Water Supply

Water Supply Vol 23 No 5, 1953 doi: 10.2166/ws.2023.100

Spatio-temporal changes in urban water consumption during 2 years of the COVID-19 pandemic in southern Brazil

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ABSTRACT

This study investigated the changes that occurred during the COVID-19 pandemic in urban water consumption in residential, commercial, industrial, and public agencies in the city of São Leopoldo, southern Brazil, which has about 55,000 consumers and over 200,000 inhabitants. Overall, the city increased water consumption by 5.6% during the 2-year pandemic, with 5.9% in 2020 and 5.5% in 2021. Residential and industrial consumption increased by 6.77 and 9.92% in the first year, and by 5.47 and 14.45% in the second year, respectively. On the other hand, commercial and public sector consumption decreased by 5.48 and 46.26% in the first year and 1.83 and 40.99% in the second year, respectively. In the first months of the pandemic, there was a sharp increase in residential water consumption at the same time as a reduction in consumption in the other categories. In contrast, there was a slight return to previous water consumption patterns in the following months. Overall, we can affirm that the more central neighborhoods presented higher changes in water consumption than the peripheral neighborhoods. In addition, the water consumption during the pandemic and pre-pandemic periods was statistically different for residential, industrial, and public consumers.

Key words: commercial water consumption, COVID-19, industrial water consumption, public water consumption, residential water consumption

HIGHLIGHTS

- Residential water consumption has increased by 1 m^3 per household per month.
- Commercial and public establishments' water consumption decreased sharply during two pandemic years.
- The increase in COVID-19 containment measures generally causes an increase in residential water consumption.
- After 2 years, there was a slight return to previous water consumption patterns.

1. INTRODUCTION

The first case of a novel coronavirus was officially recorded in December 2019 from China. Three months later, in March 2020, the World Health Organization (WHO) declared the situation a pandemic, given the alarming spread and severity of the SARS-CoV-2 virus, which causes COVID-19 (WHO 2020a). At that time, the world had recorded 118,000 cases of the disease distributed across 114 countries, of which Brazil was responsible for 52 cases (Brazil Ministry of Health 2022; WHO 2022). Two years after the start of the COVID-19 pandemic, the world registered the mark of 446 million infected. Brazil, which has been the disease's epicenter several times, exceeded the number of 26 million infected, with more than 649,000 deaths (Brazil Ministry of Health 2022; WHO 2022), four times more infected than the global average. All this resulted in a calamity that affected millions of people's health and living conditions.

To contain the spread of the new coronavirus based on WHO guidelines, many countries started public health campaigns and imposed control measures. Among these measures, the stay-at-home order has the most marked impact by limiting the movement of people and preventing viral transmission through physical and social distancing (WHO 2020a). This containment measure encompasses travel restrictions, changes in workplaces, reductions in social events, and suspension of face-to-face classes in schools and universities, thus dramatically changing people's behavioral habits. Another essential measure implemented has been the expansion of hygiene habits, such as encouraging frequent hand washing and surface disinfection to prevent viral spread (WHO 2020b). Koh (2020) states that as early as April 2020, more than a third of the global population was under some restriction or blockage to limit the virus's transmission.

The COVID-19 pandemic and its respective control measures have impacted the most diverse segments of society worldwide. Electricity consumption increased in homes located in Quebec City, Canada (Rouleau & Gosselin 2021). There were negative impacts on health and psychological well-being in the USA and European countries (Brown *et al.* 2021; Leenaerts *et al.* 2021; Misery *et al.* 2021; Mulugeta & Hoque 2021). On the other hand, anthropic pressures on the environment were reduced in Milan (Italy) and Wuhan (China) (Firozjaei *et al.* 2021). Urban water consumers were directly affected too, with a widespread increase in residential water consumption during the pandemic (Kalbusch *et al.* 2020; Alvisi *et al.* 2021; Elmaslar Özbaş *et al.* 2021; Feizizadeh *et al.* 2021; Hoolohan & Browne 2021; Kazak *et al.* 2021; Rouleau & Gosselin 2021; Nemati & Tran 2022). Studies of non-residential water consumption have also been developed showing reductions in water consumption that vary by type and level of consumer (Kalbusch *et al.* 2020; Abulibdeh 2021; Alvisi *et al.* 2021; Irwin *et al.* 2021; Li *et al.* 2021; Fritsche *et al.* 2022).

Consumption and demand for water are directly related to the services in which this resource is used, for example, industrial consumption depends on what is produced, the technology used in production, the operating hours of the plant, and the external demand for the product. Similarly, public and commercial consumption also depends on the opening hours of the establishment, and in the case of commercial, it also depends on the demand for the product sold, a situation that can be influenced by various factors, such as the weather when we think about the sale of winter clothes and summer. Finally, residential consumption is controlled by several factors, including sociodemographic (Feil & Tucci 2014; Makki *et al.* 2015; Fan *et al.* 2017; Barnett *et al.* 2020) and climatological aspects (Feil & Tucci 2014; Suh & Ham 2016; Fan *et al.* 2017a, 2017b). These factors influence water consumption in everyday situations. However, additional factors may alter water consumption during environmental disasters or health crises, such as the COVID-19 pandemic.

Relevant articles were published on water consumption during the COVID-19 pandemic (Buurman *et al.* 2022). After extensive research evaluating how water use patterns were affected by social distancing measures in different places, Buurman *et al.* (2022) found that water consumption increased by about 5% over 2020, reaching 13% during more restrictive measures.

Only three quantitative studies have been developed to investigate the relationship between COVID-19 prevention measures and urban water consumption in Brazil. Kalbusch *et al.* (2020) observed that water consumption during the first 26 days of the pandemic changed. Based on observations from a city in the south of the country, home consumption was found to have increased, while shops, industries, and public bodies showed decreases. Campos *et al.* (2021) made a more qualitative assessment of the behavior of water users through questionnaires applied in nine Brazilian states. Their study found that the hygiene habits most influenced by the pandemic were (in descending order): handwashing with soap and water, floor cleaning, food hygiene, and frequency and duration of baths, all of which involved changes in water consumption. Silva *et al.* (2022) investigated changes in residential and commercial water consumption in 31 municipalities in São Paulo, Brazil. The investigation compared observed and predicted water consumption for each sector from January to June 2020, showing an average difference equal to +6.23 and −18.59% for residential and commercial activities, respectively.

There is, therefore, a need to understand how the COVID-19 pandemic has impacted water demand, considering a range of spatial and temporal scales, communities, and diverse participants, to better understand the unique changes to water use and water-related practices, for whom and why. By composing the state of the art of current studies on the subject, and by highlighting the temporal and spatial vulnerabilities of the urban water supply system, the research helps to better prepare both users and service providers for future extreme 'stay home stay safe' situations. This is especially true in light of the fact that certain changes in routines are still in effect even after 2 years of the pandemic and will likely remain in effect for years to come. Thus, this study aims to evaluate the changes in urban water consumption during the COVID-19 pandemic, comprising data from all users of the water supply system of a city with more than 200,000 inhabitants in southern Brazil.

The main innovation of this study is aided in the spatio-temporal understanding of water consumption from an extensive database. By quantifying the impact of COVID-19 on water consumption from monthly data from 3 years before (from March 2017 to February 2020) and 2 years after (from March 2020 to February 2022) the start of the pandemic, representing a set of more than 3 million data, along with the spatial analysis of water consumption for different categories of users, it was possible to estimate which city sectors were most impacted, which categories accounted for the largest variations in consumption, and what the water consumption scenario is after 2 years of the pandemic.

In the following items, we present the methodology used in the study, which includes the description of the case study, the data of water consumption analyzed and the different categories of consumers, and the method of temporal and spatial data analysis. Finally, we present the results of temporal and spatial changes in water consumption.

2. METHODOLOGY

An analysis of the urban water consumption changes after 2 years of the COVID-19 pandemic was developed for São Leopoldo in southern Brazil. First, all urban water consumption data were analyzed and went through a data cleaning process. This preliminary analysis resulted in the selection of 54,811 consumers, for whom a total of 3,288,660 records of monthly water consumption were available for evaluation. We then assessed the changes in the total volume of water consumed, comparing data from 3 years before and 2 years after the pandemic's beginning. Then, to better understand the changes, we performed a monthly temporal assessment of the data and concluded the survey with a spatial assessment of these changes. All statistical analyses were performed in R version 4.1.3 (R Core Team 2022).

2.1. Case study

The case study considered is the city of São Leopoldo, situated in the state of Rio Grande do Sul (RS) (Figure 1(b)), in the south of Brazil (Figure 1(a)). The state of Rio Grande do Sul is in the south temperate zone, and the climate is predominantly humid subtropical; the average temperatures range from 15 to 19 °C; however, during hot, humid summers, the highs frequently surpass 40 °C in some regions and lows usually fall below 9 °C, reaching as low as −10 °C (Moreno 1961).

The São Leopoldo overall area is 102.7 km², bordered by the municipalities of Estância Velha to the north, Novo Hamburgo to the northeast and east, Sapucaia do Sul to the south, and Portão to the west. It represents 5.4% of the Metropolitan Region of Porto Alegre-RS population, located 13.4 km away (Figure 1(c)). Moreover, São Leopoldo-RS is politically and administratively divided into 24 neighborhoods (Figure 1(d)) that range in size from 0.389 km² (Padre Reus) to 8.876 km² (Arroio da Manteiga). Each community has different characteristics that also influence water consumption. The Centro, for example, is characterized as predominantly commercial and the city's administrative center. The neighborhoods of Santos Dumont, Arroio da Manteiga, São Miguel, Feitoria, Vicentina, and Santa Tereza are predominantly residential, with more socially vulnerable households than other neighborhoods, characterized by a higher presence of low-income individuals. However, there are also a few residential neighborhoods marked by the presence of industries, such as Fião and São Borja.

In 2010, there were 214,087 residents in the city, with a registered demographic density of 2,339.72 inhabitants/km^2 (IBGE 2010). Current estimates suggest that this population has increased to 240,378, with a registered demographic density of 2,340.58 inhabitants/km^2 (IBGE 2023). Of this total of inhabitants, approximately 99.6% are served by the municipal water and sewage service, SEMAE (SNIS 2020). In addition to residential services, SEMAE also supplies industries, commercial establishments, and public buildings such as hospitals, buildings of government, and many schools.

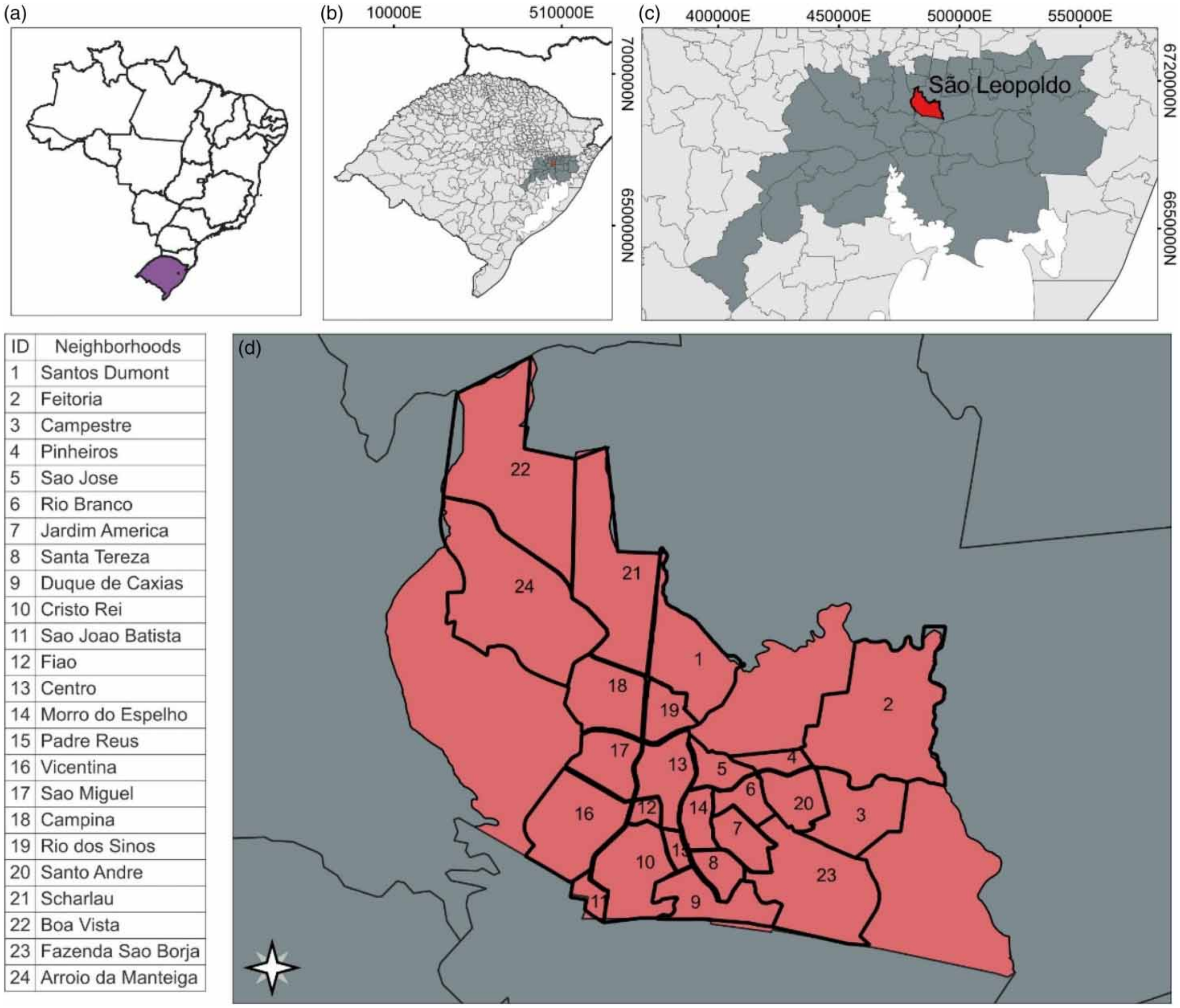
In 2020, the average monthly wage was about US$701.42. The proportion of employed people in the total population was 28.2%. Moreover, in terms of health, the average infant mortality rate in the city was 6.86 deaths per 1,000 live births in 2020, and the hospitalizations due to diarrhea were 0.3 per 1,000 inhabitants in 2016. Regarding COVID-19 incidence, São Leopoldo recorded 40,359 cases 2 years after the pandemic, indicating that 16.8% of its population was infected. This value is slightly above the national average of 12.2% of the population infected in the same period.

The city government issued 100 decrees over the course of 2 years to establish pandemic control measures. Most of the decrees implemented restrictive measures with a validity period of 15 days, often extended or updated with new measures. It is important to highlight some of the most notable decrees, including one in June 2020 that prohibited the operation of many public spaces and one in December 2020 that affected commerce, public services, and industry.

Vaccination against COVID-19 started in January 2021 in Brazil, and as a result, there was a relaxation of control measures. However, due to the vaccination process not occurring so quickly, the restriction measures had to be increased in May 2021. Between July and October 2021, no virus containment measures were published. In November, new measures were issued to regulate the community's actions before the end-of-the-year holidays.

At the end of the 2 years of the pandemic, new decrees were again issued due to the increase in the number of new cases. However, the level of restriction in these decrees was lower compared to those published in the first year of the pandemic.

In Figure 2, we present the number of confirmed COVID-19 cases and the number of containment measures implemented per month during 2 years of the pandemic. This information was taken from the Brazilian government's official internet



ID	Neighborhoods
1	Santos Dumont
2	Feitoria
3	Campestre
4	Pinheiros
5	Sao Jose
6	Rio Branco
7	Jardim America
8	Santa Tereza
9	Duque de Caxias
10	Cristo Rei
11	Sao Joao Batista
12	Fiao
13	Centro
14	Morro do Espelho
15	Padre Reus
16	Vicentina
17	Sao Miguel
18	Campina
19	Rio dos Sinos
20	Santo Andre
21	Scharlau
22	Boa Vista
23	Fazenda Sao Borja
24	Arroio da Manteiga

Figure 1 | Map of (a) the state of Rio Grande do Sul in Brazil, (b) the Metropolitan Region of Porto Alegre, the state capital, (c) the city of São Leopoldo in the Metropolitan Region, and (d) administratively divided.

portals (São Leopoldo 2022). As shown, during the first year of the pandemic, the highest number of restrictions coincides with the month in which there was a reduction in the number of infected (September 2020). Similarly, when the number of publications of restrictive measures decreased in November 2020, there was an increase in the number of new cases, shown by a peak in December 2020. In addition, Figure 2 can be observed towards an increase in the number of cases between October and December 2020, which was interrupted in January 2021 when vaccination began in the city. The second year of the pandemic was marked by a reduction in cases and a consequent reduction in virus control measures. However, in January 2022, the number of infected people increased again, which may be related to the reduction in the number of decrees, increased movement of people on the streets, especially during holidays and vacations, and the emergence of a new variant of the coronavirus.

2.2. Data collection

Monthly data on the water consumption of each user of the supply system was made available by SEMAE from March 2017 to February 2022. These data were organized into four categories of consumers: residential consumer (RC), commercial consumer (CC), industrial consumer (IC), and public consumer (PC). Note that RCs represent houses or apartments with an average of three inhabitants per residence (IBGE 2010). The CCs represent all commercial establishments in the city, such

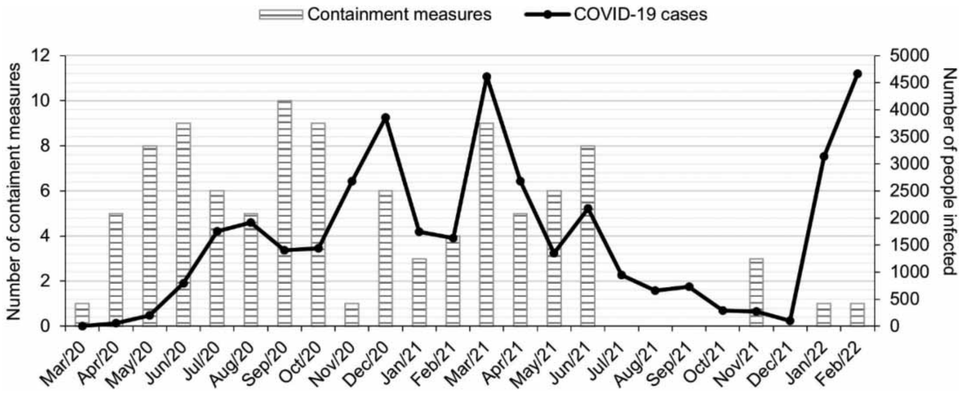


Figure 2 | Relationship between the number of newly infected and the number of containment measures published to contain the virus in São Leopoldo per month (March 2020–February 2022).

as pharmacies, supermarkets, shops, hotels, restaurants, etc. ICs are factories and industrial parks, while the PC category reflects the water consumption of schools, hospitals, and other public administration bodies. Also, the data were divided into two periods: (1) pandemic, from March 2020 to February 2022, and (2) pre-pandemic, from March 2017 to February 2020.

To assess the effects of the containment measures on water consumption in the city of São Leopoldo-RS, the entire user dataset was subjected to a preliminary analysis, as the number of consumers differed throughout the study period (64,408 in 2017, 65,250 in 2018, 66,664 in 2019, 65,804 in 2020, 66,384 in 2021, and 66,284 in 2022). In addition, several consumers recorded no consumption during the time series. Thus, to compare the same consumers over both periods (i.e., pre-pandemic and pandemic), we removed those with zero water consumption in all analyzed months, or during the 2 years of the pandemic, those consumers who were not present throughout the entire analyzed period, and those consumers who have the same consumption record across the data series. As result, a total number of 54,811 consumers were analyzed and distributed in four categories, as presented below.

Figure 3 shows the spatial distribution of users of São Leopoldo's water supply system, organized by consumer category. Figure 3 shows that users of the water supply system are predominantly residential, representing 50,813 consumers, about 92.7% of the total, followed by CC with 3,595 consumers (6.6%), IC with 339 consumers (0.6%), and, finally, the PC category with 64 consumers (0.1%). Although RC and CC are registered in all neighborhoods in the city, IC and PC are not (Figure 3). The PCs are concentrated in 16 neighborhoods, which is coherent when one observes the low number of users in this category. On the other hand, only one city neighborhood, 12-Fião, has no record of ICs.

2.3. Analysis of the temporal changes in water consumption

A temporal analysis of urban water consumption during the pandemic is the main tool used to assess the changes that occurred during this period (Kalbusch *et al.* 2020; Abu-Bakar *et al.* 2021; Alvisi *et al.* 2021; Cvetković *et al.* 2021; Feizizadeh *et al.* 2021; Kazak *et al.* 2021; Rahim *et al.* 2021; Rizvi *et al.* 2021; Rouleau & Gosselin 2021).

For each consumer category, the monthly data were organized into two groups according to the period of analysis: pre-pandemic (year 2017: March 2017 to February 2018; year 2018: March 2018 to February 2019; and year 2019: March 2019 to February 2020) and pandemic (year 2020: March 2020 to February 2021 and year 2021: March 2021 to February 2022).

In the first step, the total volumes of water consumed each year for each consumer category were calculated, considering all consumers. For each year, the percentage change related to the average water consumption in the pre-pandemic period (PPPA) was then calculated.

In the second step, the total monthly water consumed by each consumer category was estimated, considering all consumers. The Shapiro–Wilk normality test (Shapiro & Francia 1972) was used to verify the normality of the monthly data distribution, which showed that these data are not normally distributed. Based on this result, the non-parametric Wilcoxon Paired test (Wilcoxin & American Cyanamid Co., 1992) was applied considering the water consumption for 2017, 2018, 2019, 2020, and 2021, and the PPPA as has also been applied in similar previous studies (e.g., Kalbusch *et al.* 2020). A p-value < 0.05 was considered statistically significant.

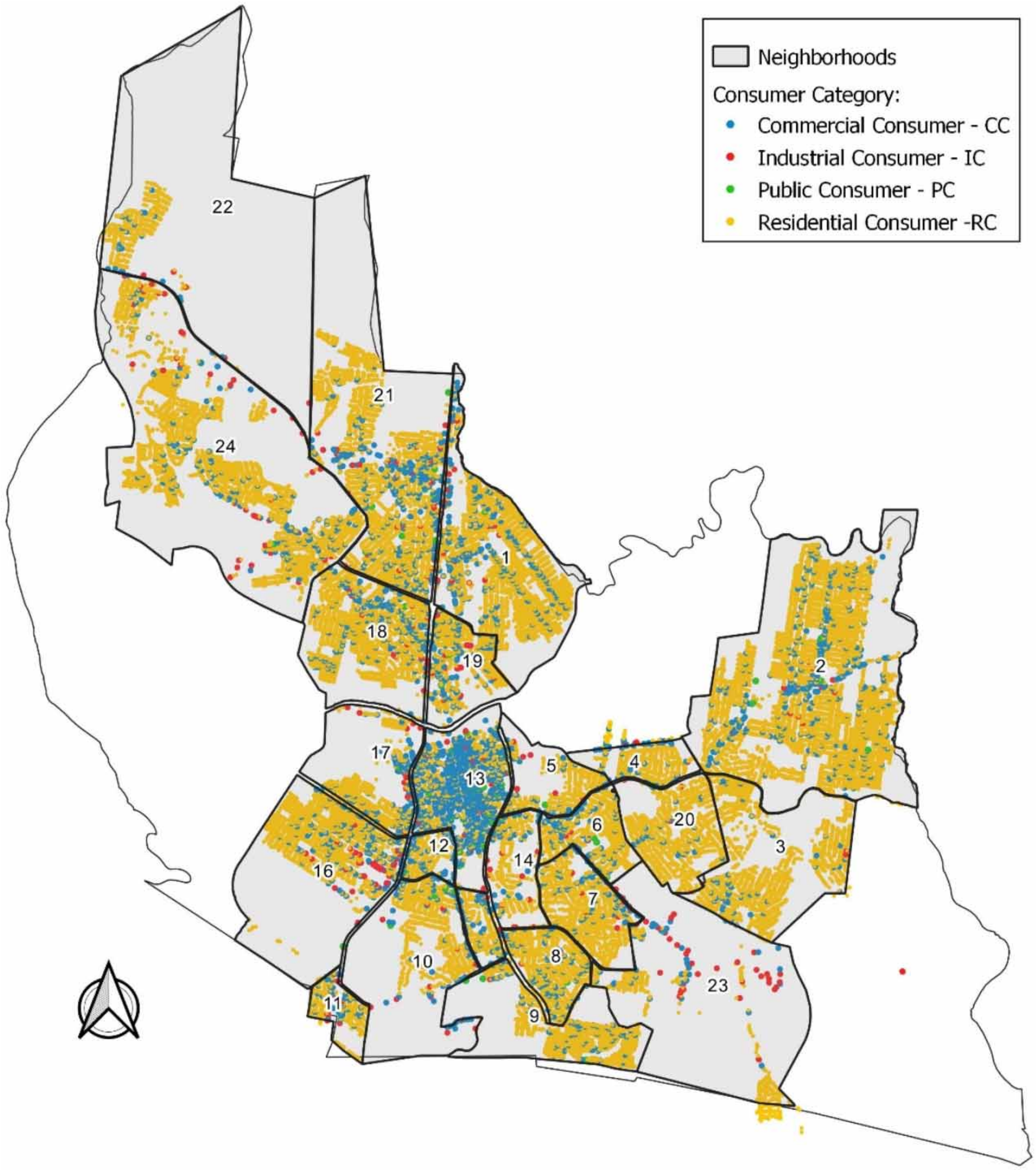


Figure 3 | The water supply system users with consumption data in the analyzed period, organized by consumer category.

Additionally, a comparison of the monthly water consumption was made using boxplot graphs. The results compared the monthly water consumption in the pre-pandemic and pandemic periods, and the observed differences were also compared with those obtained in other studies.

2.4. Analysis of the spatial changes in water consumption

Initially, we obtained each system user's monthly average water consumption in the pre-pandemic and pandemic period.

Next, we checked whether there was a statistically significant difference between the consumption in the two periods for each user of the system. This analysis was performed through hypothesis tests, which considered situations with parametric and non-parametric data, and a p-value < 0.05 as being statistically significant. Thus, the consumers who presented a statistically significant change in monthly water consumption between the two periods were selected and grouped by neighborhood and user category.

The next step was to estimate the monthly variation in water consumption in each consumer category in each neighborhood. We did this by dividing the average consumption of each category in the neighborhood by the number of consumers of each category who presented some significant change. These values, along with the percentage of consumers of each category in each neighborhood who had significant changes in water consumption, were analyzed.

3. RESULTS AND DISCUSSION

3.1. Temporal changes in water consumption

Figure 4 reveals the change in annual water consumption during the pandemic period (March 2020–February 2022) and the pre-pandemic period (March 2017–February 2020) related to the PPPA for all categories of consumers. The figure shows that the RC and IC increased the yearly water consumption during the pandemic period whereas the CC and PC decreased. Overall, the average annual total water consumption between the pre-pandemic period and the pandemic increased by 5.6% (5.9% in 2020 and 5.5% in 2021), similar to that observed in the review by Buurman *et al.* (2022). Although this value seems low in percentage, it represents a volume of around 554,000 m³ of water.

The *p*-value of the paired Wilcoxon test (Table 1) revealed the effect of the COVID-19 pandemic on water consumption. The effect of the pandemic on RC and PC water consumption was observed when there was a significant difference between 2020 and 2021's consumption compared to all the pre-pandemic years' consumption and their PPPA. On the other hand, considering only the interpretation of the *p*-values of the CC and IC consumption (Table 1), there is no guarantee to attribute all changes in consumption to the pandemic since there was no significant difference between the consumption in 2017 and 2020 for the IC, and the CC consumption showed no clear changes between the pandemic and pre-pandemic period.

In terms of quantity, the higher water consumption increase was in the RC, an observation consistent with the findings of Alvisi *et al.* (2021), Nemati & Train (2022), and Buurman *et al.* (2022). Figure 4(b) shows a water consumption change of 6.8% in 2020, representing approximately a volume of 589,000 m³, and a water consumption change of 5.5% in 2021, representing approximately 476,000 m³. This result shows that during the pandemic, there was a reflection of the social distancing measures on residential water consumption, so RCs started to stay at home for longer, which justifies the significant increase

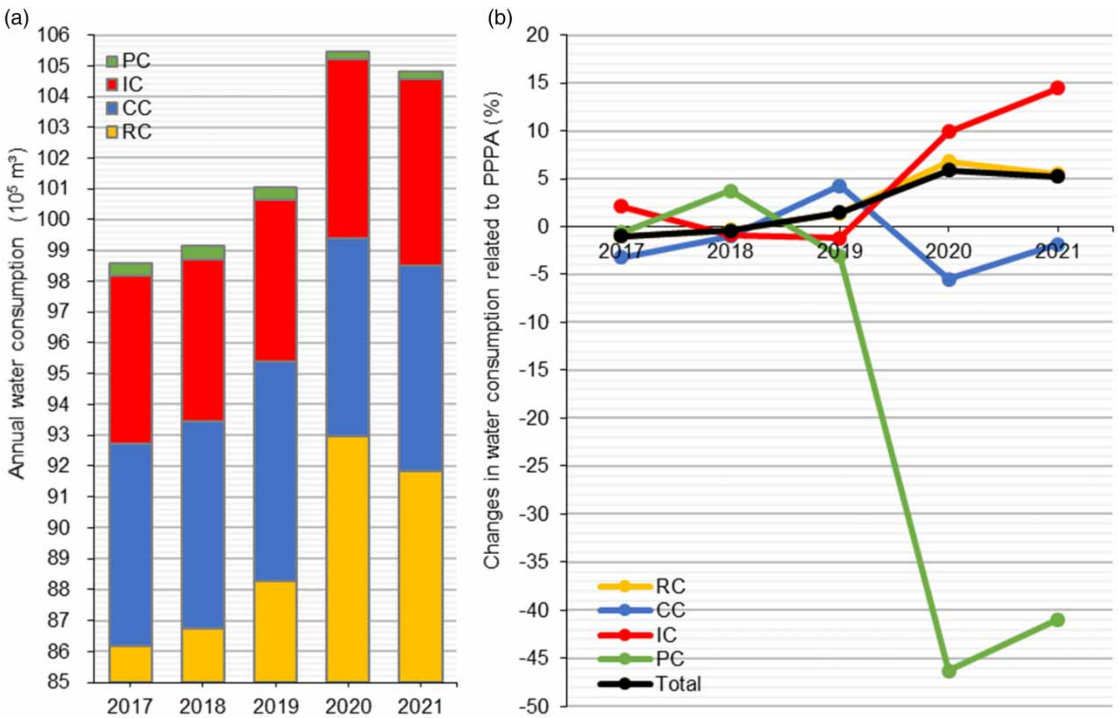


Figure 4 | Water consumption for different consumer categories from 2017 to 2021: (a) total annual water consumption, and (b) changes (%) related to PPPA.

Table 1 | *p*-value of the paired Wilcoxon test

	RC					IC					CC					PC				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
2018	0.791					0.204					0.640					0.151				
2019	0.109	0.380				0.266	0.970				0.001	0.007				0.308	0.110			
2020	0.001	0.009	0.021			0.204	0.042	0.042			0.470	0.110	0.001			0.001	0.001	0.001		
2021	0.001	0.001	0.002	0.622		0.003	0.002	0.005	0.176		0.176	0.733	0.001	0.151		0.001	0.001	0.001	0.151	
PPPA	0.339	0.791	0.151	0.002	0.001	0.204	0.519	0.340	0.034	0.001	0.001	0.233	0.001	0.042	0.301	0.470	0.092	0.064	0.001	0.001

in consumption (p-value < 0.05), especially in 2020 when there was a greater number of restriction measures published (Figure 2).

Another important point is the fact that the growth of residential water consumption showed a slightly linear pattern (about 100,000 m^3/year) in the period leading up to the pandemic (Figure 4), likely justified by population growth and urban expansion, which justifies the PPPA not significantly different to 2017, 2018, and 2019, but is significantly different compared to 2020 and 2021 (pandemic period).

In relation to IC, in 2020, it increased by 9.9% compared to the average annual consumption of the pre-pandemic period, and in 2021, this difference increased to 14.5% (Figure 4(b)). Despite the fact that IC had the highest positive percentage change and significant difference between 2020 and 2021 (p-value < 0.05), in terms of volume, the yearly increase was only 52,000 and 76,000 m^3, respectively. Industrial water consumption during the pandemic was different from that consumed in 2017, 2018, and 2019, as well as the average for this period. The only exception is the comparison between 2017 and 2020, where there was no significant difference. Industrial consumption had a slight negative slope between the years before the pandemic, thus 2017 had the highest consumption of the period. During the pandemic, this scenario changed: industrial consumption started to increase, justifying the fact that there is no significant difference between 2017 and 2020.

In contrast to the RC and IC, the water consumed by the PC and CC decreased. The reduction was more significant for public agencies (PC). Before the pandemic, PC consumed about 43,000 m^3/year, and after the pandemic started, PC consumed about 24,400 m^3/year, representing a reduction of approximately 44%. This reduction is evidenced in Figure 4, in which 2020 showed a reduction of 46.3% and 2021 of 41.0%. Similar to residential consumption, public consumption showed no significant difference between the pre-pandemic period and the pandemic period, but showed significant differences when comparing years of both periods (Table 1).

Commercial consumption had a growth pattern in the period leading up to the pandemic (Figure 4). The 2017 consumption showed a negative change (−3.2%) relative to PPPA, and that figure went to −1.0% in 2018, until it peaked in 2019 with a positive change of 4.3%, representing a significant difference from previous years (Table 1). With the COVID-19 pandemic, shopping centers had to suspend their in-person activities, mainly in 2020 (Figure 2), which implied the reduction of water consumption by these establishments to the same levels as 2017 and 2018, a situation corroborated by the p-value > 0.05 for these combinations (Table 1). With the return of face-to-face activities in 2021, commerce increased water consumption again, but maintained a low consumption compared to pre-pandemic levels.

The comparison between boxplots of the monthly water consumption volumes of all consumers in each category better explains the changes that occurred during the pandemic (Figures 5–8). As presented in Figure 5, the first months of the pandemic (Figure 5(a) and 5(b)) showed an increase in residential water consumption; this situation is consistent with observations from other countries, such as the USA (Nemati & Tran 2022), Iran (Feizizadeh *et al.* 2021), Italy (Alvisi *et al.* 2021), the United Arab Emirates (Rizvi *et al.* 2021), Poland (Kazak *et al.* 2021), and Canada (Rouleau & Gosselin 2021). After 1 year of the pandemic (February 2021), consumption had returned to similar pre-pandemic behavior.

By comparing results from 2020 to the pre-pandemic (Figure 5), a higher variability in residential water consumption during the pandemic of COVID-19 was observed. In the pre-pandemic period, half of the users had a consumption around ± 4.5 m^3 of the median value of the month; however, during the pandemic, this variation was ± 5.5 m^3. The maximum monthly values of residential water consumption showed higher changes (Figure 5).

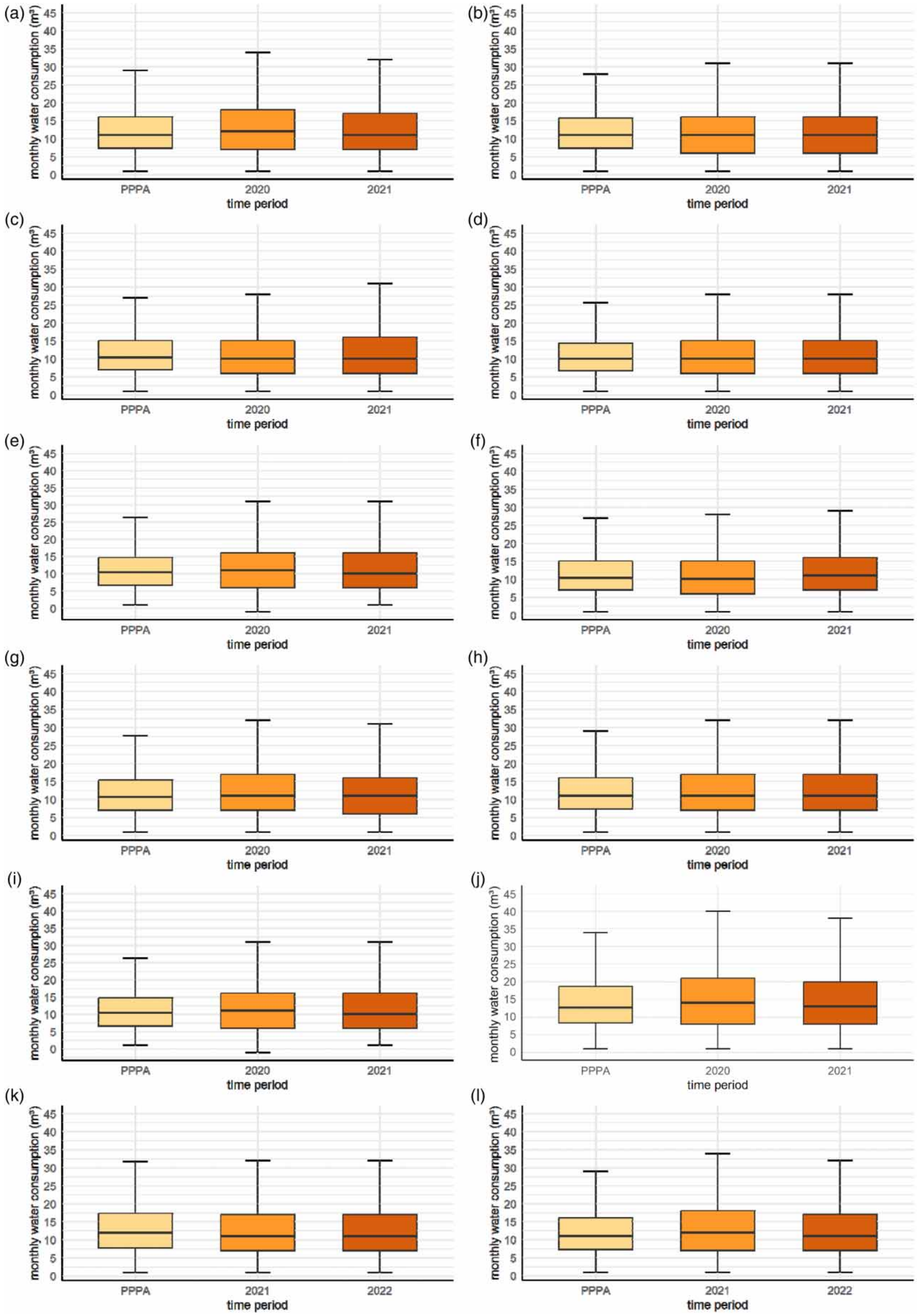


Figure 5 | Comparison between the volume of water consumed per month in the pre-pandemic and pandemic periods for residential water consumption. (a) March, (b) April, (c) May, (d) June, (e) July, (f) August, (g) September, (h) October, (i) November, (j) December, (k) January, and (l) February.

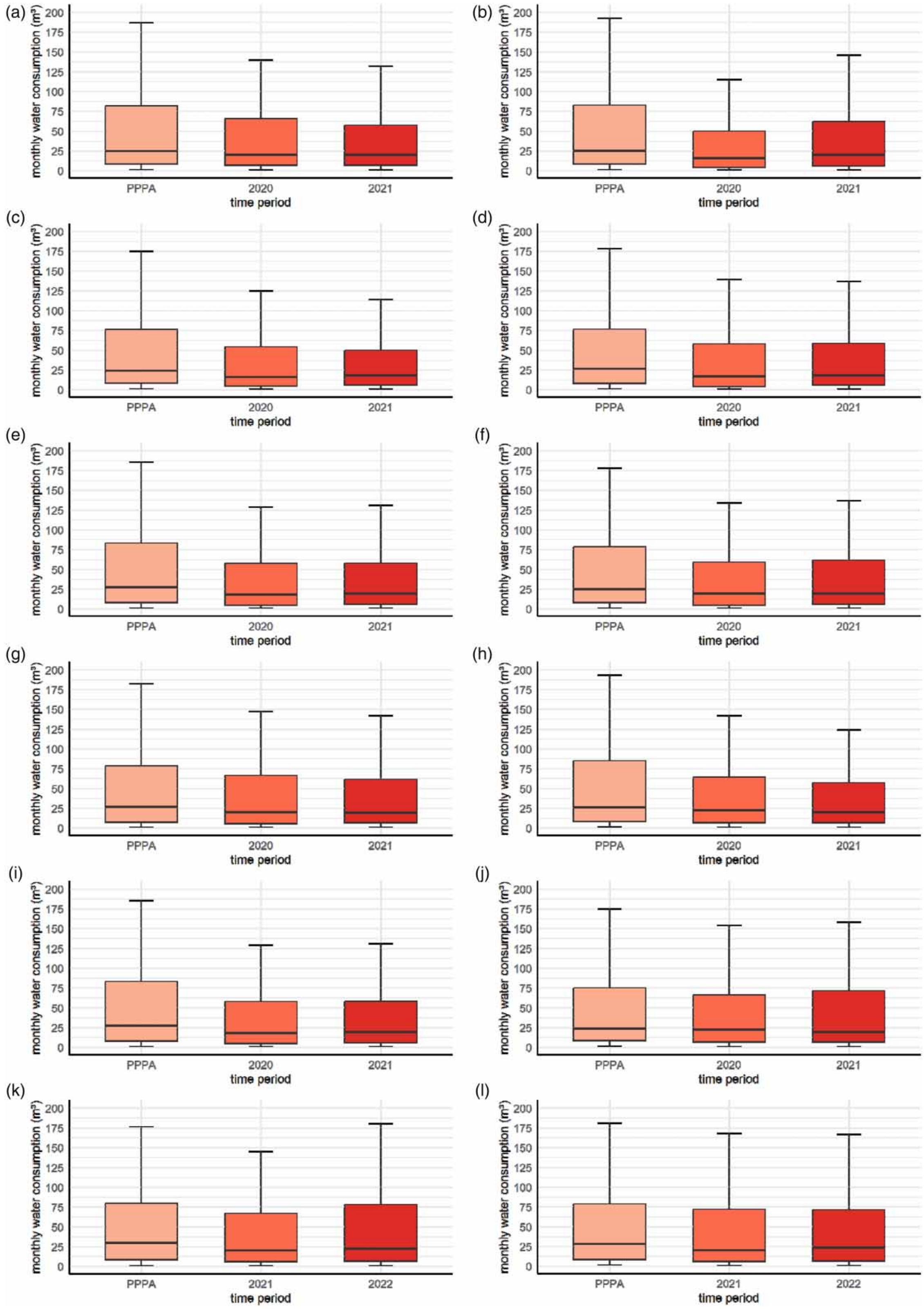


Figure 6 | Comparison between the volume of water consumed per month in the pre-pandemic and pandemic periods for industrial water consumption. (a) March, (b) April, (c) May, (d) June, (e) July, (f) August, (g) September, (h) October, (i) November, (j) December, (k) January, and (l) February.

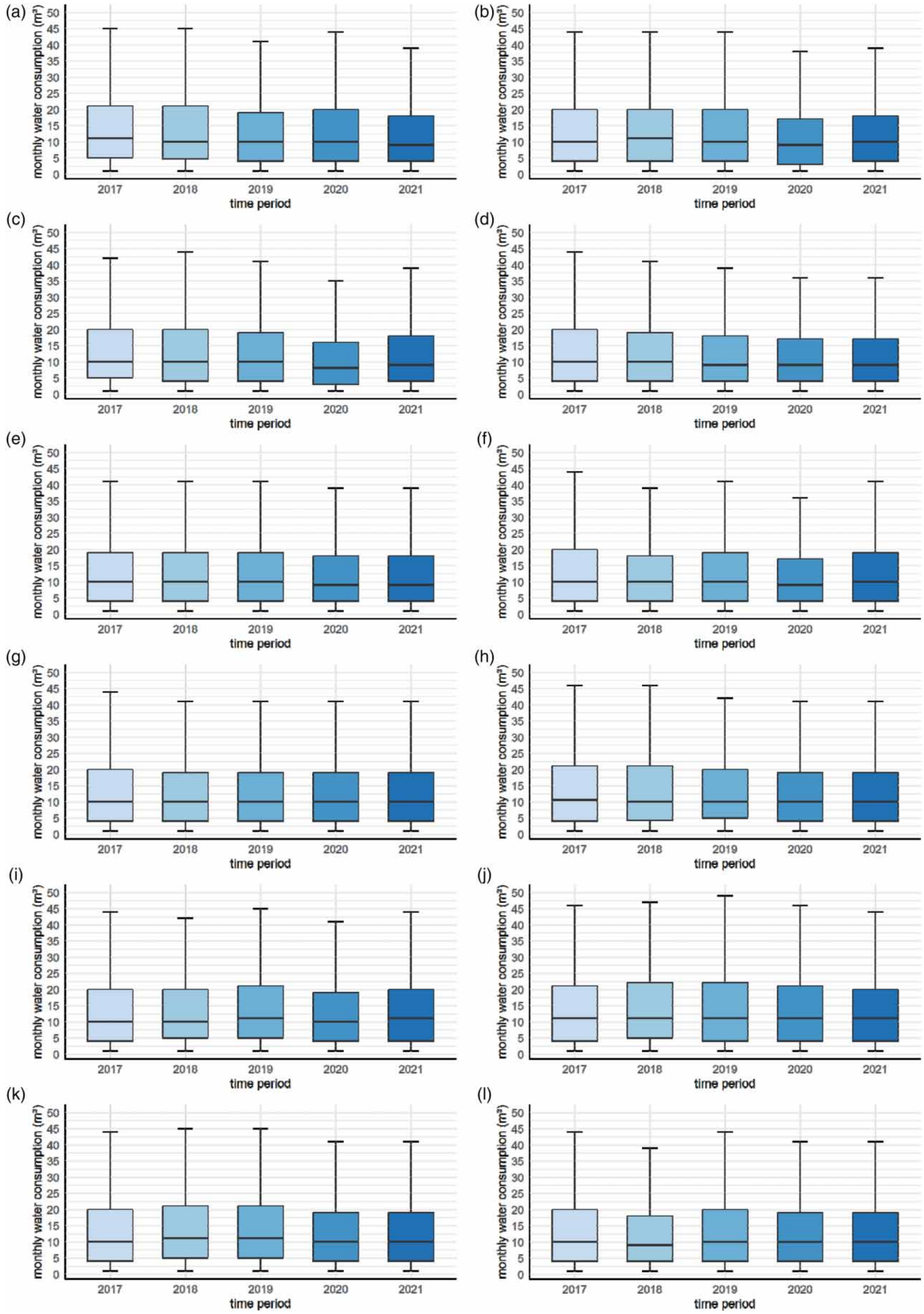


Figure 7 | Comparison between the volume of water consumed per month in the pre-pandemic and pandemic periods for commercial water consumption. (a) March, (b) April, (c) May, (d) June, (e) July, (f) August, (g) September, (h) October, (i) November, (j) December, (k) January, and (l) February.

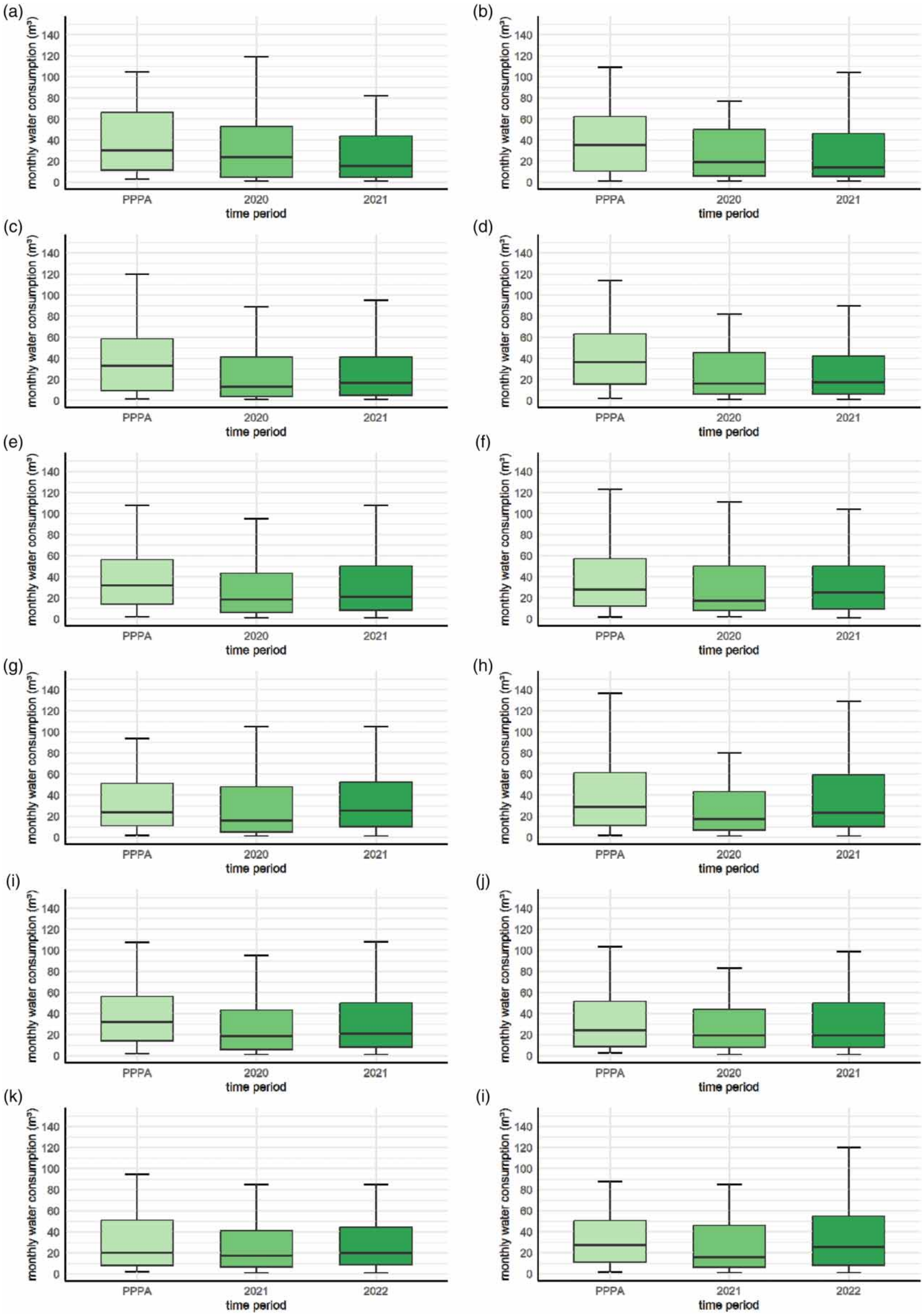


Figure 8 | Comparison between the volume of water consumed per month in the pre-pandemic and pandemic periods for public water consumption. (a) March, (b) April, (c) May, (d) June, (e) July, (f) August, (g) September, (h) October, (i) November, (j) December, (k) January, and (l) February.

During the pre-pandemic period, the maximum monthly residential water consumption values from March to November were between 26 and 29 m^3 (Figure 5(a) and 5(i) and in December (Figure 5(j)) showed the highest value of 33 m^3. The same statistic showed higher values during the pandemic period, where the values of maximum monthly residential water consumption from March to November were between 27.5 and 35 m^3 and in December reached the highest value of 39 m^3.

Despite the increased variability, it is observed that residential water consumption during the pandemic maintained a similar pattern to the pre-pandemic period (Figure 5). The months with the highest consumption were from November to February, with a maximum in December, and the months with the lowest consumption were from June to August. This coincides with the summer and winter months in the region, respectively (Moreno 1961).

The annual volume of water consumed by the IC category grew the most in percentage terms (Figure 4), although the first 3 months (Figure 4(a)–4(c)) showed a reduction, as also observed by Kalbusch *et al.* (2020) and Li *et al.* (2021).

The IC consumption between the respective minimum and median monthly values did not show major changes (Figure 6). Thus, 50% of the users consumed up to 20 m^3 of water per month, regardless of the pandemic. On the other hand, large consumers (who consume between the median and maximum value) were the most impacted by the virus control measures. It can be observed that in the pre-pandemic period, there were no monthly variations of the large consumers (Figure 6); on the other hand, during the pandemic a large variation of the third quartile and the maximum value was observed. This situation may be related to several decrees and containment measures published during this period (Figure 2), which limited the hours of operation or decreed the total suspension of activities.

Different from RC and IC, the CCs do not have a significant similarity between 2017, 2018, and 2019, and so the PPPA cannot be used as a comparison value. Thus, Figure 7 presents the boxplots of commercial water consumption between 2017 and 2022.

As observed in Figure 7, during the first 6 months of the pandemic, there was a higher reduction in commercial water consumption, a situation also identified by other research on the topic (Kalbusch *et al.* 2020; Abulibdeh 2021; Alvisi *et al.* 2021; Irwin *et al.* 2021; Kazak *et al.* 2021; Li *et al.* 2021; Buurman *et al.* 2022). Furthermore, despite the expectation for the closure and sharp reduction in commercial water consumption, this consumer category was the least impacted by the virus containment measures. In general, it was observed that 50% of the users, who consume less than the monthly median, did not show large variations in consumption. On the other hand, a slight reduction in the third quartile and maximum monthly values was observed, implying a reduction in water consumption in establishments that demanded more water.

Thus, it can be inferred that the reduction in annual commercial water consumption shown in Figures 4 and 7 was due to the reduction of water consumption in large establishments, such as malls and shopping centers, and also to the general reduction of water consumption in the first months of the pandemic.

The boxplots of the monthly water consumption in public establishments during the pre-pandemic period and the pandemic period are presented in Figure 8. When comparing Figures 8, it is possible to observe that until July 2021 (Figure 8(e)), the public water consumption remained below the mean values in the pre-pandemic period. Kalbusch *et al.* (2020) and Kazak *et al.* (2021) also identified the reduction in public water consumption during the pandemic's first months.

In general, it is observed that there was a reduction in the volume of water in all consumption ranges presented in Figure 8, as the first quartile, median, third quartile, and maximum values reduced up to 10 m^3 on average. The median of the monthly public water consumption was around 27 m^3 in the pre-pandemic period. However, the median of the monthly public water consumption was 13 m^3 in May 2020, with averages of 17 m^3 in 2020 and 21 m^3 in 2021. Consumers who demand more water, whose consumption is situated between the monthly median and the maximum value, also reduced their consumption on the same scale.

3.2. Spatial change in water consumption

The users who presented a significant change between the pre-pandemic and pandemic periods were selected to analyze the spatial changes in water consumption. This process resulted in selecting about 51% of the total users, covering all categories. This does not imply that the remaining users have not changed how they consume water, but only that this change was not statistically significant compared to the period before the pandemic. The spatial distribution of all analyzed users and the percentage of variation in consumption between the two periods are presented in the supplementary material.

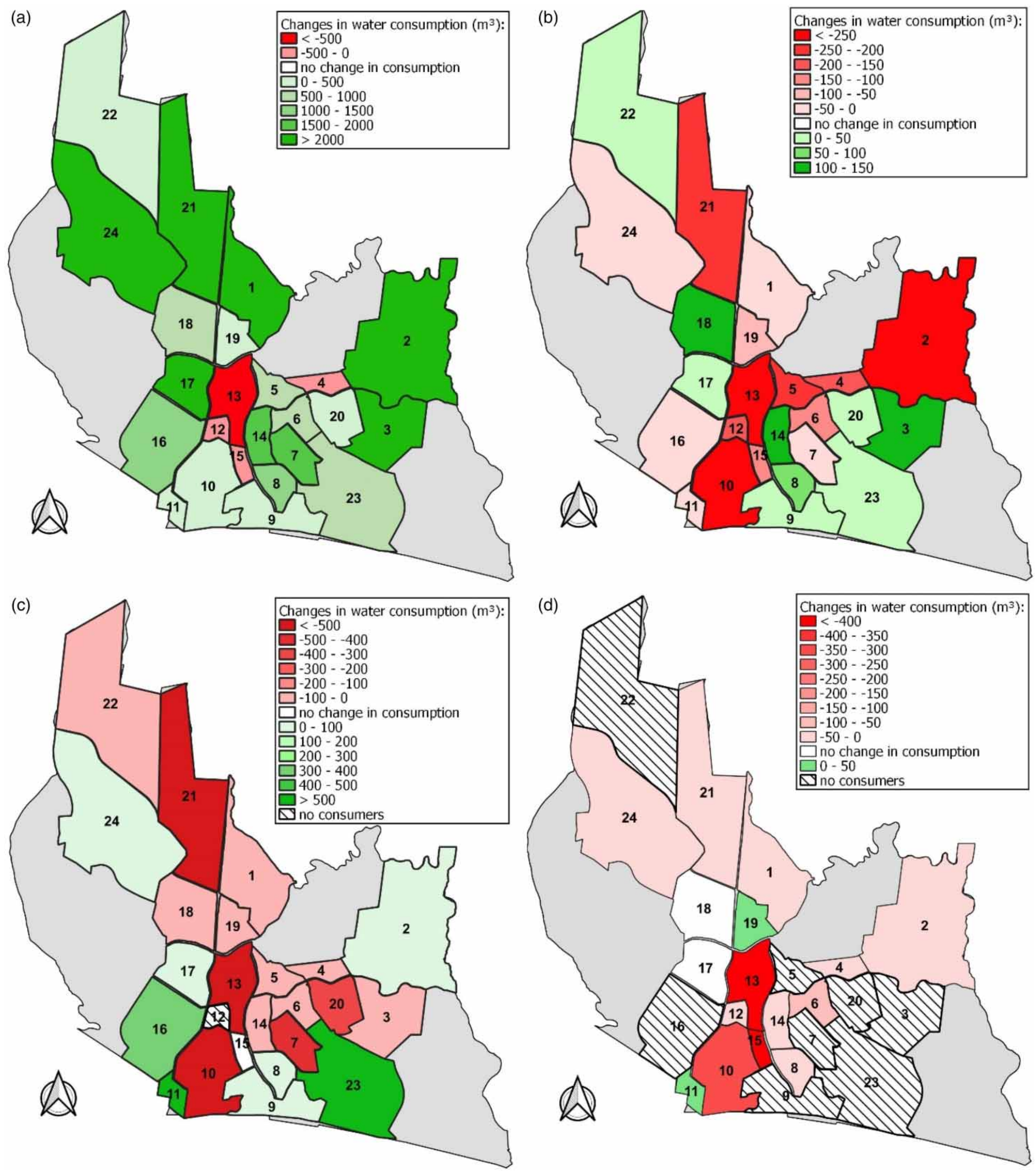


Figure 9 | Changes in monthly water consumption by neighborhood and consumer category, based on consumers with statistically significant change: (a) residential, (b) commercial, (c) industrial, and (d) public.

The percentage of users with a significant change in water consumption during the pandemic by consumer category is organized in Table 2, along with the average monthly increment of water consumed. The total changes in average monthly consumption related to consumers with statistically significant changes are shown in Figure 7, organized by neighborhood and consumer category. Most neighborhoods increased residential water consumption, slightly more

Table 2 | Average monthly increase of water consumed during the pandemic and percentage of users who changed their consumption, by consumer category

	RC		CC		IC		PC	
Neighborhoods	**Average monthly increase per consumer (m^3)**	**Users with a significant change in water consumption (%)**	**Average monthly increase per consumer (m^3)**	**Users with a significant change in water consumption (%)**	**Average monthly increase per consumer (m^3)**	**Users with a significant change in water consumption (%)**	**Average monthly increase per consumer (m^3)**	**Users with a significant change in water consumption (%)**
24-Arroio da Manteiga	0.99	50.79	−0.25	52.44	1.75	53.49	−42.56	50.00
22-Boa Vista	1.24	50.00	2.46	66.67	−33.93	50.00	–	–
3-Campestre	1.75	53.03	3.84	55.10	−11.67	16.67	–	–
18-Campina	0.43	52.07	1.11	49.52	−5.13	26.67	0.00	0.00
13-Centro	−5.86	53.13	−3.10	52.59	−53.25	52.00	−34.36	70.83
10-Cristo Rei	0.81	49.37	−17.71	57.14	−496.75	60.00	−336.32	16.67
9-Duque de Caxias	1.75	52.04	1.41	56.52	1.79	100.00	–	–
23-Fazenda São Borja	2.27	50.98	1.76	59.46	310.89	72.22	–	–
2-Feitoria	1.38	51.15	−4.21	52.30	7.33	38.46	−9.57	66.67
12-Fião	−1.25	51.81	−6.19	50.85	0.00	0.00	−15.44	100.00
7-Jardim América	1.86	50.46	−0.20	55.81	−47.72	64.29	–	–
14-Morro do Espelho	6.59	47.38	7.92	42.50	−21.19	40.00	−35.67	100.00
15-Padre Réus	−0.17	54.35	−4.42	60.00	0.00	0.00	−233.95	100.00
4-Pinheiro	−1.13	48.25	−5.85	50.00	−5.32	25.00	−1.53	50.00
6-Rio Branco	0.97	50.76	−2.64	52.48	−21.74	33.33	−31.21	100.00
19-Rio dos Sinos	0.42	49.41	−1.29	52.63	−7.45	63.16	34.13	50.00
8-Santa Teresa	0.78	51.46	1.04	52.55	2.21	50.00	−46.10	50.00
20-Santo André	0.57	48.81	1.99	42.86	−110.91	100.00	–	–
1-Santos Dumont	2.26	50.51	−0.14	52.61	−0.66	61.90	−23.29	100.00
11-São João Batista	0.09	50.82	−3.05	39.02	193.89	72.73	7.72	100.00
5-São José	1.99	49.38	−8.59	64.10	−14.45	42.86	–	–
17-São Miguel	4.42	51.83	0.23	52.69	1.83	68.75	0.00	0.00
21-Scharlau	1.19	49.74	−1.53	55.27	−91.62	45.45	−0.68	33.33
16-Vicentina	0.92	49.90	−0.15	58.65	23.14	44.44	–	–
Total	**1.07**	**50.87**	**−2.14**	**52.99**	**21.93**	**53.41**	**−43.29**	**59.38**

than half reduced commercial and industrial consumption, and most neighborhoods with PC reduced water consumption.

For all categories analyzed, there was at least one neighborhood where consumption reduction was recorded during the pandemic between consumers with statistically significant change. The neighborhood 13-Centro (Downtown) was the most impacted, with a higher reduction in residential water demand (5.86 m^3 per consumer), along with 4-Pinheiro, the only neighborhood with a reduction in consumption in all categories of users. The 12-Fião and 15-Padre Reus neighborhoods show a similar pattern of reduction in several categories, however, with a lower volume reduction and no record of PC (Figure 7(d)).

The neighborhoods 23-São Borja and 9-Duque de Caxias increased water consumption in all categories of consumers, despite all the decrees issued involving the suspension of non-essential activities.

Residential consumption had the lowest percentage of users who showed significant water consumption changes during the pandemic (Table 2). Although only 50.78% of the consumers showed significant water consumption change, on average, each residence consumed 1 m^3 more water during the pandemic. This is twice the value observed by Silva *et al.* (2022) for the city of São Paulo.

The fact that the RC represents about 93% of the total users of the water supply system made this category the primary responsibility for the increase in consumption in 2 years of the pandemic, as already presented in Figure 4.

This is reflected in the increase in monthly water consumption in 20 of the 24 neighborhoods in the city (Figure 7(a)), with six neighborhoods increasing consumption by more than 2,000 m^3. Although some neighborhoods reduced their water consumption, this volume was not enough to result in a decrease in the residential water consumption of the city. Thus, the scenario presented in Figure 7(a) suggests that in most neighborhoods, actions made people stay at home more and, consequently, increased the water demand.

The higher reduction in residential water consumption in neighborhood 13-Centro (-5.86 m^3 per consumer) and the increase in other neighborhoods may indicate that residents of this neighborhood left their homes and moved back to more peripheral neighborhoods since 13-Centro is predominantly commercial and that these establishments were more affected by the virus containment measures. This observation is corroborated by the reduction in water consumption recorded in commercial establishments in 17 of the 24 neighborhoods (Figure 7(b) and Table 2), especially 13-Centro, with a reduction of more than 250 m^3. Two neighborhoods with an expressive reduction in consumption are 2-Feitoria and 10-Cristo Rei.

Overall, there was an average reduction of 2.14 m^3 in monthly water consumption per CC. Despite the growth in commercial consumption in nine neighborhoods, the increase in water volume per neighborhood was not higher than 150 m^3, with most of them between 0 and 50 m^3. Still, it is interesting to note that these neighborhoods are in peripheral regions of the city and that an increase in residential consumption and a reduction in public consumption accompany this increase.

In relation to the PCs, Figure 7(d) and Table 2 show a reduction in water consumption in half of the neighborhoods, and this reduction was higher than 200 m^3 in three of them. Despite this, the average change in monthly water consumption per user was -43.29 m^3. Figure 7(d) shows an increase in monthly water consumption in only two neighborhoods; this volume was not higher than 50 m^3. In addition, it is possible to observe that there were no statistically significant changes in PC consumers in neighborhoods 17-São Miguel and 18-Campina.

Industrial consumption, which showed an average increase of 21.93 m^3 of monthly water volume during the pandemic, increased in only eight of the 24 neighborhoods: five neighborhoods presented an increase up to 50 m^3 and three neighborhoods of over 500 m^3. This implies that a small group of three out of the 24 neighborhoods analyzed were the most responsible for the increase in industrial water consumption during the pandemic. It is also noteworthy that in two neighborhoods, there were no statistically significant changes in IC consumers.

4. CONCLUSIONS

This research provides new insights into changes in urban water consumption during 2 years of the COVID-19 pandemic. We investigated the implications of changes in residential, commercial, industrial, and public consumption induced by COVID-19 in the context of containment measures implemented to control the spread of the virus, using a city in southern Brazil as a case study.

The total volumes of water consumed during the 2 years of the pandemic changed significantly, resulting in an average annual increase of 5.6%. Residential and industrial consumption increased by 6.77 and 9.92% in the first year and by 5.47 and 14.45% in the second year, respectively. This is reflected in an average monthly increase of 1.07 m^3 per household and 21.93 m^3 per industry. On the other hand, commercial and public sector consumption underwent negative changes, decreasing 5.48 and 46.26% in the first year and 1.83 and 40.99% in the second year, respectively. These changes reflected a monthly average decrease of 2.14 m^3 per commercial establishment and 43.29 m^3 per public establishment.

We observe that the first months of the pandemic saw an increase in residential water consumption and a slight return to pre-pandemic behaviors in the year's second half. The second half of 2020 was also marked by an increase in the number of containment measures published and a consequent reduction in cases, particularly during September 2020. However, in December 2020, the number of containment measures decreased, associated with a period of end-of-year festivities/holidays; this increased the number of cases, and urban water consumption during this month showed similar values to the pre-pandemic period. These observations highlight the importance of efficient and effective public policies – if people consider the pandemic-related adaptations to their lives (e.g., home office, changed hygiene practices) as favorable, this may lead to changes in long-term practices and, therefore, the patterns observed in this work may become long-term phenomena.

Regarding spatial differences, each neighborhood in the city was affected differently when analyzing the users with statistically significant change on their consumption. Overall, we can affirm that the more central neighborhoods presented greater changes concerning the more peripheral neighborhoods. The Centro neighborhood (administrative and commercial headquarters of the city) had the higher reduction in total volume of water consumed, while the neighborhoods that were predominantly residential had the higher increase. Thus, further in-depth research relating to sociodemographic factors needs to be undertaken.

The lack of recent social, demographic, and economic information about the neighborhoods is a limitation of the study, as the last census available is related to 2010. With this information, we could better understand which consumers were responsible for the changes in residential water consumption, as only 50.87% of residential consumers showed a statistically significant change between the pre-pandemic and pandemic periods. Sociodemographic factors affected a community's ability to stay at home during COVID-19 containment measures. Communities with higher social vulnerability may have more workers without work-from-home options or fewer resources to stay at home for extended periods, which can thus increase their risk from COVID-19 (Fletcher *et al.* 2021). In addition, these communities often have poor access to sanitation services, which limits the fight against the pandemic (Feizizadeh *et al.* 2021). Accordingly, understanding each neighborhood's characteristics, lifestyle in these locations, and how water is accessed is crucial for understanding how different communities were impacted by the COVID-19 pandemic, given the spatial change in water consumption highlighted in this research.

Overall, this work contributed to the existing knowledge about the changes in water consumption in Brazil during the COVID-19 pandemic. The results support the studies related to the hypothesis that the pandemic impacted water consumption behavior. In this sense, considering that some changes caused by the pandemic will be perpetuated, it is necessary to develop studies that contemplate this situation to contribute to the renewal of the management of sanitation systems.

Finally, adequate water for domestic use, for consumption, food preparation, and hygiene purposes is essential to protect public health and the city's full functioning. Thus, the efficient management of this resource, especially in atypical times such as the COVID-19 pandemic, can help avoid shortages and maintain the system's efficiency. This type of research assists public agencies in making decisions when there is an increased demand for drinking water.

ACKNOWLEDGEMENT

The SEMAE supported this research effort. This work has also been partially supported by the following Brazilian research agencies: CAPES and CNPq.

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.

REFERENCES

Abu-Bakar, H., Williams, L. & Hallett, S. H. 2021 Quantifying the impact of the COVID-19 lockdown on household water consumption patterns in England. *Npj Clean Water* **4** (1), 1–9. https://doi.org/10.1038/s41545-021-00103-8.

Abulibdeh, A. 2021 Spatiotemporal analysis of water-electricity consumption in the context of the COVID-19 pandemic across six socioeconomic sectors in Doha City, Qatar. *Applied Energy* **304**. https://doi.org/10.1016/J.APENERGY.2021.117864.

Alvisi, S., Franchini, M., Luciani, C., Marzola, I. & Mazzoni, F. 2021 Effects of the COVID-19 lockdown on water consumptions: Northern Italy case study. *Journal of Water Resources Planning and Management* **147** (11), 05021021. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001481.

Barnett, M. J., Jackson-Smith, D., Endter-Wada, J. & Haeffner, M. 2020 A multilevel analysis of the drivers of household water consumption in a semi-arid region. *Science of the Total Environment* **712**, 136489. https://doi.org/10.1016/j.scitotenv.2019.136489.

Brazil Ministry of Health 2022 *Coronavírus (COVID-19) Notícias*. Available from: https://news.google.com/covid19/map?hl=pt-BR&mid=%2Fm%2F015fr&gl=BR&ceid=BR%3Apt-419

Brown, A., Flint, S. W., Kalea, A. Z., O'Kane, M., Williams, S. & Batterham, R. L. 2022 Negative impact of the first COVID-19 lockdown upon health-related behaviours and psychological wellbeing in people living with severe and complex obesity in the UK. *eClinicalMedicine* **34**, 100796. https://doi.org/10.1016/j.eclinm.2021.100796.

Buurman, J., Freiburghaus, m. & Castellet-Viciano, L. 2022 The impact of COVID-19 on urban water use: a review. *Water Supply* **22** (10), 7590–7602. https://doi.org/10.2166/ws.2022.300.

Campos, A. M. S., Carvalho, S. L., Melo, S. K., Gonçalves, G. B. R. F., Santos, J. R. d., Barros, R. L., Morgado, T. M. A., Lopes, E. d. S. & Reis, R. P. A. 2021 Impact of the COVID-19 pandemic on water consumption behaviour. *Water Supply* **21** (8), 4058–4067. https://doi.org/10.2166/WS.2021.160.

Cvetković, D., Nešović, A. & Terzić, I. 2021 Impact of people's behavior on the energy sustainability of the residential sector in emergency situations caused by COVID-19. *Energy and Buildings* **230**, 110532. https://doi.org/10.1016/J.ENBUILD.2020.110532.

Elmaslar Özbaş, E., Akın, Ö., Güneysu, S., Özcan, H. K. & Öngen, A. 2021 Changes occurring in consumption habits of people during COVID-19 pandemic and the water footprint. *Environment, Development and Sustainability* **1**. https://doi.org/10.1007/S10668-021-01797-Z

Fan, L., Gai, L., Tong, Y. & Li, R. 2017 Urban water consumption and its influencing factors in China: evidence from 286 cities. *Journal of Cleaner Production* **166**, 124–133. https://doi.org/10.1016/j.jclepro.2017.08.044.

Feil, A. A. & Tucci, C. 2014 Consumo eficiente, conservação e características sociodemográficas que influenciam no consumo de água. *Revista Brasileira de Ciências Ambientais* **34**, 95–111.

Feizizadeh, B., Omarzadeh, D., Ronagh, Z., Sharifi, A., Blaschke, T. & Lakes, T. 2021 A scenario-based approach for urban water management in the context of the COVID-19 pandemic and a case study for the Tabriz metropolitan area, Iran. *Science of the Total Environment* **790**, 148272. https://doi.org/10.1016/J.SCITOTENV.2021.148272.

Firozjaei, M. K., Fathololomi, S., Kiavarz, M., Arsanjani, J. J., Homaee, M. & Alavipanah, S. K. 2021 Modeling the impact of the COVID-19 lockdowns on urban surface ecological status: a case study of Milan and Wuhan cities. *Journal of Environmental Management* **286**. https://doi.org/10.1016/J.EM.2021.112236.

Fletcher, K. M., Espey, J., Grossman, M. K., Sharpe, J. D., Curriero, F. C., Wilt, G. E., Sunshine, G., Moreland, A., Howard-Williams, M., Ramos, J. G., Giuffrida, D., García, M. C., Hartnett, W. M. & Foster, S. 2021 Social vulnerability and county stay-at-home behavior during COVID-19 stay-at-home orders, United States, April 7–April 20, 2020. *Annals of Epidemiology* **64**, 76–82. https://doi.org/10.1016/J.ANNEPIDEM.2021.08.020.

Fritsche, J. R., Whitby, P., Griffin, E., Norton, J. W., Alfahham, N., Kuhns, T. & Bell, K. Y. 2022 Changes in water demand resulting from pandemic mitigations in southeast Michigan. *AWWA Water Science* **4** (3). https://doi.org/10.1002/aws2.1286.

Hoolohan, J. C. C. & Browne, R. L. A. L. 2021 COVID-19 and water demand: A review of literature and research evidence. *WIREs Water* **9** (1), 1570. https://doi.org/10.1002/wat2.1570.

IBGE 2010 Censo Demográfico 2010. *Instituto Brasileiro de Geografia e Estatística*. Available from: https://cidades.ibge.gov.br/brasil/rs/sao-leopoldo/panorama

IBGE. 2023 Panorama 2023. Instituto Brasileiro de Geografia e Estatística. Available from: https://cidades.ibge.gov.br/brasil/panorama.

Irwin, N. B., McCoy, S. J. & McDonough, I. K. 2021 Water in the time of corona(virus): the effect of stay-at-home orders on water demand in the desert. *Journal of Environmental Economics and Management* **109**, 102491. https://doi.org/10.1016/J.JEEM.2021.102491.

Kalbusch, A., Henning, E., Brikalski, M. P., Luca, F. V. d. & Konrath, A. C. 2020 Impact of coronavirus (COVID-19) spread-prevention actions on urban water consumption. *Resources, Conservation and Recycling* **163**, 105098. https://doi.org/10.1016/J.RESCONREC.2020.105098.

Kazak, J. K., Szewrański, S., Pilawka, T., Tokarczyk-Dorociak, K., Janiak, K. & Świąder, M. 2021 Changes in water demand patterns in a European city due to restrictions caused by the COVID-19 pandemic. *Desalination and Water Treatment* **222**. https://doi.org/10.5004/dwt.2021.27242.

Koh, D. 2020 COVID-19 lockdowns throughout the world. *Occupational Medicine* **70** (5), 322. https://doi.org/10.1093/occmed/kqaa073.

Leenaerts, N., Vaessen, T., Ceccarini, J. & Vrieze, E. 2021 How COVID-19 lockdown measures could impact patients with bulimia nervosa: exploratory results from an ongoing experience sampling method study. *Eating Behaviors* **41**, 101505.

Li, D., Engel, R., Ma, X., Porse, E., Kaplan, J., Margulis, S. & Lettenmaier, D. 2021 Stay-at-home orders during the COVID-19 pandemic reduced urban water use. *Environmental Science and Technology Letters* **8** (5), 431–436. https://doi.org/10.1021/acs.estlett.0c00979.

Makki, A. A., Stewart, R. A., Beal, C. D. & Panuwatwanich, K. 2015 Novel bottom-up urban water demand forecasting model: revealing the determinants, drivers and predictors of residential indoor end-use consumption. *Resources, Conservation and Recycling* **95**, 15–37. https://doi.org/10.1016/j.resconrec.2014.11.009.

Misery, L., Fluhr, J.-W., Beylot-Barry, M., Jouan, N., Hamann, P., Consoli, S.-G., Schollhammer, M., Charleux, D., Bewley, A. & Rathod, D. 2021 Psychological and professional impact of COVID-19 lockdown on French dermatologists: data from a large survey. *Annales de Dermatologie et de Vénéréologie* **148** (2). https://doi.org/10.1016/A.DERMATOLOGIE.2021.101105.

Moreno, J. A. 1961 *Clima do Rio Grande do Sul. Secretaria da Agricultura*. Porto Alegre, Brazil. (in Portuguese).

Mulugeta, W. & Hoque, L. 2021 Impact of the COVID-19 lockdown on weight status and associated factors for obesity among children in Massachusetts. *Obesity Medicine* **22**. https://doi.org/10.1016/O.MEDICINE.2021.100325.

Nemati, M. & Train, D. 2022 The impact of COVID-19 on urban water consumption in the United States. *Water* **14** (19), 3096. https://doi.org/10.3390/w14193096.

Rahim, M. S., Nguyen, K. A., Stewart, R. A., Ahmed, T., Giurco, D. & Blumenstein, M. 2021 A clustering solution for analyzing residential water consumption patterns. *Knowledge-Based Systems* **233**, 107522. https://doi.org/10.1016/J.KNOSYS.2021.107522.

R Core Team 2022 *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. Available from: https: //www.R-project.org/.

Rizvi, S., Rustum, R., Deepak, M., Wright, G. B. & Arthur, S. 2021 Identifying and analyzing residential water demand profile; including the impact of COVID-19 and month of Ramadan, for selected developments in Dubai, United Arab Emirates. *Water Supply* **21** (3), 1144–1156. https://doi.org/10.2166/ws.2020.319.

Rouleau, J. & Gosselin, L. 2021 Impacts of the COVID-19 lockdown on energy consumption in a Canadian social housing building. *Applied Energy* **287**, 116565. https://doi.org/10.1016/J.APENERGY.2021.116565.

São Leopoldo 2022 *Painel Coronavírus*. Available from: https://www.saoleopoldo.rs.gov.br/coronavirus

Shapiro, S. S. & Francia, R. S. 1972 An approximate analysis of variance test for normality. *Journal of the American Statistical Association* **67** (337), 215–216. https://doi.org/10.1080/01621459.1972.10481232.

Silva, G. M. E., Oliveira, T. H., Carvalho, R. S., Fialho, H. C. P., de Souza, F. A. A., Mendiondo, E. M. & Ghiglieno, F. 2022 Assessing the impact of SARS-CoV-2 on water consumption in Sao Paulo State, Brazil. *Journal of Water Resources Planning and Management* **148**, 11. https://doi-org.ez45.periodicos.capes.gov.br/10.1061/(ASCE)WR.1943-5452.0001606.

SNIS 2020 Sistema Nacional de Informações sobre Saneamento. *SNIS Água e Esgotos* **2019**. Available from: http://appsnis.mdr.gov.br/indicadores/web/agua_esgoto/mapa-agua

Suh, D. & Ham, S. 2016 A water demand forecasting model using BPNN for residential building. *Contemporary Engineering Sciences* **9** (1–4). https://doi.org/10.12988/ces.2016.512314.

WHO (World Health Organization) 2020a *Protective measures COVID-19 – Stay Healthy at Home*. Available from: https://www.who.int/southeastasia/outbreaks-and-emergencies/covid-19/What-can-we-do-to-keep-safe/protective-measures/stay-healthy-at-home

WHO (World Health Organization) 2020b *Director-General's Opening Remarks at the Media Briefing on COVID-19*. Available from: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19—11-march-2020.

WHO (World Health Organization) 2022 *WHO Coronavirus (COVID-19) Dashboard*. Available from: https://covid19.who.int/

Wilcoxon, F. & American Cyanamid Co. 1992 *Individual Comparisons by Ranking Methods*, 196–202. https://doi.org/10.1007/978-1-4612-4380-9_16.

First received 30 November 2022; accepted in revised form 3 April 2023. Available online 18 April 2023