

Study of domestic water consumption in intermittent supply of the Riberas de Sacramento sector in Chihuahua, Mexico

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ABSTRACT

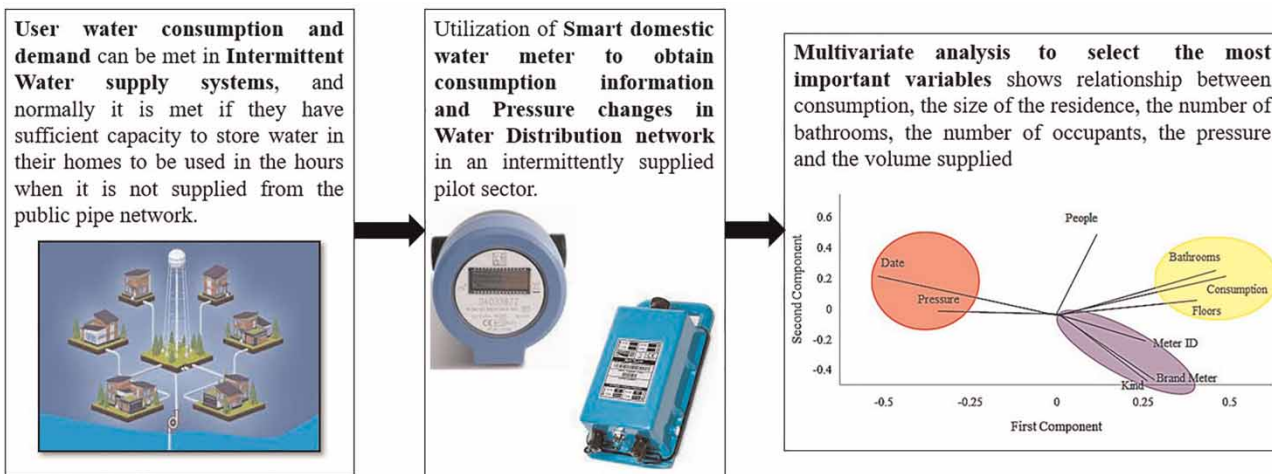
User water demand can be met in intermittent water supply systems, and normally it is met if they have sufficient capacity to store water in their homes to be used in the hours when it is not supplied from the public pipe network. The situation in many intermittent water supply systems is that they have enough water to cover the demand of the users but are supplying it intermittently, and the challenge is to achieve a transfer from intermittent to continuous supply. If the delivery of water is continuous, which supplies drinking water 24/7, it covers not only the basic needs of the user, but all the needs for water they may have. The present study was carried out using smart domestic water meters to obtain consumption information in an intermittently supplied pilot sector. The electromagnetic meters record the water flow through pulses and generate consumption information, which gives us the consumption pattern in volume of water and in the time it is used. During the study, multivariate statistical methods were applied to obtain information from the domestic meters and to identify, as realistically as possible, the consumption of drinking water and the relationship between consumption and specific characteristics of the users and thus anticipate future demand. The results showed a close relationship between consumption and the size of the residence. The most influential factors were the number of bathrooms and the number of occupants. A direct relationship between the pressure and the volume supplied was presumed at the beginning of the study but the opposite was found. Equipment was installed to measure the pressure in the network at the time of establishing the continuous supply of drinking water. The multivariate analysis provides a selection of the most important variables that influence and explain the behavior of the water use and consumption pattern, with the operation determined by the operating agency.

Key words: consumption, continuous, intermittent, multivariate analysis, supply

HIGHLIGHTS

- Users' water consumption and demand.
- Intermittent water supply systems.
- Water distribution network with changes of pressure.
- Smart domestic water meter to obtain consumption information.
- Multivariate analysis to select the most important variables.

GRAPHICAL ABSTRACT



INTRODUCTION

Research on the consumption of a sector helps us to understand the habits of the users and to establish the best way to supply drinking water to their homes. However, the investigation involves difficulties since the supply of drinking water varies from one place to another.

In some areas of Mexico, the water supply service follows a continuous delivery scheme, 24 hours a day, 7 days a week. In other zones, it is scheduled for certain hours of the day by the water utility in charge and catalogued as 'intermittent supply' (Andey & Kelkar 2009). Countries with arid and semi-arid climate opt for intermittent supply (IWS) to manage consumption and preserve their water reserves. Many cities with exponential population growth turn to intermittent supply to solve the imbalance of supply and demand. However, such drastic measures often fail, as they do not contemplate the negative effects of intermittent supply in piped networks and the resulting water losses (Christodoulou & Agathokleous 2012). In an intermittent supply, the water required depends on user needs and the amount of water collected by the users depends on system pressure. In this type of supply, the transit time in the pipes is reduced, so the operator may be forced to increase the pressure to boost the flow and take advantage of the few hours of supply.

It is important to monitor water consumption and changes in the current supply to anticipate future demand, especially in areas of controlled population where no present or future growth is anticipated. On the other hand, the know-how serves as a reference for application in similar sectors. Consumption characteristics help to improve management and operation, including meeting the demand of users according to their activities. In addition, the water utility in charge will be able to determine balances as a tool for flow recovery (Serrano *et al.* 2018).

There is currently no study that analyzes the consumption of drinking water in intermittent supply mode. This is the case in Mexico and, consequently, in the state of Chihuahua as well. In literature isolated efforts exist. They are of short duration, poor sampling and are basically focused on continuous delivery (Alcocer *et al.* 2012). In the study described in this report, an effective and objective tool was used to design the sampling tests. The domestic water meter generates measurements autonomously which avoids human error, it also generates a pulse when it detects water flow in the service connection pipe and creates a numerical value that is sent and processed to quantify the volume and is recognized by any current or future receiving system.

The definition of steady and unsteady flow is key to the investigation. This is achieved by looking closely at the time interval of permanence, the pressure and the type of flow in the network. Water networks have been designed, throughout history, by assuming a steady flow that maintains constant pressure and flow characteristics (Bon 2017). Generally, the flow rate in continuous supply networks is not permanent due to variations in demand. Neither is the flow rate in intermittent supply networks; the filling of pipes and evacuation of air within them result in changes of both pressure and velocity. After air evacuation and network filling, modeling standards (Nagarajan *et al.* 2003) are applied to measure the permanent flow: water in liquid phase with no gas mixture (air). Few field studies present evidence of the process, which depends on 'how' the water

flow transits in the network, by recording velocity and pressure (Nelson & Erickson 2017). Domestic water consumption in intermittent supply systems (IWS) has been calculated using retrospective surveys, structured observations, storage inventories, metered (limited) data and flowmeters. The items can be used individually or in tandem (Guragai *et al.* 2018). This methodology is also used in particular locations to link objective measurement of equipment with the user's and the operator's perception.

The target of this research is to analyze the drinking water consumption of domestic users employing smart domestic water meters in an area with intermittent supply. A consumption relationship must be established with data collected in surveys, such as the number of bathrooms, size of the dwelling and number of tenants. Then, based on the information obtained, the transition to continuous delivery can be made.

METHODOLOGY

Site description

The State of Chihuahua is one of 32 states in the Mexican territory. It has a population of 3,741,869 inhabitants, 3.0% of the country's population (INEGI 2019). The Municipality of Chihuahua is located at latitude north 28° 38', longitude west 106° 04', altitude 1,455 masl (metres above sea level). It has an area of 9219 km² (3.4% of the state's total area). Chihuahua City is the state capital (IMPLAN 2017). The neighborhood of Colonia Riberas de Sacramento is a low-quality housing complex made up of 1,500 families. It is located to the north of the city of Chihuahua (Figure 1) and covers an area of approximately 1.1 km² with an average altitude of 1,500 masl. It has an annual dry-temperate climate of 18.5°C.

Riberas de Sacramento is a high priority area for the government of Chihuahua because of its low levels of schooling and social structure. Most of the community members are young and have long work schedules, so they come home to rest. Such a routine is opposed to the recording of potable water consumption. The high consumption reflected in the government agency records do not match; the activity and type of residents suggest low consumption. The area was chosen for study based on this discrepancy.

Representative study points

In a previous analysis of this research (Mendoza & Navarro 2020), the general consumption of users in the Riberas de Sacramento sector was examined. The research identified important elements related to consumption, such as topography, typology of the existing network, economic capacity of the users and the type of existing supply. This led to the division of the sector into areas with homogeneous technical and social characteristics and also to locate future measurement points for the individual study of the consumption of representative users in the sector's areas according to the population size. This also allowed us to determine a sample size based on the inspection level of the MIL-STD 105E sampling (Montgomery 2004), where the sample varies according to its total population by levels (Table 1).

To identify the main guiding characteristics of the sector's consumption pattern, a survey was performed among the different users studied (Figure 2), at the same time as the pressure and flow data were read. Although the survey was developed by

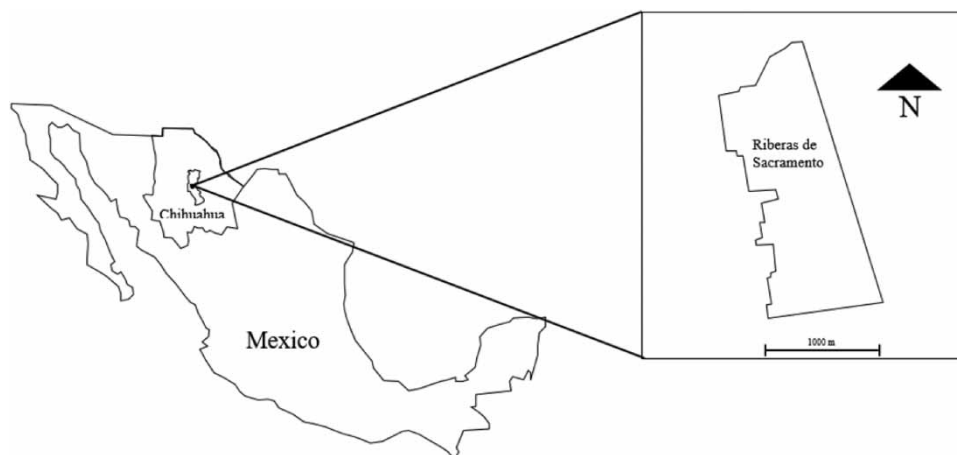


Figure 1 | Study area: Riberas de Sacramento.

the research group, it was based on standardized surveys used by the authorities to ascertain and evaluate the user's perception regarding service and fees (Dorantes 2016).

Data compilation and data sampling

The objective of statistical interpretation is to obtain information on one or more of the characteristic parameters of the inhabitants. To achieve this, a population measurement of the analyzed sector must be performed and conclusions must be drawn based on the values resulting from the number of samples tested (Devore 2008). The method of analysis was

Table 1 | Sampling quantities obtained (Mendoza & Navarro 2020)

Sector	Classification	Population size	Inspection level	Sample size
1	(0–15 m ³)	456	F	8
1	(16–200 m ³)	28	C	2
2	(0–15 m ³)	502	G	13
2	(16–200 m ³)	38	C	2
3	(0–15 m ³)	1,339	G	13
3	(16–200 m ³)	178	D	3
4	(0–15 m ³)	680	G	13
4	(16–200 m ³)	98	D	3

Note: Abbreviations in the level inspection column signify a particular classification based on population size.

Drinking water consumption analysis pilot test

Registration Data

Date _____
 Address _____
 Time _____

Meter Information

Meter Serial Number _____
 Initial reading _____
 Final reading _____

User information

Number of bathrooms at home _____
 Number of people living _____
 Number of story housing _____
 Kind of user _____

Figure 2 | User characteristics survey.

performed using the Military Standard 105E (MIL-STD-105E) sampling technique (Montgomery 2004). This procedure has a significant statistical value of 80%, according to the characteristics surveyed and analyzed in the sector.

The measurement points detected in a previous analysis of this research were inspected by installing Contazara CZ4000 flow domestic water meters (CONTAZARA 2022) and Multilog 2 pressure recorders (HWM 2022) to obtain information on the water consumption of each user per week, and their subsequent analysis on the specific kind of consumption and its relationship with the existing drinking water supply in the sector. According to the sample size defined in the stratified experimental design, a methodology for the measurement installation and to obtain the survey monitoring point in a synchronized manner was carried out. The Contazara CZ4000 domestic water meter (Figure 3) and the Multilog pressure recorder are intelligent instruments that detect maximum and minimum flow, operating ranges and automatic consumption peaks.

The consumption measurement took 3 months from April to June 2020, with stays of one week per household but not the same week for all; there were only five meters, so they took turns on installation. Fifty-five samplings were performed in consumption households. It required one week to measure the pressure per zone according to the classification of zones previously detected (Mendoza & Navarro 2020) so five samplings were performed. Measurements were made in the same spring season, so there was no problem in the analysis with respect to having readings from different seasons of the year. Recorded for study were: date, address, meter ID, number of bathrooms, number of tenants, number of storeys, customer category (domestic or commercial), meter brand, consumption and pressure. Cumulative flow volumes were taken per week and at the time of meter installation. Users were asked about the number of tenants and characteristics of the residence to determine the real water endowment of the area under study. A multivariate analysis was performed with Minitab software (Minitab 2022). This software offers statistical analysis of variables and correlations. This tool was chosen because it provides an objective evaluation of the variables obtained independently and establishes the relationship between variables and factors numerically or visually, making it possible to identify the most important variables and the predominant relationships in the problem analyzed.

Data analysis

Water distribution network models are widely used by water companies. Consumer demands are one of the main uncertainties in these models, but their calibration is not feasible due to the low number of sensors available in most real networks. However, individual demand behavior can also be gauged if background information is available (Sanza & Perez 2014). From the data obtained in a previous stratigraphic analysis, the consumption demand can be inferred by calculating the estimated water endowment of the sector from the relationship between average consumption and population typology.

Consumption readings were taken with Contazara CZ4000 meters. These smart devices recorded data ranging from 0 m³ to 8.84 m³ of consumption per week. Through the process it was possible to establish the time of highest consumption and determine the flow passing through the meter. Consumption was classified by group, volume of accumulated consumption and independent consumption by meter used, in order to compare the heterogeneity of the data and its independence with respect

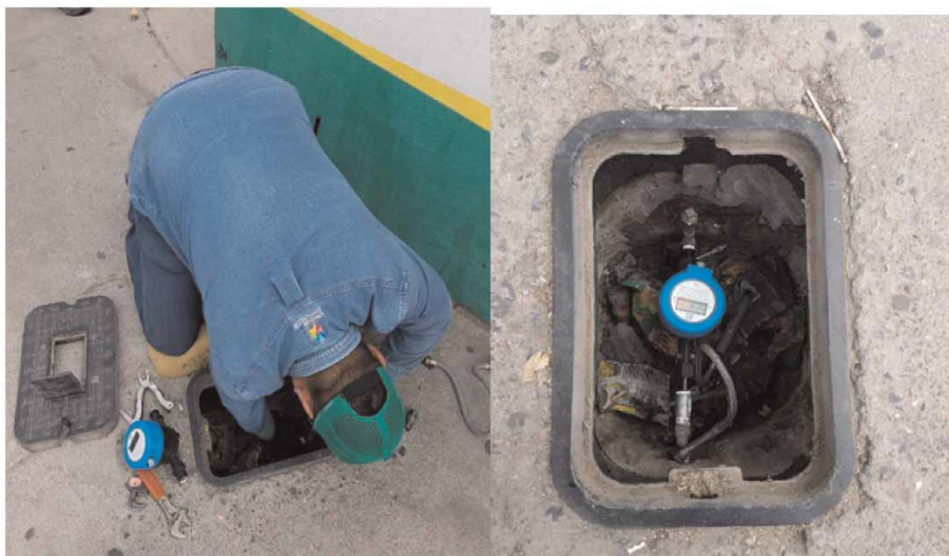


Figure 3 | Contazara CZ4000 meter installation.

to the similarity of meter operation. This also allowed us to establish the actual water supply existing at the site and led to a future forecast calculation to make a demand prediction in Riberas de Sacramento, Chihuahua. The analysis of these data was performed statistically and with a multivariate support that reflects the relationship between the variables of the analysis such as pressure, flow, topography, time and user characteristics. A statistical model was formulated to differentiate the effects of the factors (Wong *et al.* 2010).

Much more attention needs to be given to probabilistic forecasting methods if water utilities are to make decisions that reflect the level of uncertainty in future demand forecasts. Reliable urban water demand forecasting facilitates operational, tactical and strategic decisions that are critical for effective drinking water supply (Donkor *et al.* 2014).

RESULTS AND DISCUSSION

Consumers and homes: features and consumption

Data on the particular characteristics of each network user were classified as shown in Figure 4. The chart showing type of meter reflects that most of the users do not have a meter at all, and those that do have a meter have very different brands. The type of use is mostly domestic, with only five measurements in commercial premises. The average number of people living in each home is three, ranging from a minimum of one to a maximum of six people. Almost all of the houses are single storey and there are a few two storey houses. The vast majority of the houses have only one bathroom, although there are a few with two or three bathrooms. Finally, the registered consumption per week is around the average of 3 m³, with maximums of 9 m³

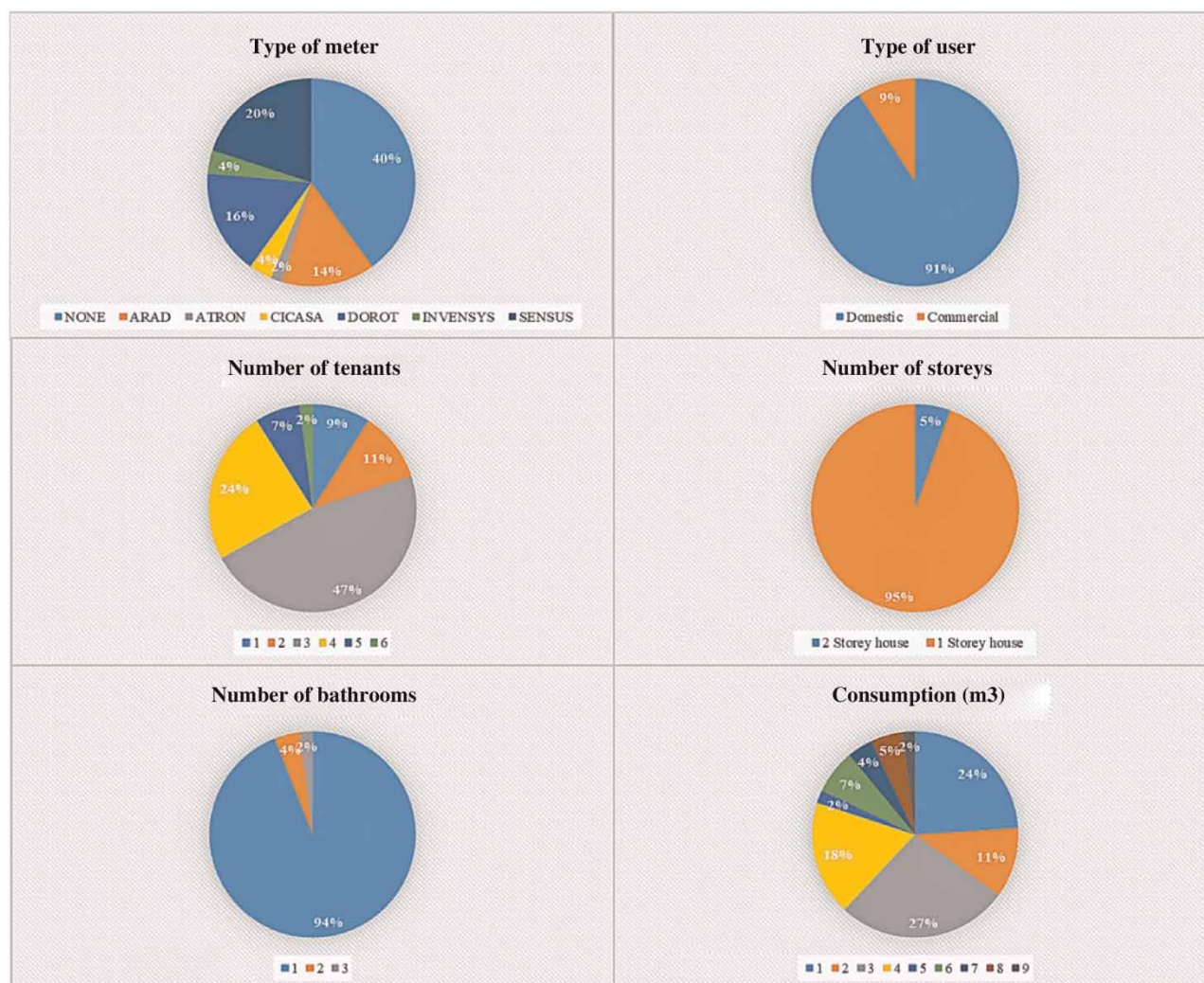


Figure 4 | Summary of factors influencing water consumption in Riberas de Sacramento.

and minimums of 1 m^3 . Several brands of meters were registered in the homes surveyed: Arad, Sensus, Dorot, Invensys and Cicasa. However, the vast majority of the surveyed users did not have a meter, but connected to the network with a tap hose. The total data from the surveys carried out is shown in Table 2.

Multivariate analysis of consumption

Comparative graphs of maximum consumption flow (Figure 5) and hourly rate of highest consumption (Figure 6) were obtained directly from Contazara software which provides this advantage of instant analysis through its algorithm based on the data collected. In both graphs, consumption represents the total amount of water accounted in m^3 for the time in which the smart water meters were in place (a week), within the ranges specified on the other axis (flow rate and time range). This information confirmed the intermittency of supply in the sector due to its relationship with the visible increase in measurements during the opening hours of supply in the sector, which were from 4:00 am to 8:00 am and from 4:00 pm to 8:00 pm. The increase in consumption is reflected in the high flow rates, mostly 500 to 1,000 liters/hour, due to the effect of the refilling of containers in homes. When the supply valves are opened in the morning and evening hours, users in the area store water in tanks, cisterns and other containers, causing a peak in consumption that is reflected in readings of 500–1,000 L/hr (liters per hour). These are the consumption characteristics of the average user. The existing supply in the sector is also evident.

By comparing these two graphs (Figures 5 and 6), it is possible to immediately detect that the water supply is intermittent. The saturation of the network indicates the beginning of semi-continuous supply and a schedule in which consumption increases. As consumption stabilizes, users resume regular consumption at a stable pressure. A new study can be proposed at this point under the premise that the network can be analyzed as a continuous system.

The consumption classification in ascending order was also obtained (Figure 7). A wide variety of private consumption is observed, ranging from 8.84 m^3 to 0 m^3 per week, although it registers a parity between 2 m^3 and 4 m^3 per week. This is shown in the consumption classification graph (Figure 7) and means that the peak in consumption is due to the water storage tank in the house (Arreguin *et al.* 2010). The tank is constantly refilled because when the supply is cut off, the user consumes the stored water. The deficit of 1 m^3 to 2 m^3 is maintained since that is the standard storage capacity of the installed reservoirs. At the end of the tank filling, the water flow is stabilized and continuous flow begins. However, the supply ends soon. Valves controlling intermittent service must be closed. Using Minitab software, it was possible to compare the range of values for each consumption category by means of a box plot (Figure 8). It can be observed that four ranges are registered outside the average. The range with no record is the highest.

In addition to the graphs of the overall flow rate of the meters, a comparative graph of the readings of the different meters is elaborated in Figure 9, which shows a comparison of the measurements taken by each of the five meters available for sampling. In this graph it can be seen that the measurement points were evenly distributed among the different meters installed (Pau *et al.* 2013) using similar trend lines in each of the representative lines per registered meter.

A comparative graph of the information generated by the pressure gauges (Figure 10) was generated to corroborate the drinking water supply schedule in the sector, which is consistent with the information from the government agency that controls the operation of the hydraulic infrastructure and establishes a current service schedule from 4:00 to 8:00 and from 16:00 to 20:00. A variety of pressures is also observed in the sector, ranging from 10 mwc (meter water column) to 21 mwc, confirming that all the previously defined homogeneous areas are suitably representative.

Subsequently, by means of a multivariate analysis of the principal components, the sedimentation (Figure 11) and components (Figure 12) plots were obtained. Principal component analysis is a method that evaluates each variable independently, defining the associations with other variables and their impact in terms of the magnitude of the eigenvector (Bartholomew 2010). In this way, different conjectures could be corroborated, such as that pressure and consumption have a similar behavior, although they behave in the opposite direction in the component graph. On the other hand, the sedimentation graph shows that there is a variable with greater weight in determining the general behavior. In fact, four variables are the most important to achieve results in the research.

In the component graph (Figure 12), many items are highlighted, including pressure and date, which appear on the negative side of the graph but mean a relevant but opposite importance from the consumption data and user characteristics of bathrooms and floors. It establishes a relationship between both variables, since the weather generates a behavior of higher or lower pressure on water consumption. There are three analysis subsets that do not seem to influence the results notably

Table 2 | Riberas de Sacramento measurement data

Date	Address	Meter ID	Start reading	End reading	Bathrooms	People	Number of storeys	Water Use	Meter type	Consumption (m ³)
May 13, 2020	C. Rio Volga #23928	P18VA426876	26.84782	35.695	1	4	1	Domestic	Arad	9
April 8, 2020	C. Rio Missouri #23124	P18VA426864	7.41216	15.80156	3	5	2	Commercial	Arad	8
April 22, 2020	C. Rio de la Plata #23910	P18VA426842	33.0887	40.896	1	3	1	Domestic	None	8
April 22, 2020	C. Rio Mosela # 2222	P18VA426864	19.49136	27.0193	1	4	1	Domestic	None	8
April 1, 2020	C. Rio Columbia #1840	P18VA426876	10.89898	17.90348	1	2	1	Commercial	None	7
April 8, 2020	C. Rio Amur #2202	P18VA426876	17.90348	24.44186	1	4	1	Domestic	None	7
April 8, 2020	C. Rio Elba #1413	P18VA426852	11.46338	17.8234	1	3	1	Domestic	Invensys	6
April 1, 2020	C. Rio Rhin #2416	P18VA426842	22.87054	28.92836	1	4	1	Domestic	Dorot	6
April 22, 2020	C. Rio Lorenzo #23324	P18VA426876	27.27098	32.89292	1	3	1	Domestic	None	6
April 1, 2020	C. Rio Madeira #1841	P18VA426852	5.88214	11.46338	2	4	2	Domestic	None	6
June 3, 2020	C. Rio Meta #1818	P18VA426849	45.00964	50.3927	1	5	1	Domestic	Sensus	5
June 3, 2020	C. Rio Marañon #1409	P18VA426864	35.67138	40.15034	1	3	1	Domestic	Dorot	4
May 6, 2020	C. Rio Missouri #23522	P18VA426849	35.695	39.9546	1	3	1	Domestic	Arad	4
April 29, 2020	C. Rio Obi #2034	P18VA426852	22.3848	26.391	1	3	1	Domestic	None	4
April 15, 2020	C. Rio Negro #2220	P18VA426849	26.57582	30.5554	1	4	1	Domestic	Cicasa	4
May 6, 2020	C. Rio Amur #1626	P18VA426842	42.1728	46.0518	1	4	1	Domestic	Invensys	4
April 15, 2020	C. Rio Tigris #2434	P18VA426864	15.80156	19.49136	1	4	1	Domestic	None	4
April 1, 2020	C. Rio Mississippi #2203	P18VA426849	19.44754	23.0997	1	3	2	Domestic	Sensus	4
May 27, 2020	C. Rio Missouri #23114	P18VA426852	27.7685	31.38972	1	3	1	Domestic	Dorot	4
May 20, 2020	C. Rio Obi #1608	P18VA426849	40.897	44.48428	1	3	1	Domestic	None	4
May 20, 2020	C. Rio Indo #1408	P18VA426876	26.84782	30.39876	2	4	1	Domestic	Sensus	4
April 8, 2020	C. Rio Lena #2222	P18VA426849	23.0997	26.57582	1	3	1	Domestic	Arad	3
April 22, 2020	C. Rio Parana #2400	P18VA426852	19.08756	22.3848	1	1	1	Domestic	None	3
June 10, 2020	C. Rio Rojo #1841	P18VA426852	32.11138	35.33296	1	3	1	Domestic	None	3
May 13, 2020	C. Rio Murray #1600	P18VA426842	46.0518	49.237	1	1	1	Domestic	Sensus	3
June 10, 2020	C. Rio Cauca #1800	P18VA426842	53.17556	56.29048	1	4	1	Domestic	Sensus	3
June 10, 2020	C. Rio Cauca #1600	P18VA426864	40.15034	43.1789	1	3	1	Domestic	Arad	3
May 27, 2020	C. Rio Ventuari #23106	P18VA426842	49.33734	52.30882	1	5	1	Domestic	Arad	3
April 29, 2020	C. Rio Rhin #2213	P18VA426849	32.776	35.695	1	3	1	Domestic	None	3
April 1, 2020	C. Rio Arno #1405	P18VA426864	7.41216	10.31966	1	2	1	Domestic	None	3
May 27, 2020	C. Rio Yojoa #23103	P18VA426864	32.8125	35.67138	1	3	1	Domestic	None	3

(Continued)

Table 2 | Continued

Date	Address	Meter ID	Start reading	End reading	Bathrooms	People	Number of storeys	Water Use	Meter type	Consumption (m ³)
April 15, 2020	C. Rio Zambeze #23718	P18VA426876	24.44186	27.27098	1	3	1	Domestic	Sensus	3
June 3, 2020	C. Rio Maraño #1800	P18VA426876	31.16744	33.9712	1	3	1	Domestic	Sensus	3
April 15, 2020	C. Rio Obi #2219	P18VA426842	30.5082	33.0887	1	4	1	Domestic	Sensus	3
May 6, 2020	C. Rio Pardo #2003	P18VA426852	26.391	28.96428	1	3	1	Commercial	None	3
June 10, 2020	C. Rio San Fco #22500	P18VA426876	33.9712	36.52192	1	3	1	Domestic	None	3
May 20, 2020	C. Rio Yojoa #23108	P18VA426864	30.3384	32.8125	1	2	1	Domestic	Dorot	2
April 22, 2020	C. Rio Amur #2040	P18VA426849	30.5554	32.776	1	2	1	Domestic	None	2
May 13, 2020	C. Rio Ventuari #23532	P18VA426852	26.7912	28.96428	1	1	1	Domestic	Sensus	2
May 6, 2020	C. Rio Mayo #1810	P18VA426864	27.643	29.8004	1	3	1	Domestic	Arad	2
April 29, 2020	C. Rio Congo #2008	P18VA426876	32.89292	34.669	1	6	1	Domestic	None	2
April 8, 2020	C. Rio Obi #1800	P18VA426842	28.92836	30.5082	1	3	1	Domestic	None	2
April 29, 2020	C. Rio Mayo #2037	P18VA426842	40.896	42.1728	1	4	1	Domestic	None	1
April 15, 2020	C. Rio Yang Tse Kiang #2420	P18VA426852	17.8234	19.08756	1	3	1	Domestic	Cicasa	1
May 20, 2020	C. Rio Beni #1614	P18VA426852	26.7912	27.7685	1	5	1	Domestic	Dorot	1
May 13, 2020	C. Rio Murray #1626	P18VA426849	39.9546	40.897	1	1	1	Commercial	Sensus	1
June 3, 2020	C. Rio Arauca #1801	P18VA426842	52.30882	53.17556	1	4	1	Domestic	Sensus	1
May 27, 2020	C. Rio Mosa #23104	P18VA426876	30.39876	31.16744	1	3	1	Domestic	Dorot	1
May 6, 2020	C. Rio Obi #1838	P18VA426876	34.669	35.4366	1	2	1	Commercial	Atron	1
June 3, 2020	C. Rio Meta #1437	P18VA426852	31.38972	32.11138	1	3	1	Domestic	Dorot	1
April 29, 2020	C. Rio Missouri #23322	P18VA426864	27.0193	27.643	1	1	1	Domestic	None	1
May 13, 2020	C. Rio Congo #2207	P18VA426864	29.8004	30.3384	1	3	1	Domestic	Arad	1
May 27, 2020	C. Rio Columbia #1432	P18VA426849	44.48428	45.00964	1	2	1	Domestic	Dorot	1
May 20, 2020	C. Rio Niger #1410	P18VA426842	49.237	49.33734	1	3	1	Domestic	Dorot	1
June 10, 2020	C. Rio Rojo #1403	P18VA426849	50.3927	50.39284	1	3	1	Domestic	None	1
Mean					1	3	1	Domestic	None	3
Max					3	6	2	Domestic	None	9
Min					1	1	1	Commercial	Atron	1

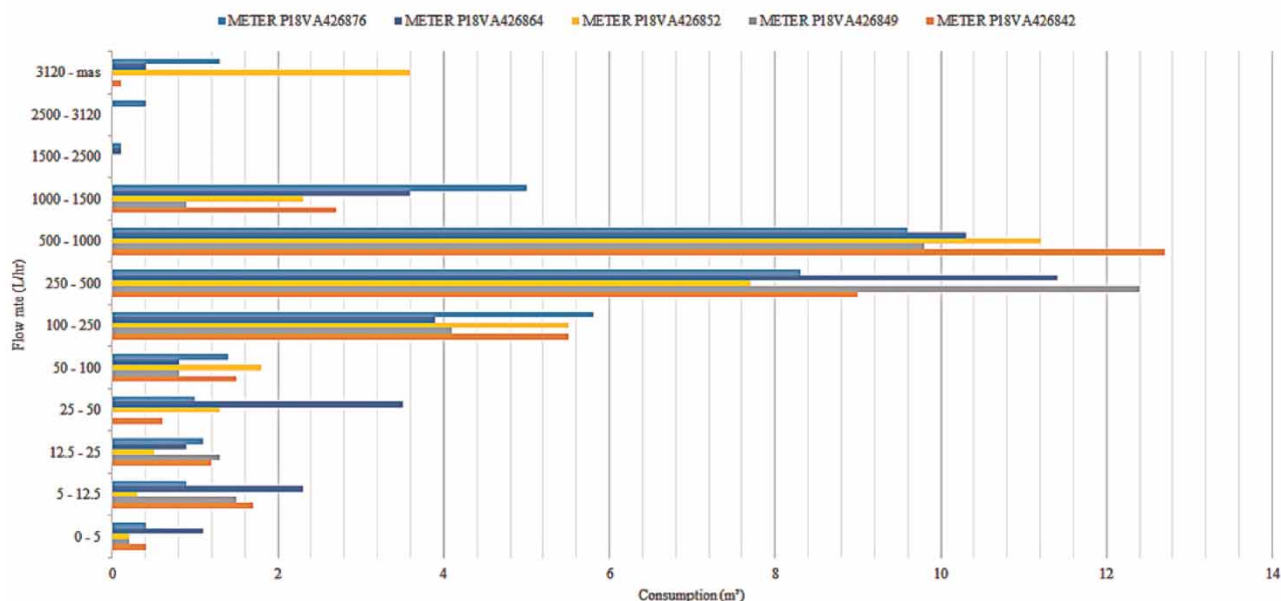


Figure 5 | Maximum consumption flow in Riberas de Sacramento.

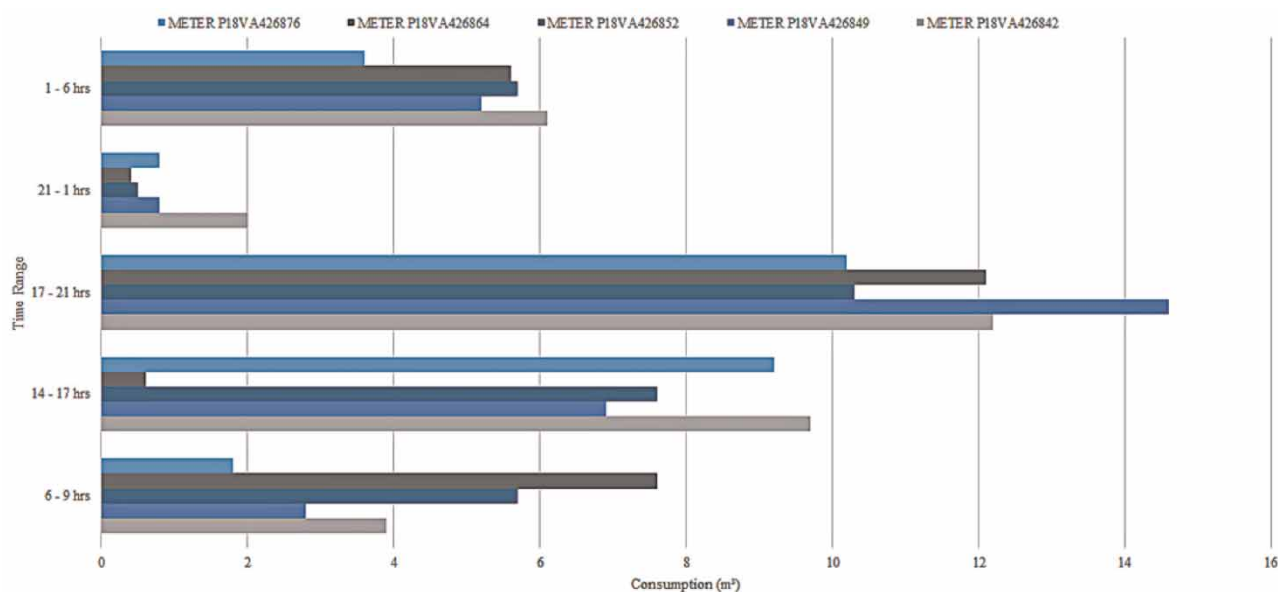


Figure 6 | Hourly range of highest consumption.

(Meter ID, Meter brand and type), but should be considered because of their trend line. Bathrooms, consumption and floors are closely related components and their values reflect high correspondence.

The analysis of value and eigenvector is used to evaluate how the response means of the different subsets differ between the levels of the different terms in the model. Emphasis is placed on the eigenvectors whose coefficients or magnitude correspond to high eigenvalues. The values of the eigenvector coefficient components (Table 3), which are data obtained from the multivariate factor analysis in Minitab, give us the relationship of the most important components (the highest), which are also highlighted in Figure 12 (bathrooms, storeys and consumption).

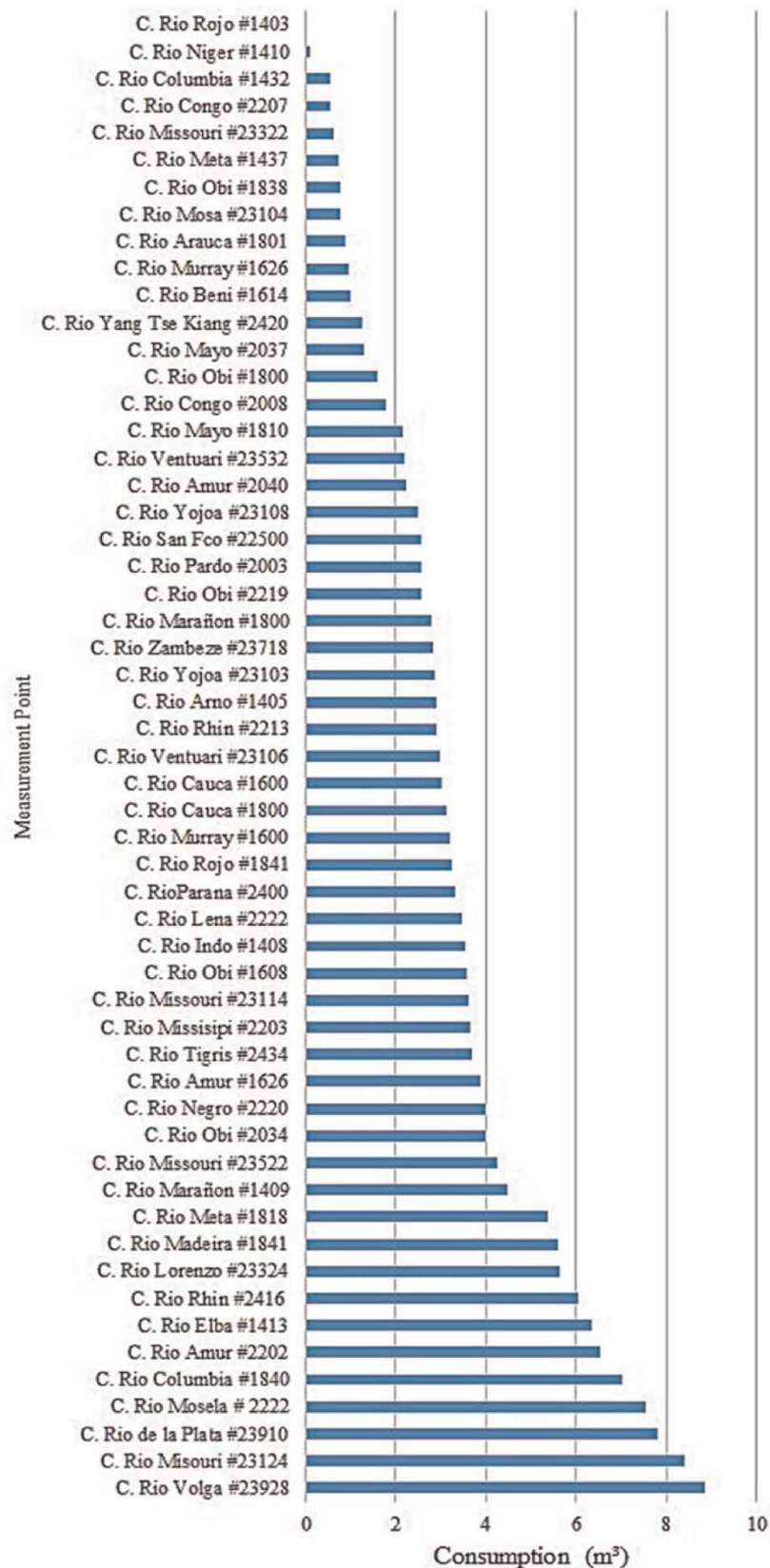


Figure 7 | Consumption classification in ascending order.

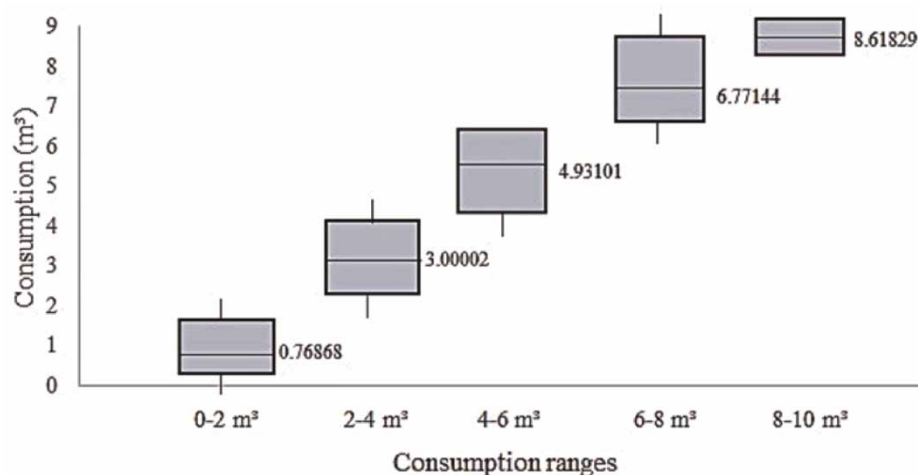


Figure 8 | Box plot for consumption ranges.

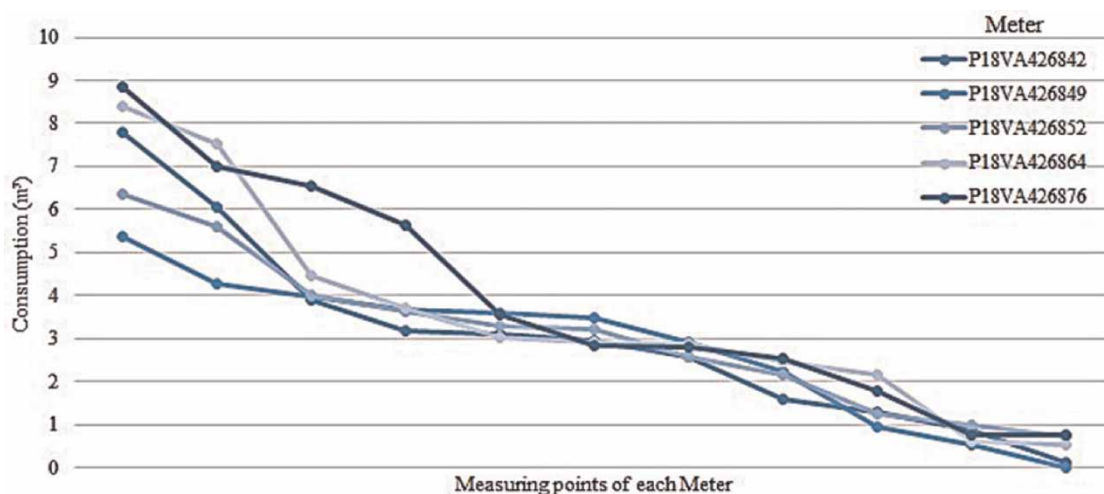


Figure 9 | Comparison of meter readings.

Estimated future water endowment

In addition to the characteristics of the users, information was collected on individual consumption per week, with the purpose of estimating the real water endowment of the sector (CONAGUA 2007), with a result of 150 L/person/day. This result is important for real modeling and to determine, in the near future, the behavior of continuous flow and demand. This would be achieved using the EPANET simulation model.

Demand forecast calculations, based on consumption analysis, resulted in the following:

3,500 user accounts in the sector.

3 users per account means 10,500 users in total.

150 L/person/day equals 1,605,500 L/day or 18.6 L/sec.

The Riberas de Sacramento sector has a flow meter that generates a graph of the actual consumption flow in the sector that allows us to compare data and draw some conclusions. The research allowed us to identify the characteristics of consumption in Riberas del Sacramento: actual supply in the area (150 L/person/day), hours of highest consumption (17.00–21.00), water flow rate with the highest value in L/sec (500–1,000 L/h) and classification of users regarding the type of consumption in general (2 m³ to 4 m³ average per week).

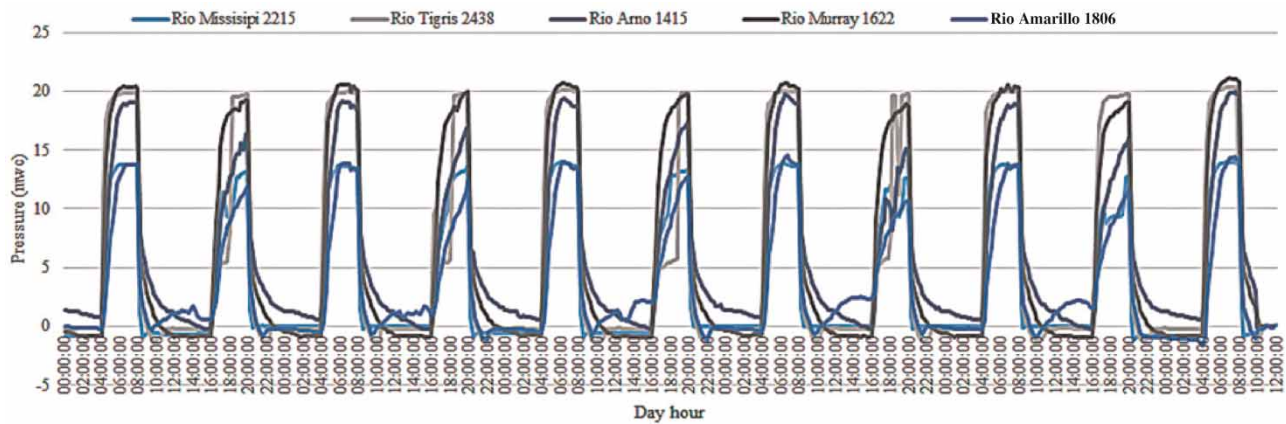


Figure 10 | Comparison of pressures by representative points of zones.

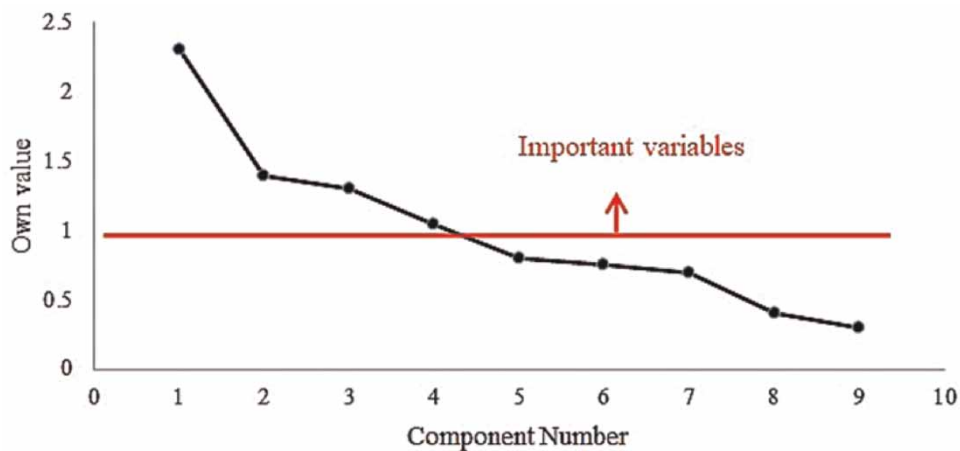


Figure 11 | Multivariate sedimentation analysis.

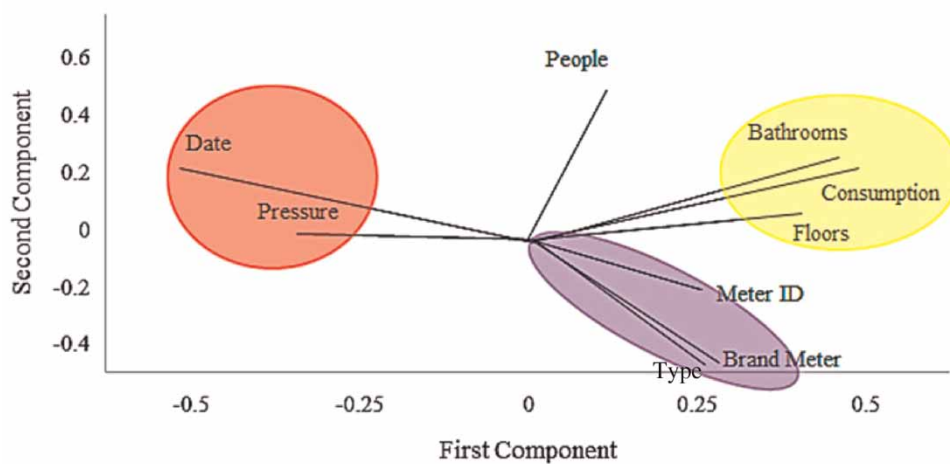


Figure 12 | Components of multivariate analysis.

Table 3 | Values of coefficient components

Variable	PC 1
Date	−0.417
Meter ID	0.182
Bathrooms	0.441
People	0.184
Floors	0.357
Meter type	0.264
Meter brand	0.279
Consumption	0.457
Pressure	−0.286

This analysis will be useful for forecasting future demand, based on per capita consumption. Water consumption in liters per capita per day was correlated with the pattern of supply, green areas, family size and age of the householder (Fan *et al.* 2013). For this reason, the characteristics of the population in a study are important to detect certain variants that cause effects on the results (Willis *et al.* 2013).

CONCLUSIONS

The analysis of information on the housing characteristics of users reflects important trends in the future behavior of the sector. The vast majority of the users surveyed are classified as: three-member family, one-storey house. They do not have a meter and are connected to the network with a hose. This is representative of the sector. The consumption of these users will be reflected in the global analysis of the consumption information.

Multivariate analysis of the consumption of the target population indicated that there was an opposite relationship between pressure and consumption. That is, flow pressure did not affect consumption, nor did higher pressure increase consumption. As pressure and consumption were on opposite sides of the components graph; it is assumed that in this study what reflects more the amount of consumption of the users are characteristics such as the number of bathrooms and the number of floors of the house. The pressure is not analyzed in depth because the service is intermittent and most of the time that there is good pressure is dedicated to filling water networks and water tanks in the houses.

Another important observation is the direct relationship between consumption and the number of toilets in the dwelling. The number of similar users reflects a trend that can be considered a pattern when it comes to normalizing their consumption to a detected average value. The correlation between variables resulted in several graphs with a common result between consumption values and living conditions by stratigraphic location according to the classification performed. By means of the previous stratigraphic analysis, the basis of this research, it was possible to find a uniformly distributed sample that reflects the general behavior of the sector. The study evidences the pattern and magnitude of consumption data, previously recorded in the equipment, sub-classified by the characteristics of the people living in the site: inhabitants of the house, size of the dwelling, number of bathrooms and the type of meter installed in the register. Not having a meter is a peculiar characteristic that defines non-discriminate consumption.

It is difficult to establish, from the results of this research, the exact time in which the supply behaves on a continuous delivery and not intermittent mode. It can only be said that, thanks to the multivariate analysis of the consumption data and its correlation with the particular characteristics of the users, it is certain that the study area had a non-permanent supply due to the flow variations.

This modality forced users to develop consumption practices, including storage in water tanks and cisterns, and to reduce consumption during the hours when the supply valves are closed. An important factor to consider is the detection of the impact generated by the constant filling of individual storage tanks that affects the time taken by the network to re-establish a continuous flow of water.

It is important to gather this information for future analysis to identify consumption patterns in the area, which can also be adapted to any other area of the city, based on a multivariate analysis of the specific characteristics of the users already

detected and their actual consumption. The intermittent water supply invariably affects the consumption pattern of the user under the schedule that is being discussed since it forces them to use a minimum of 1 hour to fill the tank that is used as a reserve for water during the hours of the day when water is not supplied. These patterns could be elaborated with the combination of the analysis of a study performed with Contazara domestic water meters and with pulse domestic water meters to complement the first analysis and the specific detection of the exact moments of change from permanent to non-permanent flow by recording the pressure behavior by means of autonomous equipment designed for that purpose.

The comparison of the daily supply calculation from particular measurements of the users under study and the actual consumption of all users in the sector, gives us a similarity that encourages a favorable extrapolation of the study to another region or sector and to generate reliable data for forecasting future demand based on the growth of the population. This result is not close to the standard of current values, billed by consumption in the sector, of the regulatory agency of the drinking water service and differs from what is considered in the literature for sectors with similar characteristics and average water endowments proposed in the country. In other words, the water endowment for each particular community has to be based on a previous analysis such as the one performed in this research in order to be more realistic.

This study functions as a preliminary reconnaissance of the area to later carry out an analysis of the same sector, using pulse sensor meters to determine the stochasticity of the users' consumption and its correlation with a hybrid demand pattern that is better adapted to the type of potable water supply existing in the area. Note that analyses can be made not only in a continuous supply but also in an intermittent supply that is intended to transition to a continuous supply. As limitations for the improvement of this study, it should be mentioned that it will be difficult for the Riberas de Sacramento sector to change to a continuous supply due to the lack of knowledge of the operating agency regarding the benefits that it entails and because they are accustomed to an intermittent supply which in a very comfortable way has allowed them to manage the distribution of water volumes at their discretion. It is intended that through this study we begin to have knowledge of water consumption in intermittent supply to be compared later in another study with a continuous supply and see results that would lead to a change in thinking about the intermittent supply that causes many limitations.

DATA AVAILABILITY STATEMENT

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

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