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Influence of the number of residents and climatic factors on residential water consumption

Ricardo Prado Abreu Reis[a,*], Dariane Gomes Rocha[a], Gustavo Porto de Rezende[a],
Marcus André Siqueira Campos[a], Raviel Eurico Basso[a] and Bruna Fioramonte[a,b]

[a] School of Civil and Environmental Engineering, Federal University of Goiás, Goiânia, Brazil
[b] Federal Institute of Education, Science and Technology, Goiânia, Goiás, Brazil
*Corresponding author. E-mail: ricardo_reis@ufg.br

RPAR, 0000-0002-1252-1976

ABSTRACT

Water scarcity is becoming increasingly noticeable in large urban centers. Therefore, the aim of this research is to analyze the factors that influence residential water consumption in a residential building located in the city of Goiânia, Brazil, during a pre-pandemic period of 6 months. To this end, graphical analysis, trend curves, and multiple regressions were used using the R language. The sample consisted of 43 housing units with a population of one to five people in each. Once the construction aspects of the building were fixed and the water price and the type of consumption measured, it was found that the number of residents, the monthly precipitation, and the maximum daily temperature directly influence residential water consumption.

Key words: climatic factors, drinking water consumption, Goiânia, number of residents, residential water consumption, statistical analysis

HIGHLIGHTS

- The increase in the number of residents of a residential apartment results in an increase in the total water consumption and a decrease in per capita consumption.
- Maximum daily temperatures and the monthly rainfall were the parameters that most influenced water consumption.
- A water consumption equation was proposed through the correlation between the number of consuming agents, temperature, and rainfall intensity.

INTRODUCTION

Over the years, there has been great concern regarding the availability of natural resources, especially water resources. As it is a finite resource, its quantity and quality are necessary to maintain life and aid its development. Therefore, the adoption of more sustainable practices in the consumption and destination of water is necessary and should be encouraged, with the aim of reducing the negative impacts of human actions.

The quest to preserve water resources and the natural cycle initially focused on supply management, seeking new sources to obtain it. It was only after difficulties in obtaining water in abundance, as well as dealing with the sewage generated by its unbridled consumption, that concern for demand and destination management became a focus of attention (Silva *et al.* 2006).

Added to this concern are the actions and policies guided by the Sustainable Development Goals (SDGs). The SDGs were approved at the United Nations (UN) Sustainable Development Summit in September 2015 and comprise 17 objectives and 169 targets to be achieved by 2030. Focusing on this study, Goal 6 stands out: 'Ensure the availability and sustainable management of water and sanitation for all' (UN 2015). Its goals include, among others, universal access to quality water, increased use efficiency, and untreated wastewater reduction.

The Brazilian territory is extensive and has different regions, each with their own climatic characteristics. Its extension guarantees the privileged availability of certain resources, especially water resources, which does not mean that the entire population lives in an environment with water abundance. The unequal distribution of water resources, both territorial

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and temporal, combined with the unequal distribution of the population in the territory, the high demand for the resource, and the precarious water infrastructure, makes some regions present a comfortable situation, while others often have to deal with water scarcity (Santos & Farias 2017; ANA 2018, 2019).

Data referring to the average water consumption of Brazilian macro-regions in 2018 are shown in Table 1. In view of these data, there are large variations in water consumption across the country: in the state of Rio de Janeiro, per capita consumption is 64.56% higher than the national average, while in Amazonas it is 40.54% smaller. In addition to the differences in availability and use of water resources presented by each Brazilian region, it is important to emphasize that average consumption may not necessarily portray the reality of consumption of a population because, in certain regions, the estimated consumption index can exceed the amount of micromeasured volume. Table 1 also highlights the average drinking water consumption in the city of Goiânia and the State of Goiás, located in the central-western region of Brazil, where this study was developed, in addition to the national average consumption indicator.

Several factors interfere with residential drinking water consumption. A large number of studies have been developed in several countries, in order to analyze the impact factors on water consumption (Romano *et al.* 2016). These factors can be of an economic nature (price of water and income of users), as well as sociocultural and climatological in nature.

Some international studies have analyzed the relationship between the price of water, linked to the user's income and associated with the total water demand in urban residential units (Martínez-Espiñeira 2002; Arbúes *et al.* 2004; Romano *et al.* 2014; García-López & Montano 2020). The negative impact of the increase in water price is widely known and often explored in Brazilian public policies as an economic mechanism aimed at reducing the volume of water consumed.

In research carried out specifically in Brazil, some studies have verified the impact between family income and the profile of water demand in different regions of the country (Ruijs *et al.* 2008; Willis *et al.* 2013; Piffer *et al.* 2016; Paiva *et al.* 2018). In these studies, it is possible to verify the impact that income has on consumption in different regions of the country. The researchers noted that the greatest demand for water occurred in wealthier families.

Another issue that should be highlighted in a water consumption profiling model is the influence that the number of residents has on the volume of water consumed in the residences. It is important to highlight that the way in which the number of residents influences the per capita consumption of water, referring to each user individually, differs from the way this variable influences the total volume of water consumed in the residence. In Joinville (Santa Catarina, Brazil), Dias *et al.* (2018) worked with two different models to evaluate the influence of socioeconomic and constructive variables of a building (a) on its total consumption (m^3/month) and (b) per capita consumption (L/person/day) in residential buildings. The results obtained showed that, although the number of residents has an influence on the total water consumption of the building in the sense of increasing consumption, the influence on per capita consumption occurs in the sense of decreasing consumption. This means that the presence of more residents (users) increases total residential consumption but decreases the average consumption of each user.

Cruz *et al.* (2017) evaluated several variables relating to constructive, socioeconomic, and consumption habits which could influence the water consumption demand of a residence. Through the study, the researchers noticed that increasing the

Table 1 | Average per capita water consumption in 2018, according to macro-regions

		Higher consumption in the macro-region		**Lower consumption in the macro-region**	
Macro-region	**Average consumption (L/p./day)**	**State**	**L/p./day**	**State**	**L/p./day**
North	131.8	Amapá	178.6	Amazonas	92.1
Northwest	115.4	Alagoas	143.0	Pernambuco	95.3
Southeast	182.6	Rio de Janeiro	254.9	Minas Gerais	155.2
South	146.1	Santa Catarina	154.0	Paraná	137.9
Central West	144.9	Mato Grosso	161.2	Distrito Federal	135.2
		Goiás	139.2		
	Goiânia		136.87		
	Brazil		154.9		

Source: adapted from SNIS (2019a).

number of residents concentrated in a single residential unit reduces the average volume of water consumption per person. This occurs because many of the water demands are related to housing maintenance and not to a specific demand from a single user, so the per capita average consumption reduces since consumption is shared by all the residents of the unit.

Willis *et al.* (2013) assessed the factors that influence residential water consumption, considering different family compositions, and noted that per capita water consumption generally decreases with increasing family size. This trend does not apply, however, to all residential water uses, specific laundry and bathroom uses tend to increase with family size. The authors attributed this contrary trend to the greater probability of large families having children who demand more water, for activities such as food preparation, hygiene, and house cleaning, as well as a greater number of people being present indoors for longer periods of time.

Although its influence on domestic water consumption is less frequently studied, environmental and climatic variables, such as temperature, air humidity, precipitation, and altitude, have also been studied. The basis of most studies that analyze the effect of these variables on water demand is justified by the strong influence of climatic and environmental factors on human habits related to the consumption of water resources, such as the frequency of bathing, washing clothes, watering the garden, and using the swimming pool. In this way, the influence of climatic factors can occur differently in different regions and in societies with particular cultural characteristics and habits.

Regarding the influence of climatic parameters on per capita drinking water consumption in residential buildings, the research developed by Romano *et al.* (2014), using a linear correlation model, pointed out that, for buildings evaluated in different cities in Italy, the variables of precipitation and altitude significantly influenced the drinking water consumption profile. The researchers found that water consumption was higher at low altitudes and higher during dry periods. On the other hand, the ambient temperature had no significant influence on water demand. In a more recent study, Romano *et al.* (2016) concluded that of precipitation, temperature, and altitude, only the latter had a significant effect on residential drinking water demand.

In Spain, Martínez-Espiñeira (2002) found consistency in the influence of the number of rainy days and temperature on residential water consumption. Despite this, he found that for the region studied, in the northwest of Spain, these variables were not as significant in altering water consumption as in areas with a hotter and drier climate.

In Brazil, Ruijs *et al.* (2008) noticed that in the Metropolitan Region of São Paulo (Brazil), the greater the precipitation in the previous month to the currently observed water consumption period, the smaller the volume of drinking water consumed. The impact of the average temperature on consumption, however, was positive: higher temperatures influence higher water consumption. Vianna & Depexe (2013) made similar observations regarding the impact of temperature on consumption in Umuarama, Paraná, Brazil, concluding that the influence of maximum temperature on the increase in water consumption is greater than that presented by the average and minimum temperatures.

In a survey developed with water consumption data from Uberlândia-MG (Brazil), Dalmônica (2014) found that the drinking water demand showed a strong correlation with air humidity ($r = -0.80$), a moderate correlation with precipitation ($r = -0.41$), and a weak correlation with temperature ($r = 0.13$). This last finding was attributed to the low thermal amplitude observed during the years of research development, which resulted in a temperature variable with low oscillation. In this context, it is relevant to consider that the influence of climatic factors on water demand can be more complex than a linear relationship. Finally, an important observation was made by Maidment & Miaou (1986), in a study contemplating water use data in cities in Florida, Pennsylvania, and Texas, USA. The researchers observed situations in which, depending on the range of values in which the daily maximum temperature was found, its influence on drinking water consumption varied. Thus, it is reasonable to consider that the temperature parameter does not influence drinking water consumption in certain climatic conditions or seasonal periods of the year, despite being relevant in others, emphasizing that the effect of climatic variables on water consumption is not linear.

Based on the thesis that climatic factors and the number of people alter the consumption of drinking water in residential buildings and that it is possible to model these factors, this work is presented. Thus, this paper aims to evaluate the influence of the number of residents in housing units and climatic factors on the consumption of drinking water in a residential building in the city of Goiânia, GO (Brazil).

METHODS

To achieve the proposed objectives, this study was conducted in two stages, as shown in Figure 1. The first stage consisted of a general study on water consumption using electronic spreadsheets, obtaining graphs and trend curves that relate average

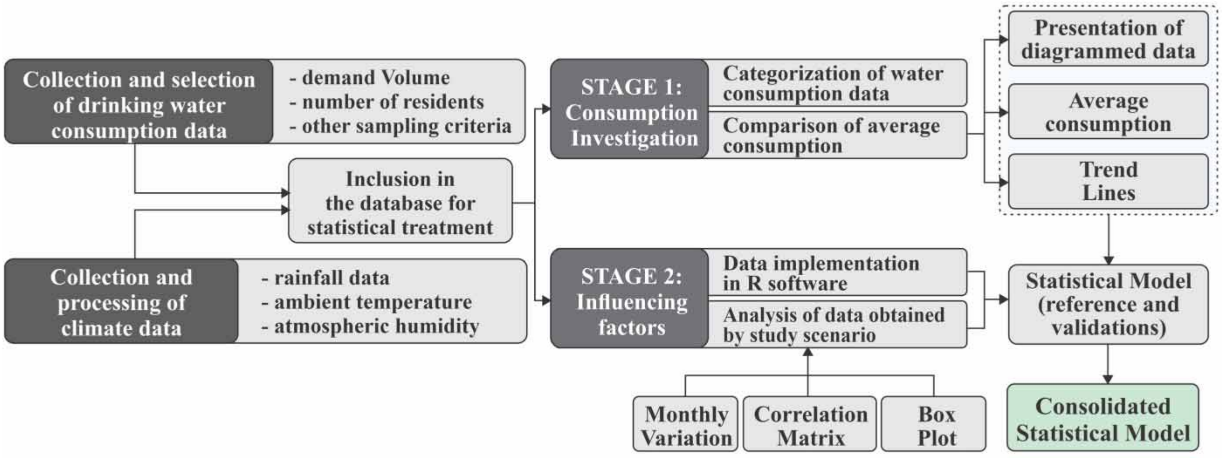


Figure 1 | Methodological structure. *Source*: Own authorship.

residential and per capita consumption with the number of residents. The subsequent step was based on a statistical study using multiple regressions to analyze the existence of a correlation between the variable of water consumption and the variable numbers of residents and climatic factors.

Characterization of the object of study

The city of Goiânia, where this study was conducted, is located in the central-western region of Brazil, at latitude 16°40′48″ south and longitude 49°15′18″ west; it is the largest city in the state of Goiás, in terms of population (IBGE 2020). According to the Brazilian Institute of Geography and Statistics (IBGE 2020), the city has a population of 1,536,097 inhabitants and a population density of 1,776.74 hab/km². The schooling rate of the population between 6 and 14 years is 96.4% and the average monthly salary of formal workers corresponds to 3.4 times the minimum wage.

The study region has hot weather throughout the year, with temperatures ranging from 15 to 33 °C, rarely above 36 °C or below 12 °C (Diebel *et al.* 2020). The annual rainy season encompasses 6.2 months, from October to April, with a maximum probability of daily precipitation equivalent to 81% in December. The dry period extends for 2.4 months, from April to October, with a minimum probability of 2% rain in July. Finally, Goiânia has a large seasonal variation in the relative humidity rate, with averages of 37.31% in August, a period that registers momentary indices below 10%, and 78.85% in the month of March.

Goiânia has its water supply provided by Companhia de Saneamento de Goiás (SANEAGO) and is the second Brazilian capital with the lowest rate of losses in the distribution of this resource (SNIS 2019a); 97.22% of water consumption units have water meters to register monthly demand, with the average consumption per unit being equivalent to 9.31 m^3/month. Residential consumption units represent 90.54% of total consumers, highlighting the relevance of the study regarding the water consumption profile for this category (SNIS 2019b).

The objects of study of this research are residential units located in a multifamily building in the central region of the city of Goiânia – Goiás – Brazil (Figure 2); it was constructed in the 1960s. The building has 21 floors, of which 17 are standard floors with four apartments per floor, each unit having a total area between 120 and 137 m², with three bedrooms in each. It is noteworthy that, during its useful life, the building had a single water meter measuring the water used by the apartments and the common area; this was later replaced by the individualized water metering system, so that each housing unit now has its own water meter.

Collection and processing of data

For the development of this research, data were collected from the 77 apartments located in the residential building under study, of which 43 were selected to comprise the sample. The sample was selected in order to avoid outliers in the analysis of water consumption, opting for the maintenance of standard apartments that, in the months in which the study data were collected, (1) showed exclusive water consumption for residential purposes, (2) kept their population density fixed and in the range of one to five people, and (3) had a complete history of water consumption.

Figure 2 | Study object location map. *Source*: Own authorship, adapted from Google maps and Google earth (2022).

For the development of the study, data from 7 months of consumption observations were considered, totaling 212 days of monitoring. The data considered from the observation of water consumption disregarded the records after March 2020 because during the SARS-COV-2 pandemic, water consumption profiles changed due to the change in users' hygiene habits (Campos *et al.* 2021). The months used in the study covered only two seasonal characteristic periods of the region: (1) hot weather with low relative humidity and (2) mild weather with high relative humidity. Water consumption data were collected from the water bills of each apartment, which are provided by SANEAGO monthly and include the consumption history of the semester prior to the invoice. It is noteworthy that, in the measurement practice adopted by the water supply company, the fractional consumption values measured monthly are approximated to the first integer value above, in m^3.

The weather data were obtained from the website of the Brazilian National Institute of Meteorology (INMET), in the form of a spreadsheet, corresponding to the daily weather data from the study period. The average daily values were used for temperature data (maximum temperature, average temperature, and minimum temperature) and relative humidity, in order to obtain a representative monthly value to be worked on in the second stage of this study. For the variable related to rainy events, it was decided to work with the total monthly precipitation (sum of the daily precipitations) since the average would not be representative. The aim was to work with the same temporal unit of water consumption data.

Study of the influence of the number of residents

With the monthly water consumption history, it is possible to calculate the general average consumption of the building and each apartment (total per apartment and per capita). The average consumption observed in the building was compared with the average consumption of Goiás and Brazil, in order to verify if the adopted sample can be considered representative of the extrapolation of results in a larger population.

As the historical water consumption provided by the concessionaire is available in the form of integer values and is not necessarily measured at equal time intervals, the average consumption results were calculated to a precision of one decimal place, and in the case of average consumption per capita, these were converted to the usual unit of liters per inhabitant per day. The values reported for each month correspond to the water meter reading interval that the SANEAGO concessionaire uses to account for consumption and generation of the water bill, it does not exactly correspond to the number of days in the month, since the date of water consumption registration does not occur on weekends or holidays and days when the concessionaire staff does not operate (Table 2).

To study the influence of the number of residents on total and per capita residential consumption, the water consumption data were categorized by considering the month of consumption and the number of residents in each residence. The respective average consumptions were obtained using Equations (1) and (2):

$$C_{e,i} = \frac{\sum C_{r,i}}{N_{r,i} * m} \tag{1}$$

where $C_{e,i}$ is the average consumption of households with i residents, m^3/ap./month; $\sum C_{r,i}$ is the sum of all consumption data of households with i residents, m^3; $N_{r,i}$ is the number of households with i residents; m is the number of months of consumption covered by the sample, with $m = 7$ months.

$$C_{me,i} = \frac{\sum C_{r,i}}{N_{p,i} * d} = \frac{C_{e,i} * 1,000}{i * \dfrac{d}{m}} \tag{2}$$

where $C_{me,i}$ is the average per capita consumption of households with i residents, L/p./day; i is the number of residents; $N_{p,i}$ is the sum of the number of residents for households with i residents; d is the number of days of consumption covered by the sample, with $d = 212$ days

The results were analyzed in order to obtain the best trend curves to represent residential water consumption (total and per capita) as a function of the number of residents.

Study of the influence of climatic factors

For the statistical study of the influence of climatic factors on residential water consumption, monthly climatic data were incorporated into the database, containing the average consumption results of the first stage of the study. Table 3 presents a summary and description of the variables used in the statistical study.

It should be noted that in this study, the comparison variables were restricted to the number of residents of each housing unit of a building occupied by middle-class families and by the characteristic climatic factors of the city of Goiânia-Go, Brazil. Comparisons with variables associated with socioeconomic factors and specific consumption habits of users, which could result in greater accuracy of the modeling data of the water consumption profile, were not considered.

The second stage began with an evaluation of the database in three ways: a graph of the average monthly consumption, categorized by the number of residents; a box and whisker plot; and a correlation matrix between variables. Subsequently,

Table 2 | Number of days per month of consumption

Month/Year	Number of days
August/2019	29
September/2019	32
October/2019	29
November/2019	33
December/2019	28
January/2020	30
February/2020	31

Source: Own authorship.

Table 3 | Variables used in the statistical study

Definition of variables	Data source	Description
C_e: Consumption (m^3/ap./month)	Residents	Average monthly water consumption per household
Pe: Number of people (people)	Residents	Number of residents per household
C_{me}: Per capita consumption (L/p./day)	Estimation	Consumption ratio with residents (C_e/Pe)
Ch: Monthly rainfall (mm/month)	INMET	Sum of daily rainfall
T_{ma}: Maximum temperature (°C)	INMET	Average daily maximum temperatures
T_{me}: Average temperature (°C)	INMET	Average daily average temperatures
T_{mi}: Minimum temperature (°C)	INMET	Average daily minimum temperatures
U_m: Relative air humidity (%)	INMET	Average daily relative humidity

Source: Own authorship.

and with the aid of the computational language R, multilinear regressions were applied to the database, obtaining statistical models that allowed the verification of the existence (or not) of a significant correlation between the variables described in Table 3.

The reference scenario of the statistical model consisted of verifying the existence of a correlation between all eight variables presented, by considering the variable total residential consumption (Ce) as the dependent variable (X) and the other variables as independent (Y). Based on the results obtained for the p-value coefficient, referring to each variable of the resulting statistical model, as well as the analysis of the general result of the initial scenario (R^2 coefficient), variations were proposed in order to determine the most adequate model for the studied pattern, thus obtaining the best possible correlation between the variables.

RESULTS AND DISCUSSION

The stages of the study, with their respective results, are presented below.

Influence of the number of residents on residential water consumption

The general analysis of the water consumption of the 43 residential units that make up the sample resulted in an average consumption per residence of 13.6 m^3/apartment/month and per capita of 172.9 L/inhab./day, which was significantly higher than the average consumption in Goiás and Brazil (136.87 and 154.9 L/inhab./day, respectively). The graph presented in Figure 3 allows a comparative view of the average consumptions mentioned. It is observed that 55.6% of the sample (25 apartments) had an average consumption equal to, or lower than, the average of the building, while this amount is even lower

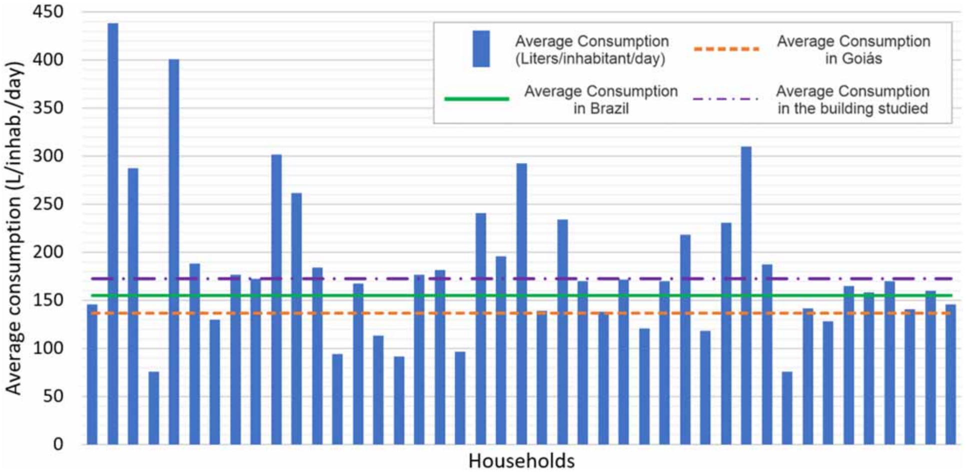


Figure 3 | Comparison of average household consumption. *Source*: Own authorship.

when the comparison refers to the national and municipal average consumption (only 37.2 and 23.5% of apartments, respectively).

The high average consumption of the building can be partially explained by its constructive characteristics. The literature points out that locations in city centers and the size of the residential units are factors that influence the sense of increasing water consumption, as well as the age of the building (about 60 years old). Larger built-up areas require greater consumption of water for maintenance and older buildings (more than 20 years old) are more likely to have unidentified leaks not detected by residents, resulting from a lack of periodic maintenance or even the type of hydraulic solution adopted (Cruz *et al.* 2017; Dias *et al.* 2018). It should be noted that it was not the objective of this study to survey leaks in the plumbing system for maintenance.

Table 4 shows the water consumption, discretized into categories of numbers of residents. In order to allow the comparison of the results with the general result for the building, the last line of Table 4 is intended for the results without categorization of the sample. Subsequently, the data in this table are arranged graphically in Figures 4 and 5.

Figure 4 shows the trend curve that best represents the average residential consumption as a function of the number of residents. The use of second-order linear and polynomial trend curves presented the best fits to the data (both with $R^2 = 0.94$), offering a good approximation for predicting the water consumption of a residential unit. Therefore, the linear curve with the best fit was defined, given the greater simplicity of its application and, also, for being compatible with the usual methodology for calculating residential consumption. It is observed that the consumption curve is increasing with the population, corroborating what is presented in the literature (Romano *et al.* 2016; Cruz *et al.* 2017; Dias *et al.* 2018).

Based on the analysis of Figure 4, it should be noted that there is a similarity between the average consumption for residences with three and four residents. This similarity in water consumption values can be attributed to water demand practices that do not depend on the number of users, such as cleaning environments, and also concerns arising from a greater number of residents in an apartment, such as a greater concern with the costs arising from water consumption. There may be a need to share the same bathroom or even use the same cycle for larger volumes of washing clothes (washing machines) or

Table 4 | Average consumption values categorized by the number of residents

Number of residents (*Pe*)	**Units analyzed**	**C_{e},i (m^3/apartment/month)**	**C_{me},i (L/inhab./day)**
1	6	7.8	256.3
2	17	10.7	177.4
3	11	17.1	188.1
4	6	16.9	139.7
5	3	22.6	149.1
112	43	13.6	172.9

Source: Own authorship.

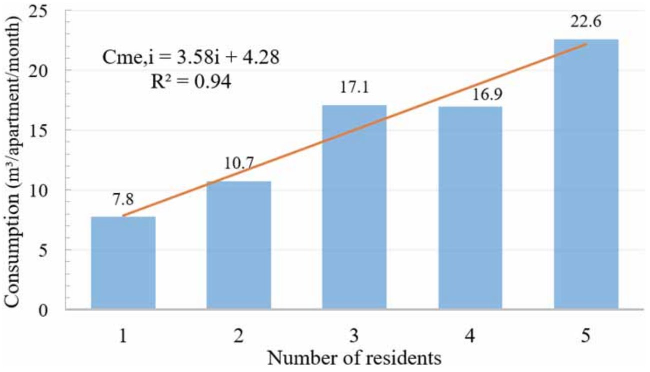


Figure 4 | Variation in residential consumption as a function of the number of residents. *Source*: Own authorship.

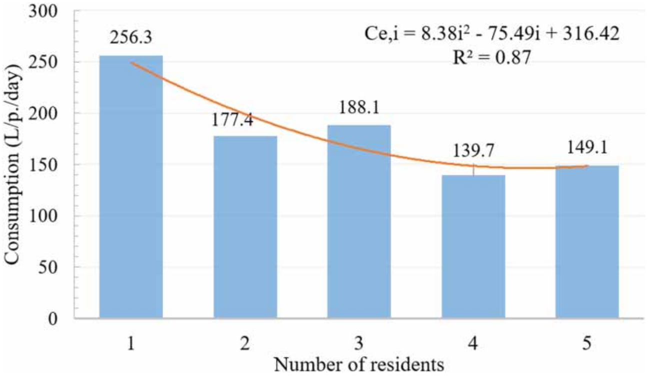


Figure 5 | Variation in per capita consumption as a function of the number of residents. *Source*: Own authorship.

dishwashers. Usage practices shared by a greater number of people can lead to a reduction in consumption profiles, such as a reduction in the time to use the shower (the device which consumes more water in homes in Brazil) or a reduction in the number of cycles used for washing clothes and dishes (Barreto 2008; Willis *et al.* 2013).

Another analysis that can be carried out by observing Figure 4 relates to the increase in water consumption between housing units with two people and above three people. It should be mentioned that, in buildings with more people, the probability of the presence of children is larger. Thus, as mentioned, the trend is for greater consumption of water in households with three or more residents.

An inference derived from the trend curve, obtained for the graph in Figure 4, concerns the linear intercept: when the number of residents is equal to zero ($i = 0$), the curve presents a monthly consumption of 4.28 m^3/ap./month. A possible interpretation of this value is that it represents the basic consumption for the maintenance of a residence, regardless of the number of residents, including common activities that are shared by residents (house cleaning, for example). It is interesting to note that the 4.28 m^3/apartment/month represents 141.32 liters of water daily, more than enough for the average consumption of one person in Goiânia, which reinforces the hypothesis that there is waste in the building, both visible and invisible.

In terms of the variation in per capita consumption as a function of the number of residents, Figure 5 illustrates the average consumption obtained and the best-fit trend curve. Again, two curves presented close fits (exponential with $R^2 = 0.87$ and power with $R^2 = 0.86$), so that the best fit was attributed to the simplest application curve which, in this case, referred to the exponential.

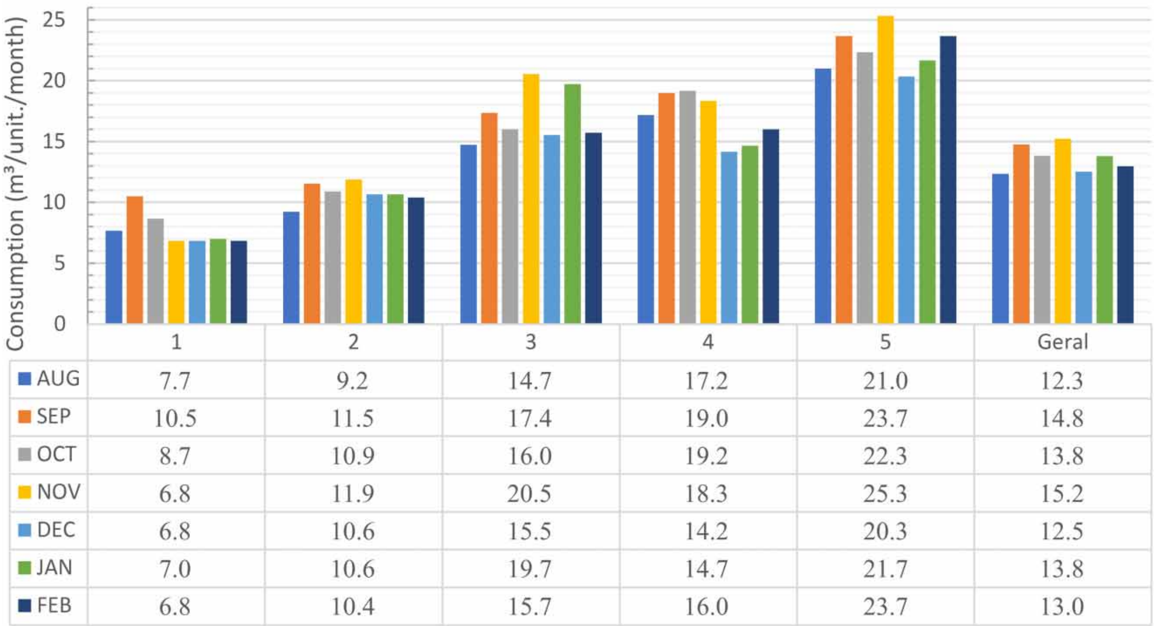
The graph in Figure 5 shows important information: while the total residential consumption tends to increase with the number of residents, per capita consumption tends to decrease. This downward trend in consumption corroborates the justifications already presented, regarding the increased concern with water consumption and the need to share devices that consume this resource when the number of residents increases, as well as with previous studies (Willis *et al.* 2013).

Influence of climatic factors on residential water consumption

The initial assessment of consumption data, categorized by the number of residents, resulted in Figures 6 and 7, which illustrate the variation in consumption over the months. Starting from a visual analysis of consumption over the months, by residence and per capita, a significant variation in consumption can be observed, albeit without a characteristic trend.

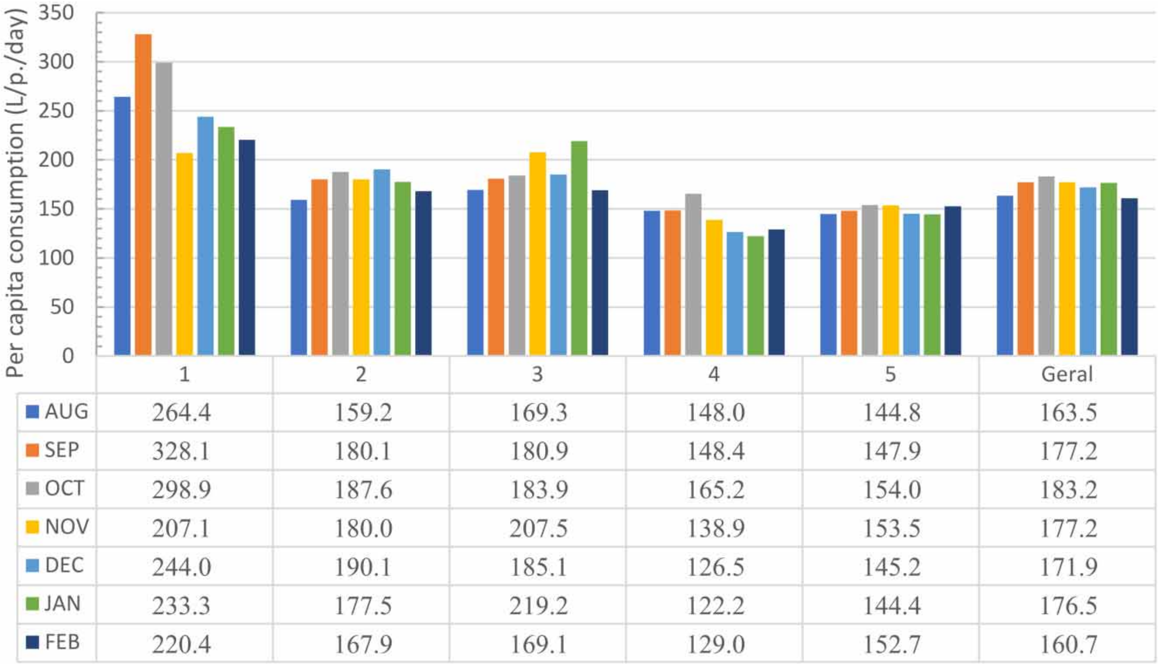
Figure 8 is the box and whisker plot of the sample used. Observations that are outside the presented limits are identified in the diagram and considered to be outliers (values that are discrepant from the data sample). In this study, it was decided not to remove the outliers indicated in the box and whisker plot, since the sample was carefully selected and there were few incidences.

To guide the variations of the reference scenario, it was necessary to evaluate the correlation matrix between the variables (Figure 9) in order to know which variables are or are not relevant to the model, i.e., which variables should be removed from the sample. According to Rocha (2018), a correlation is considered positive when $r > 0$ ('blue color'), which means that both variables move in the same direction, or negative when $r < 0$ ('red color'), which means that the variables move in opposite



	1	2	3	4	5	Geral
AUG	7.7	9.2	14.7	17.2	21.0	12.3
SEP	10.5	11.5	17.4	19.0	23.7	14.8
OCT	8.7	10.9	16.0	19.2	22.3	13.8
NOV	6.8	11.9	20.5	18.3	25.3	15.2
DEC	6.8	10.6	15.5	14.2	20.3	12.5
JAN	7.0	10.6	19.7	14.7	21.7	13.8
FEB	6.8	10.4	15.7	16.0	23.7	13.0

Figure 6 | Monthly variation of residential consumption × number of residents. *Source*: Own authorship.



	1	2	3	4	5	Geral
AUG	264.4	159.2	169.3	148.0	144.8	163.5
SEP	328.1	180.1	180.9	148.4	147.9	177.2
OCT	298.9	187.6	183.9	165.2	154.0	183.2
NOV	207.1	180.0	207.5	138.9	153.5	177.2
DEC	244.0	190.1	185.1	126.5	145.2	171.9
JAN	233.3	177.5	219.2	122.2	144.4	176.5
FEB	220.4	167.9	169.1	129.0	152.7	160.7

Figure 7 | Monthly variation of per capita consumption × number of residents. *Source*: Own authorship.

directions; i.e., when the value of one variable increases, the value of the other decreases. Correlation can also be null or zero, which means that the variables are not related.

When analyzing Figure 9, it is possible to verify that the variables Ch and U_m present a strong correlation with each other ($r = 0.91$), as well as the variables U_m and T_{ma} which, in this case, are negatively correlated ($r = -0.81$). Therefore, in the

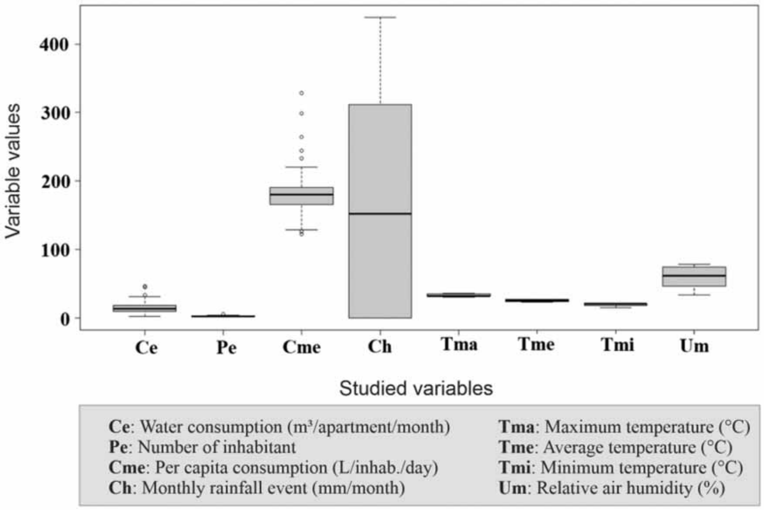


Figure 8 | Box and whisker plot of the database used. *Source*: Own authorship.

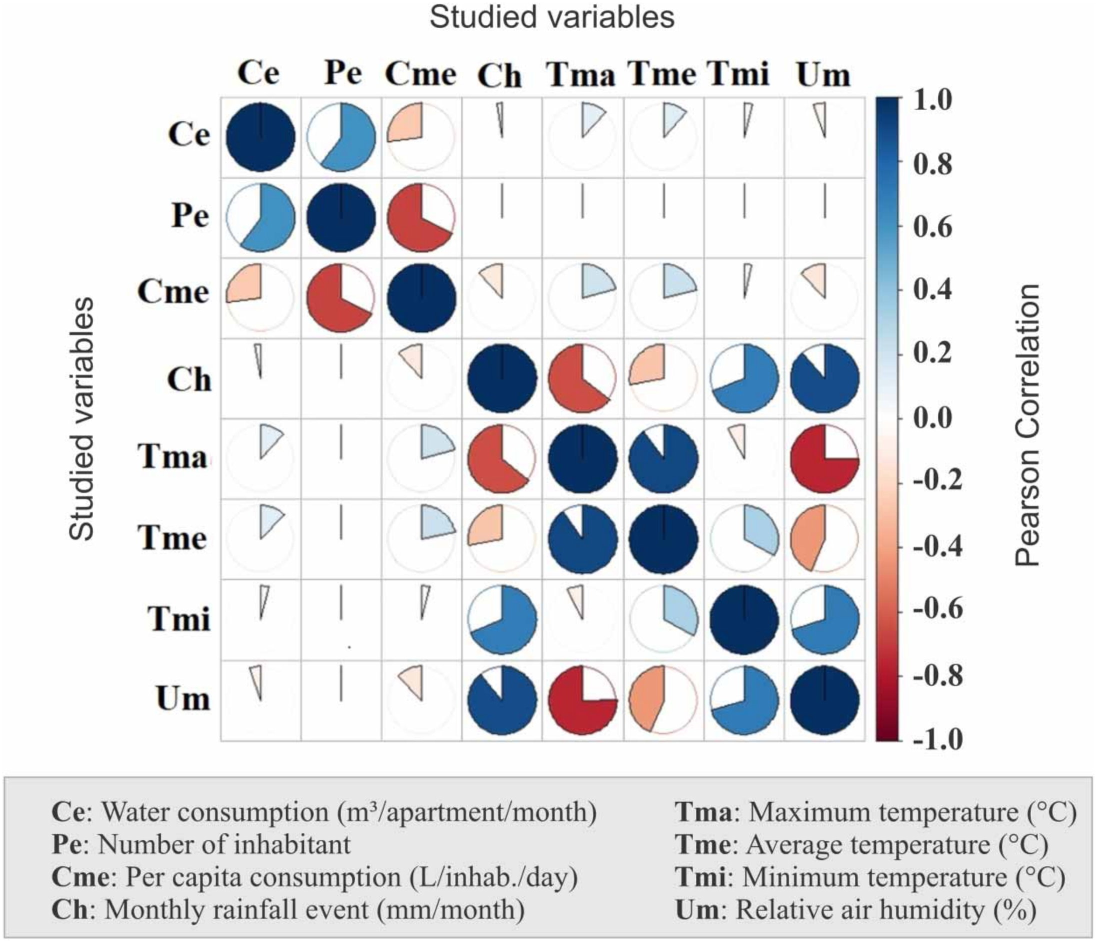


Figure 9 | Correlation matrix of the database used. *Source*: Own authorship. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2023.067.

variations of the scenario, it is of interest to keep such variables in the regressions, in order to verify their correlation with the object of study of this article (water consumption).

After implementing the reference scenario, the results obtained by the first multiple regression, performed on the R language platform, corresponded to those shown in Table 5. It can be seen that, in the regression result, the values for the p-value coefficient closest to zero refer to the variables Pe and C_{me}, demonstrating that these are highly related to the monthly residential water consumption. It is worth mentioning that the variable T_{ma} showed a good relationship with the variable, since its p-value is less than 5%.

By corroborating the results in Dias *et al.* (2018) with the first stage of this study, the good correlation between total water consumption and the number of people corresponded to the expected results: there is a strong influence of the number of people on total consumption, and the higher the number of consumers, the greater the consumption of the housing unit.

When evaluating the influence of the other variables on the total residential consumption, however, the results did not correspond to those expected, obtaining only three variables that were significant for the study. Only the variables Pe, C_{me}, and T_{ma} had a significant influence on consumption, although studies carried out in Brazil by Ruijs *et al.* (2008) and Vianna & Depexe (2013) have observed the influence of factors such as precipitation on the residential consumption of water.

In view of the aforementioned observation, the hypothesis was raised that the inclusion of the variable C_{me} in the study could be the reason for the biased result of the statistical analysis. This hypothesis resulted from the fact that the value of C_{me} was obtained by the ratio between consumption (C_e) and number of people (Pe), characterizing a linear relationship. Thus, the linear relationship of the dependent variable with C_{me} makes it expected that the latter has high significance in the determination of C_e.

Given the hypothesis raised, the first variation of the scenario was proposed. Table 6 presents the result of this variation, in which the variable C_{me} was removed. The second multilinear regression result showed a significant improvement in the p-value coefficients and in the F-statistic value, with the lowest p-value coefficient being maintained for the variable Pe, and therefore the best correlation result. For the variable representing the maximum monthly temperature, a p-value was obtained very close to the ideal of $p < 0.05$: a result that is in agreement with Vianna & Depexe (2013) when demonstrating the existence of a greater influence of the maximum temperature on residential water consumption, compared to the influence of average and minimum temperatures.

As can be seen in Table 6, the maximum temperature has an impact on the increasing monthly consumption of water. This result is consistent with the practical observations in the city of Goiânia. At times of maximum temperature, it is common to increase the consumption of water to increase thermal comfort in homes, either by ingestion or by more frequent baths. The statistical model showed no significant influence of relative air humidity (U_m) on residential water consumption, and the influence of monthly precipitation (Ch) was less expressive than the influence resulting from the variable maximum temperature.

Table 5 | Reference scenario

Variable	**Estimated parameter**	**Standard error**	***t*-Value**	***p*-Value**
(Intercept)	−18.724743	34.128422	−0.549	0.583660^{+}
Pe	4.711438	0.383269	12.293	$<2 \times 10^{-16}$***
C_{me}	0.043033	0.011279	3.815	0.000166***
Ch	0.014068	0.006733	2.090	0.037523*
T_{ma}	2.885800	1.318008	2.190	0.029348*
T_{me}	−3.898324	2.514018	−1.551	0.122069^{+}
T_{mi}	0.980623	1.733831	0.566	0.572111^{+}
U_m	−0.098002	0.258011	−0.380	0.704343^{+}
R^2: 0.4127		Adjusted R^2: 0.3987		

Source: Own authorship.

Notes: Statistical significance level: ***(99.99%); **(99%); *(95%); $^{++}$(<90%); $^{+}$(not statistically significant)

F-statistic: 29.41 in 7 and 293 DF, p-value: $<2.2 \times 10^{-16}$.

The largest F-Statistc represents the one that best fits the proposed model.

Table 6 | First reference scenario variation

Variable	Estimated parameter	Standard error	*t*-Value	*p*-Value
(Intercept)	−21.345000	34.899386	−0.612	0.5413^{+}
Pe	3.692552	0.281191	13.132	$<2\times10^{-16***}$
Ch	0.010338	0.006813	1.517	0.1302^{+}
T_{ma}	2.494173	1.343961	1.856	0.0645^{++}
T_{me}	−2.639471	2.549091	−1.035	0.3013^{+}
T_{mi}	0.492405	1.768522	0.278	0.7809^{+}
U_m	−0.023152	0.263129	−0.088	0.9299^{+}
R^2: 0.3835		Adjusted R^2: 0.3709		

Source: Own authorship.

Notes: Statistical significance level: ***(99.99%); **(99%); *(95%); $^{++}$(<90%); $^{+}$(not statistically significant)

F-statistic: 30.48 in 6 and 294 DF, p-value: $<2.2\times10^{-16}$.

The largest F-Statistc represents the one that best fits the proposed model.

Beginning with the analysis of the second multiple regression performed, it was decided to propose a new variation of the reference scenario, now with the removal of the variables average temperature (T_{me}), minimum temperature (T_{min}), and relative humidity (U_m) from the statistical model, given their high *p*-values. In this new variation of the reference scenario, the variables with the lowest *p*-values were maintained (namely, *Pe*, T_{ma}, and *Ch*) and the linearization hypothesis caused by the inclusion of the variable C_{me} was considered valid, so that the option to remove it was maintained in the study.

Due to the strong correlation between the variables *Ch* and U_m (see correlation matrix in Figure 9), it was considered of interest to evaluate a scenario in which *Ch* was replaced by U_m, resulting in the third variation of the reference scenario. In this way, the second and third variations of the reference scenario are presented in Tables 7 and 8, considering the variables *Ch* and U_m, respectively.

Both the second and third variations of the reference scenario maintained a good correlation between the number of consumers and consumption, also showing a significant reduction in the *p*-value of the variable T_{ma}. As for the variables U_m and *Ch*, the regression maintaining the latter presented the best results of *F*-statistics and *p*-values, demonstrating that there is a greater correlation between the variables *Pe*, T_{ma}, and C_e with precipitation than with relative humidity.

In view of the above, and the relatively small size of the data sample worked, the second variation of the reference scenario (Table 7) presented the best overall result of the correlation between the variables studied, therefore being considered satisfactory for the objective proposed by this study. Equation (3) presents the equation referring to the final statistical model.

$$C_e = 16,330759 + 3,692552 * Pe + 0,003700 * Ch + 0,600142 * T_{ma} \tag{3}$$

where C_e is the water consumption (m^3/apartment/month), *Pe* is the number of inhabitants, *Ch* is the monthly rainfall event (mm/month), T_{ma} is the maximum temperature (°C).

Table 7 | Second variation of the reference scenario

Variable	Estimated parameter	Standard error	*t*-Value	*p*-Value
(Intercept)	16.330759	7.304878	−2.236	0.02612^{*}
Pe	3.692552	0.280764	13.152	$<2\times10^{-16***}$
Ch	0.003700	0.002692	1.374	0.17039^{++}
T_{ma}	0.600142	0.211750	2.834	0.00491^{**}
R^2: 0.3791		Adjusted R^2: 0.3728		

Source: Own authorship.

Notes: Statistical significance level: ***(99.99%); **(99%); *(95%); $^{++}$(<90%); $^{+}$(not statistically significant)

F-statistic: 60.45 in 3 and 297 DF, p-value: $<2.2\times10^{-16}$.

The largest F-Statistc represents the one that best fits the proposed model.

Table 8 | Third variation of the reference scenario

Variable	Estimated parameter	Standard error	*t*-Value	*p*-Value
(Intercept)	−18.99621	9.58656	−1.982	0.0485*
Pe	3.69255	0.28098	13.141	$<2 \times 10^{-16}$***
U_m	0.03694	0.03099	1.192	0.2343^{+}
T_{ma}	0.63333	0.24607	2.574	0.0105*
R^2: 0.3781		Adjusted R^2: 0.3790		

Source: Own authorship.

Notes: Statistical significance level: *** (99.99%); **(99%); *(95%); $^{++}$(<90%); +(not statistically significant).

F-statistic: 60.20 in 3 and 297 DF, p-value: $<2.2 \times 10^{-16}$.

The largest F-Statistc represents the one that best fits the proposed model.

It is worth mentioning that the result obtained is in agreement with that presented by other studies conducted in Brazil, on the influence of precipitation and maximum temperature on residential water consumption (Ruijs *et al.* 2008; Vianna & Depexe 2013). This corroborates the statement by Miaou (1990) and Arbués *et al.* (2003) about the importance of studies that investigate the limits in which these variables affect water demand more deeply.

CONCLUSIONS

Through this study, it can be concluded that the increase in the number of residents of a household unit directly impacts the increase in total water consumption of that unit (increasing linear trend curve, $R = 0.94$). On the other hand, this increase results in a decrease in per capita water consumption (decreasing exponential curve, $R = 0.87$).

Given the database used in this study, containing the constructive characteristics and particularities of the monitored building, water price and typology of the individual and constant water consumption measurement system, the results of the statistical analysis (regarding the existence of a correlation between the residential consumption of water, the number of residents and climatic factors) demonstrate a significant influence by the following climatic factors: average daily maximum temperature (p-value $= 4.91 \times 10^{-3}$) and monthly precipitation (p-value $= 0.17039$), in addition to the already observed influence of the number of residents (p-value $\leq 2.0 \times 10^{-16}$). This conclusion is the result of a multilinear regression with an adjusted regression coefficient $R^2_{\text{Adjusted}} = 0.3728$ which, for the study conditions, demonstrates a good reliability index.

With the results obtained, this paper contributes to a better understanding of the relationship between water consumption in household units and the number of residents and climatic factors. Thus, it was possible to define an equation to determine the drinking water consumption of housing units. This understanding is essential for guiding the estimation of residential water consumption and, therefore, the dimensioning, control, and more efficient operation of plumbing systems.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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