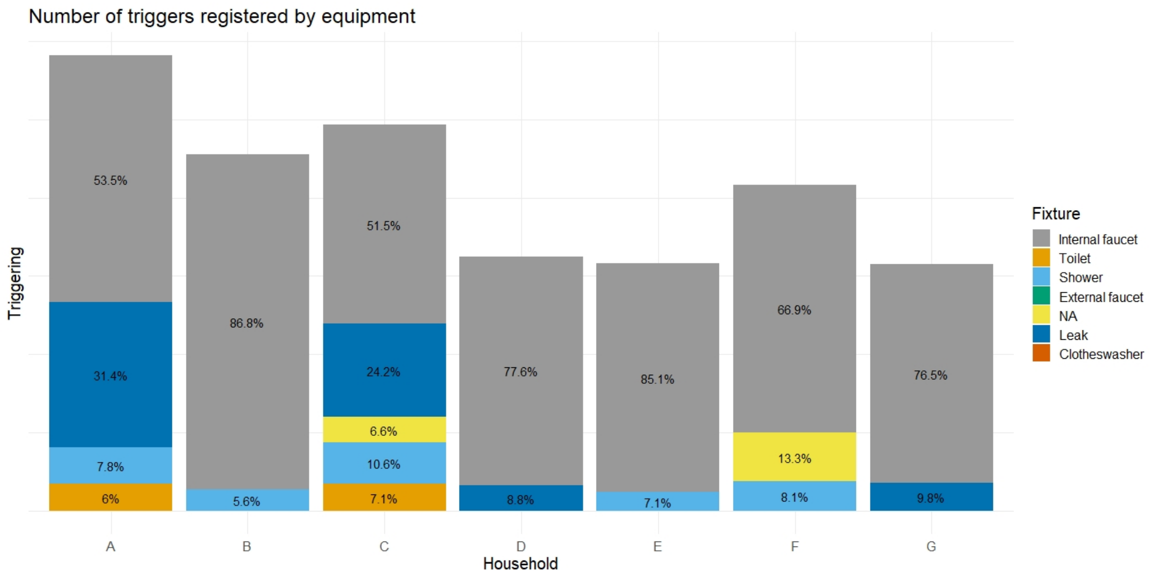

Figure 17. Total number of activations in the period per house, including the percentage related to activated devices.

Because of the various purposes to which they apply, it appears that internal faucets are the appliances with the highest participation in consumption (both activation and volume) in most homes. As a result, it is critical to focus on the rational use measures analysis. The shower is the second most used device, closely followed by the toilet. Although toilets and showers are not the most frequently activated devices in daily use, with a percentage of total activations ranging from 4% to 15% (Figure 17), the volume of water consumed can correspond to up to 40% (Figure 16) of the total consumed per month in the period. Thus, even though the number of these activations appears to indicate that such equipment has no effect on total consumption, when the associated volume is examined, these require attention.

For example, the toilet is a hydraulic device that, to achieve optimal consumption values, must combine an economic model with conscientious use. This is because replacing the device with a water-saving model without informing and involving residents in its proper usage will not contribute to reduced consumption.

Based on the data in Figures 16 and 17, it is clear in which areas there is a need to explore alternative forms of conscious consumption. However, numerical data do not distinguish which daily activities are associated with each activation, necessitating a better understanding of household dynamics to identify opportunities for action.

5.3. Comparison of Consumption with Reported Values

When characterizing water consumption in a specific area, many studies tend to use the average value to define consumption patterns [33,34,52]. However, in the same studies, high values of standard deviation (approximately 60% of the mean value) were found even in areas with homogeneous characteristics (in terms of income, type of construction, and climate). This high variability highlights the dynamic nature of household water use.

Other studies used average values to define the minimum consumption required to meet basic human needs. Gleick [31], Inocencio et al. [32], and WHO [52] determined that the average minimum consumptions are 50, 54, and 70 L/person/day, respectively. However, because of influencing factors such as distance from the water source, local climate, age of inhabitants, technology used in water use devices, number of consumption points in the house, and multiple uses of the same equipment, among others, the minimum value can vary.

Furthermore, there is no agreement on which uses are considered essential. Cooking, drinking, bathing, laundry, washing the hands and face, brushing teeth, washing dishes, flushing the toilet, and cleaning the toilet were all considered basic consumption by Inocencio et al. [32]. Gleick [31] did not include laundry, washing the hands and face, brushing teeth, or cleaning toilets as basic uses, whereas WHO [52] included subsistence planting.

Thus, because of the numerous nuances of human behavior and the fact that each action interferes with the consumption of indoor water, the consumption pattern should be unique for each family, as what is considered essential consumption in one family may not be a necessity in another. With advancements in computational science and water consumption measurement systems, a future trend will be the adoption of personalized demand management recommendations for each family based on their specific needs [48,53].

As previously stated, comparing water consumption in a case study to values in the literature is not recommended because of the numerous dimensions involved and the high variability found even in places with similar characteristics. Table 3 supplements Figures 18–22 by providing information on each evaluated location.

Table 3. A summary of key household information from other studies.

Reference	[33]	[34]	[36]	[35]
Local	South East Queensland (SEQ) Australia	12 study sites across the United States and Canada	Florianópolis (SC)—Brazil	North region of Portugal
Sample size	252 residences	1188 residences	48 residences	52 dwellings
Description	High income	High income	Low income	High income

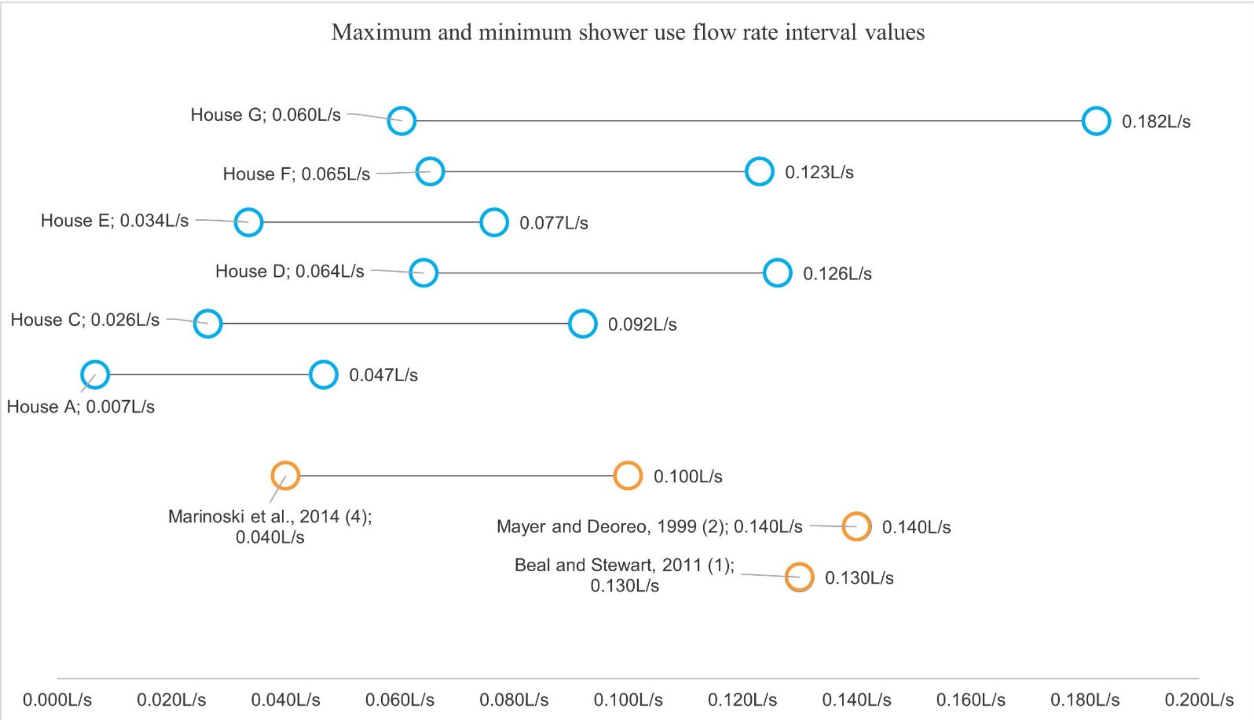

Figure 18. Comparison of flow rates for the use of showers between Houses A–G and the literature, (1) [33], (2) [34] and (4) [36].

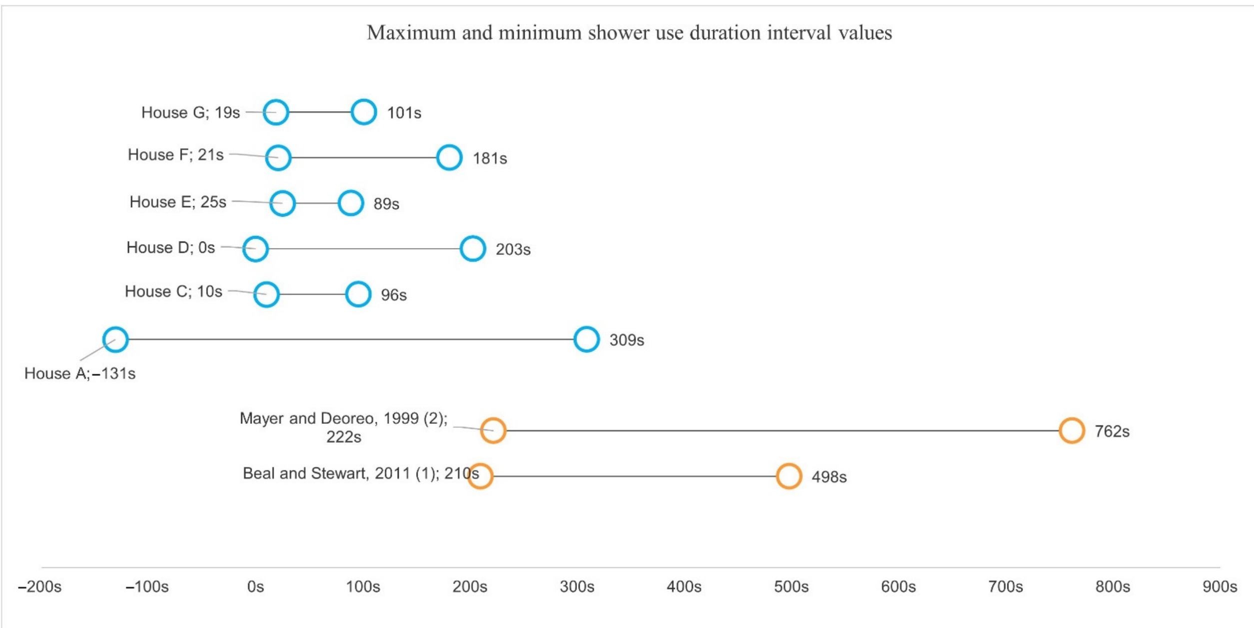

Figure 19. Durations per activation of showers in Houses A–G and the literature, (1) [33], (2) [34]. The negative value in House A occurs because in that house the data did not follow a normal distribution and the deviation values were very high.

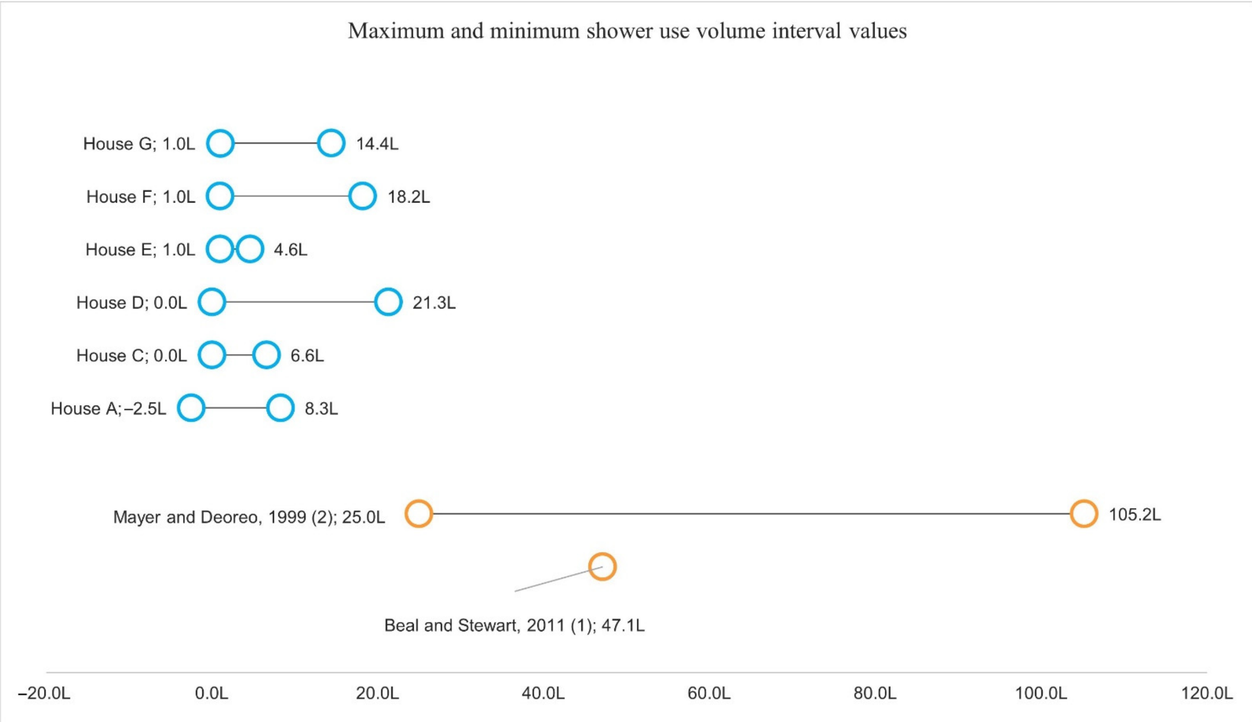

Figure 20. Comparison of the volume consumed by shower use between Houses A–G and the literature, (1) [33], (2) [34].

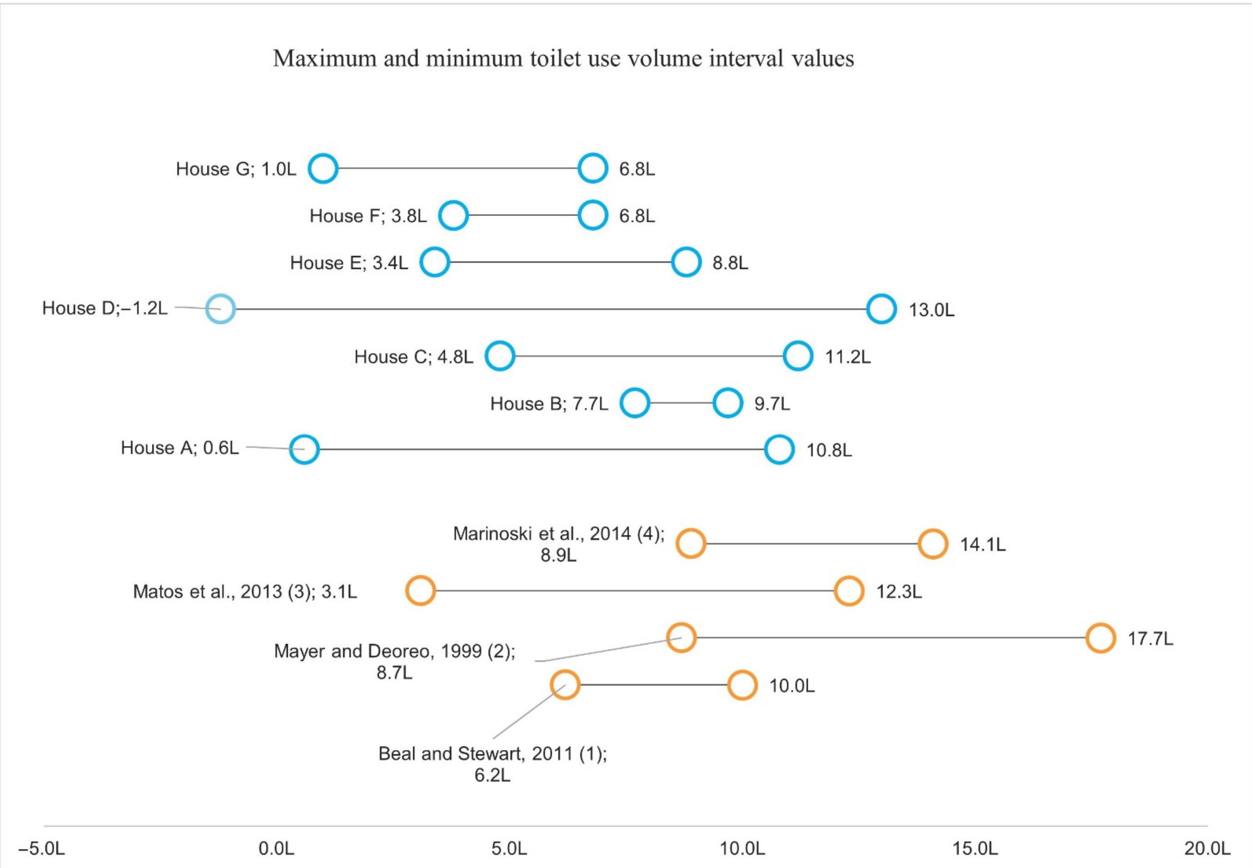

Figure 21. Comparison of the volume consumed by use of a toilet between Houses A–G and the literature, (1) [33], (2) [34], (3) [35] and (4) [36].

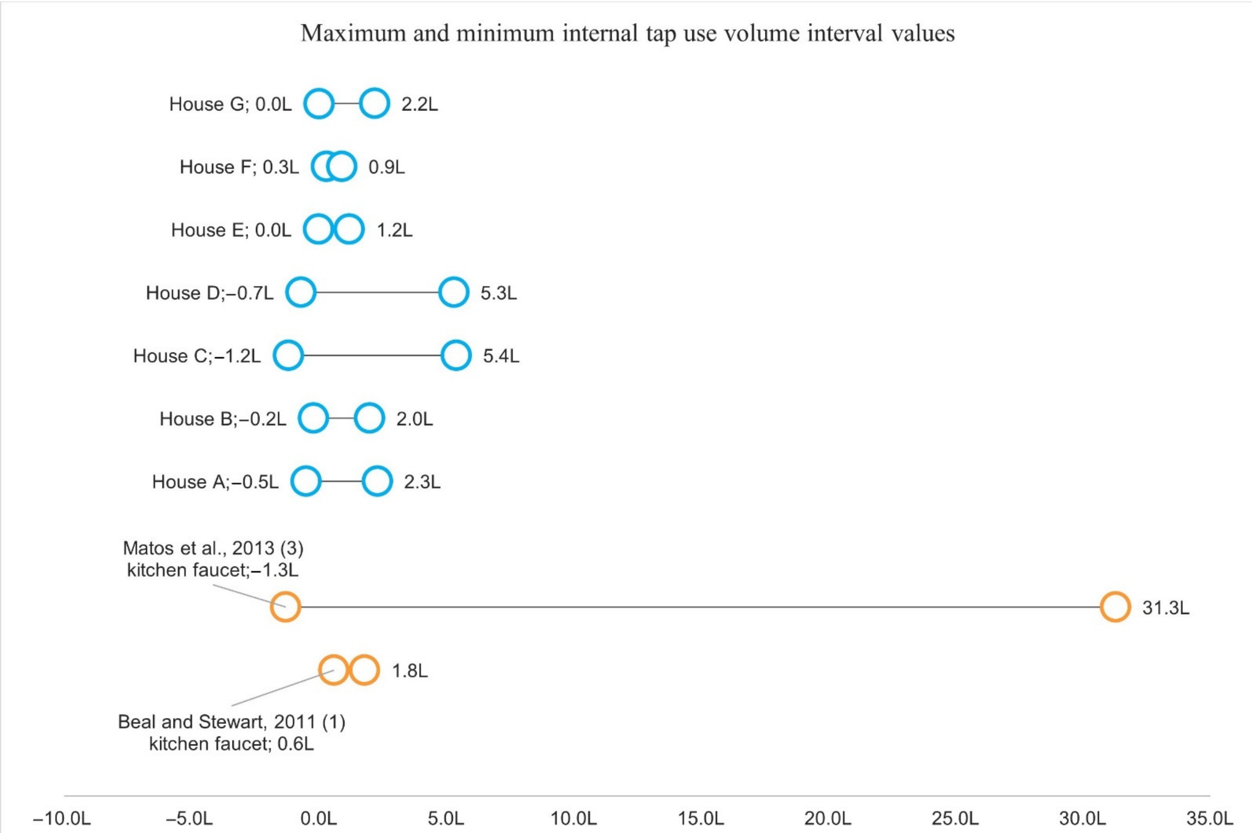

Figure 22. Comparison of the volume consumed using indoor taps between Houses A–G and the literature, (1) [33], (3) [35].

The flow values for the shower are critical, as they determine both the user's comfort during bath time and the amount of water consumed, which is influenced by the characteristics of the household's hydraulic installations as well as the custom of the individual who regulates the opening of the shower valve. Figure 18 shows that there are significant differences in flow rates among the studied houses, which is related to the various types of shower valve openings, which depend on the residents' habits; by analyzing only the flow, it is deduced that, in general, Houses G, F, and D have higher values, which is confirmed by observing the volumes (Figure 20).

The trend toward shorter shower durations (Figure 19) observed in the research houses compared to other studies in the literature may reflect that most of the homes analyzed do not have an electric shower, or it may be due to the habit of turning off the shower during certain intervals of use, such as when soaping or using shampoo. House A, which uses a shower for bathing and washing clothes, has the widest range of duration intervals, which is related to the greater number of possible uses.

Each volume consumed in the research houses corresponds to an opening and closing event of the shower valve. For example, in a bath, there may be multiple openings and closings, so this volume does not correspond to the entire bath but to the triggering event. Mayer and DeOreo [34] and Beal and Stewart [33] (Figure 20), who used Trace Wizard® to measure uses in the USA, Canada, and Australia, verified much larger volumes per actuation. This certainly reflects the climate and income discrepancies, and more specifically, the use of hot water in the shower for greater comfort, or not turning off the shower at times during use. House D, the only house with an electric shower, had the most varied activation volumes.

The volume per flush of the toilet is directly related to the type of toilet and the capacity of the flush tank. Furthermore, the user's activation mode influences both a lower consumption (when a partial discharge is performed, dosing the force to pull the cord or press the flush button) and a higher consumption (when the discharge is activated more than once, at intervals greater than or equal to its filling time). Even though all the toilets in the research houses were of the attached flush tank variety, there were differences in volume that can be attributed to their mode of use.

Regarding the consumption ranges for the toilet (Figure 21), there is variation between research houses and the works reviewed. The highest consumption occurred in the USA and Canada [34]; among the surveyed houses, the one that presented the greatest amplitude and reached the highest volume was House D, which was related to the type of device and its mode of use. There was no evidence in the interviews of waste for this device in any of the houses, but leakage in the toilet was recorded in House C during the research period. To permit appropriate comparison, the models of the toilets must be similar, particularly in terms of their flushing process and the amount of water used for activation.

Figure 22 illustrates the volume range of the internal faucets, which is determined by the residents' use habits and hydraulic characteristics of the residences, the faucet type, and how the water arrives at the residence. If the flow comes directly from the public network (street level) or via a water reservoir. Internal faucets correspond to the kitchen faucet and washbasin and have short durations and low volumes per use.

According to Figure 22, Houses C and D had the widest ranges of volume consumption, which may be related to the fact that residents in these houses stated in an interview that they did not have a habit of turning off the tap at intervals of use.

In general, residents' behavior demonstrates that they had both well-optimized activities (with water reuse) and activities that needed to be modified (washing with open faucets). As a result, evaluating the situation numerically does not provide the correct dimensions.

5.4. Discussion

The purpose of our framework is to systematize the identification of water consumption patterns to understand and overcome the subjectivity barrier in demand measurement strategies, such as rational use.

The developed framework can be applied to representative samples from specific areas of study, allowing the development of bottom-up residential end-use demand forecasting models based on a selection of predictor variables, from water consumption on a micro scale (i.e., meanings (needs, desires, and waste), materials and competencies identified for each use activity), and a macro scale (characterization of the local area).

To optimize the model, sensitivity analyses and statistical tests are recommended to verify the most important variables. Furthermore, a significant sample is required so that proper steps to create the model (e.g., training, calibration, and validation) can be used. It is possible to use evidence-based approaches to guide demand management decisions in this manner. A problem identification example would be noticing a type of soap that results in higher consumption when washing clothes; a solution could be to legislate acceptable soap formulas to be marketed in the country. Figure 23 summarizes all the important steps for this type of research, and the present work focuses on the conceptual scope and the pilot project.

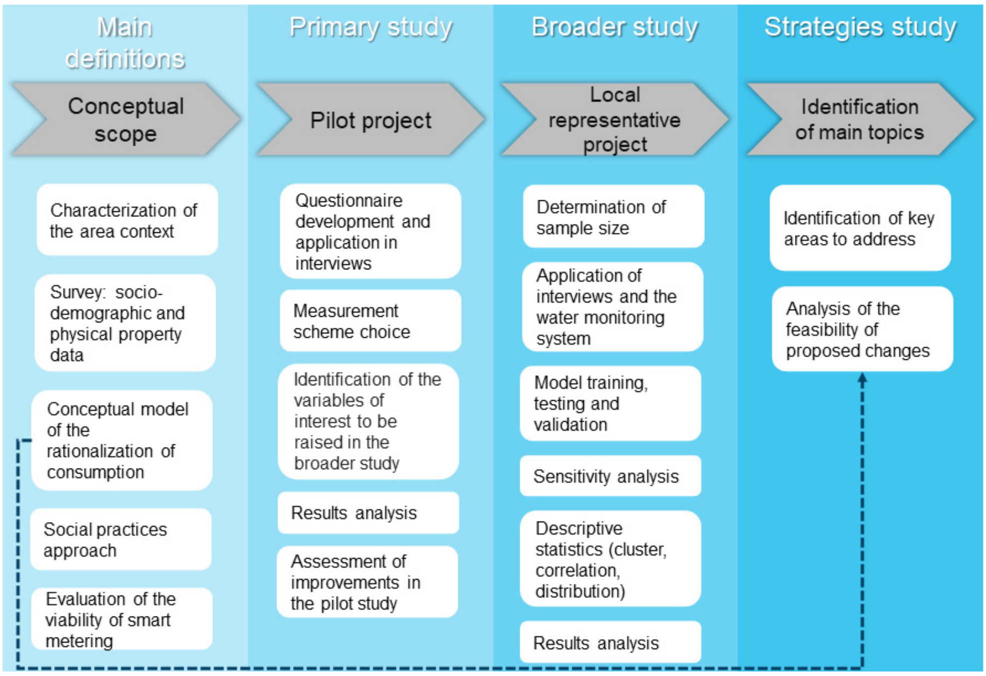

Figure 23. Flowchart to illustrate the developed framework application.

In areas where it is difficult to develop unique models and address specific demands, the framework can be indirectly applied by using insights and strategies from regions with similar attributes, such as size, climate, demographic, and culture (top-down analytics). The identified benefits and limitations of the framework are described below.

Benefits:

- Possibility of relating qualitative information on micro (user behavior) and macro scales to quantitative data
- Possibility of addressing cultural and climate issues through habit evaluation
- Water use practices in households are universal, and the local peculiarities reported in a specific study can allow for the promotion of insights by people from other cultures when changing their own habits.
- Possibility of highlighting possible excessive consumption or waste

Limitations:

- Requires the user to answer numerous questions.
- Demands a significant amount of time to interpret the answers.
- Care must be taken when preparing the interview script and its application to avoid bias.
- Smart metering infrastructure and a team are required for data processing and model creation.

The purpose of our pilot study was to comprehend the composition of water consumption for four residences on a micro scale of qualitative data, related to four specific daily water use practices. This approach allowed us to suggest customized measures to promote rational use for residents.

In the results of the pilot study, we answered three fundamental questions: (i) how consumption occurs in everyday life, at the level of meanings, materials, and competencies related to uses; (ii) how some residential water consumption practices have changed over time, and how these changes affect the meanings, as well as the evolution of materials and competencies related to use and conservation; and (iii) whether there is a consumption pattern between the residences studied (which had a similar context) and between residences in different contexts.

With the analysis of the results, we discovered that there is still considerable subjectivity in the analyses performed, but that this can be reduced by providing key information in future interviews, such as:

- An identification of all materials involved in the practice, both directly and indirectly (e.g., types and brands of hygiene products, brands, and shower models).
- Details of the procedure performed in practice and its frequency.
- Specifics about triggers that lead to practice (e.g., relaxation and sweat).
- Details on the times of day when the practice is carried out (and if they are linked to other daily activities, such as bathing before bed).
- Duration of stay at home for each inhabitant.
- Each family member's activities, which may lead to increased consumption (e.g., exercise and heavy work).
- A history of diseases (some diseases imply a higher frequency of urine, for example, which increases the amount of water used in flushing).

We also noted that when applying models to samples to generalize the results in a given area, caution should be exercised because there were significant differences in consumption between the houses in the pilot study, despite similar contexts.

5.5. Implementation of Policies on Water Rationing and Water Use

With advancements in information delivery technologies for both decision makers and users [48,53], a future trend may be the ability to distinguish between what is necessary consumption, desired consumption, and waste. Thus, a policy to be implemented could be a subsidy for necessary consumption, particularly for low-income families, as well as a higher rate for desired consumption and waste.

The urgency of the need for rational water consumption presupposes that this concept is present in users' daily concerns. However, in any case, water utilities and the government must launch intelligent and ongoing campaigns to address this issue. The points raised here, as well as others that can be researched, including the basic concepts underlying these theories, can and should be incorporated into campaigns. Concessionaires can open a communication and teaching interface, bringing them closer to citizens and providing incentives for those who consume rationally.

Interactions between the water dealership and the population to educate them to be able to fix and maintain their hydraulic system is also a great opportunity. Creating an online manual for the maintenance of residential plumbing installations would also be very helpful in dealing with domestic problems. It could contain basic instructions on how to check for leakage/loss and the need for intervention by a professional (plumber) and indicate whether the users can perform the task themselves.

6. Conclusions

In this article, we presented a framework for identifying information about water consumption by characterizing the study area to obtain detailed daily habits of users. The proposed framework can be applied to develop both water and energy management strategies and is especially interesting to understand the subjectivity involved in the rational use of resources.

A part of our developed framework was tested on a pilot scale to identify aspects that could be refined. We identified opportunities to improve the interview guide, including questions to access more clearly the meanings, materials, and competencies linked to consumption. The pilot study also sought means to achieve rational water consumption by studying residents' consumption dynamics.

The pilot test main suggestions to rational use revolve around improving the ergonomics of the activity, replacing equipment with energy-saving equipment, and encouraging residents to change their habits. One opportunity was also identified of involvement of the water dealership in instructing residents how to fix problems indoors. However, before requiring the population to behave more efficiently, the state must set an example, beginning with adequate maintenance of its facilities to reduce the alarming levels of losses, which in Salvador account for more than half of the volume of water produced.

The analysis of the evolution of uses over time reveals that, in general, this was not favorable for the rational use of water. Comfort, convenience, and the development of new products were prioritized over lower water consumption.

The current study's analyses, which were carried out at strategic points within the low-income population, increase the diversity of situations that will be the basis for future research. Future studies with larger samples, including the changes that occurred after the pandemic, will benefit from a deeper dive into the categories of consumption.

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