Case Study

Effects of the COVID-19 Lockdown on Water Consumptions: Northern Italy Case Study

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Abstract: The spread of the COVID-19 pandemic induced many countries, including Italy, to implement social distancing measures and to suspend the majority of educational and working activities, which significantly impacted peoples' lifestyles. To support water utilities in understanding the impacts of the COVID-19 pandemic on water consumption and improving water distribution system resilience, the effects of the lockdown were investigated with reference to a residential district metered area (DMA) in the city of Rovigo (northern Italy), in which smart monitoring of water consumption at the level of individual users started in 2019. The water consumption recorded during the lockdown period was analyzed at different levels of temporal and spatial aggregation and compared with the consumption recorded in the same period of the previous year. The results show that, during the lockdown period, the overall water consumption in this mainly residential area increased by 18%. Moreover, water consumption was observed to be more spread out over the day, with a decrease (and a delay) in peak morning consumption, which was particularly evident on weekdays. **DOI: 10.1061/(ASCE)WR.1943-5452.0001481.** *© 2021 American Society of Civil Engineers.*

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Introduction

Water consumption is the driver of water distribution systems. Knowing water consumption and water use profiles over time can be useful to a utility company for managing water distribution networks (Aksela and Aksela 2011; Sanchez et al. 2018). In fact, when detailed information on water consumption and water use profiles is available, the utility can optimize the functioning of control devices within the network (Cardell-Oliver et al. 2016), thus ensuring an appropriate spatial and temporal allocation of water resources. Both water consumption and water use profiles over time depend on users' habits and lifestyles and can be influenced by multiple factors from economic to climatic, sociodemographic, and geographic (Jorgensen et al. 2009; Hester and Larson 2016).

Focusing on water consumption and considering economic factors, several studies investigated the correlation between water consumption and water pricing. On the one hand, low-income people or people using taps as the primary source of drinking water are generally more responsive to price changes as they will likely decrease their consumption if the cost of water increases (Grafton et al. 2011; Zamenian et al. 2020). On the other hand, high-income users tend to be rather inelastic in respect to price, as bills are a small proportion of their income (Arbués et al. 2003). Concerning climatic factors, it was proven that both temperature and rainfall could significantly impact water consumption. Specifically, water consumption is, in general, positively correlated with temperature and inversely correlated with rainfall. Indeed, high temperatures generally imply high water consumption, while rainfall may reduce the amount of water used for irrigation (Hoffman et al. 2006; Chang et al. 2014; Xenochristou et al. 2020). Water consumption can also be affected by sociodemographic factors. Awareness-rising campaigns may have a positive effect on water consumption because users are encouraged to adopt water conservation attitudes (Howart and Butler 2004). The adoption of water conservation policies may be significantly useful when water resources are scarce due to geographic factors, e.g., in areas often affected by drought (March and Saurì 2010; Maggioni 2015; Salvaggio et al. 2014).

Focusing on water use profiles over time, several studies analyzed the evolution of water consumption at different spatial and temporal scales. Regarding residential water use, it was observed that water consumption generally varies during the day, assuming the lowest values at night (Gargano et al. 2012). During weekdays, water consumption is typically characterized by the first peak in the early morning and a second (lower) peak in the evening, corresponding to the periods in which people prepare to go to work and come back home, respectively (Gargano et al. 2012; Cheifetz et al. 2017). Additionally, water consumption tends to increase over the weekend due to the presence of more people at home and more frequent use of appliances (Loureiro et al. 2015).

However, it is worth noting that the aforementioned studies refer to standard situations. In contrast, water consumption may not adhere to the preceding results in the case of emergency or disaster situations when, in worst cases, water distribution systems can even stop functioning (Miyajima 2013; Capponi et al. 2019; Hidayat et al. 2020).

The recent SARS-CoV-2 (COVID-19) epidemic represented an emergency situation for many countries throughout the world. After breaking out in the region of Hubei, China, between December 2019 and January 2020 (WHO 2020), the epidemic spread rapidly

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around the globe, so that it was declared a pandemic by the WHO on March 11, 2020 (McNeil 2020).

In order to limit the spread of the pandemic, the Italian government implemented a series of restrictive measures (Governo Italiano 2020): on February 23, 2020, the government ordered home isolation and the suspension of all school and nonessential work activities, as well as recreational and sports activities. On March 11, 2020, a nationwide closure of all commercial establishments (except for those selling essential goods) was decreed, along with a ban on travel outside the municipality of residence, except for documented work-related needs, situations of absolute urgency, or health reasons (Camera dei Deputati 2020). These measures remained in force until May 4, 2020, when the restrictions started to be gradually lifted, and various businesses and facilities were reopened. Therefore, from March 11 to May 3, 2020, Italy underwent a period of lockdown with a halt to activities and movements (Governo Italiano 2020).

Analogous situations, albeit with timing and modalities varying from case to case, have also occurred in many other countries, such as, for instance, Spain, France, and Great Britain (BBC 2020a, b). Clearly, such restrictions affected the habits and lifestyles of most of the population. This, in turn, was also reflected in water consumption.

Within this framework, a study proposed by Balacco et al. (2020) reported the changes in the hourly water inflow before and after the lockdown restrictions with reference to five areas in Southern Italy. Moreover, Kalbusch et al. (2020) studied the evolution of daily water consumption for a set of around a thousand users in Joinville (southern Brazil). Both studies reported a heavy drop in the water consumption for industrial and commercial activities along with increases in residential water consumption and changes in water use profiles due to confinement and teleworking.

In general, changes in water consumption can be an issue for water utilities, revealing vulnerabilities of water distribution networks. For instance, water consumption drops for industrial and commercial activities can result in zones of water stagnation, with a consequent increase in water age, disinfectant decay, and microbial growth (Faust et al. 2021). Moreover, changes in water consumption may alter water flows to the point that new operational criteria are required for adequate management of the network. In addition, social distancing policies and the obligation to work from home can limit water utility employees' inspections, thus decreasing maintenance actions and meter readings (Berglund et al. 2021).

This study investigates the effects of the lockdown due to the COVID-19 pandemic on water consumption with reference to the case study of a residential district metered area (DMA) in the city of Rovigo (northern Italy), in which smart monitoring of water consumption at the individual user level has been ongoing since April 2019. Although focused on a single DMA, the study can support water utilities in assessing the most relevant impacts of COVID-19 on water consumption. Specifically, the analyses were conducted at different levels of temporal and spatial aggregation, up to the level of hourly water use profiles for individual users. As far as the authors are aware, no other studies in the scientific literature evaluated the effects of the COVID-19 pandemic on water consumption with this level of spatiotemporal detail.

In the following sections, the case study DMA and the monitoring operation for smart meter data collection are introduced. The adopted methodology to assess the effects of the COVID-19 pandemic on water consumption is then described. Finally, the results achieved and the related key findings, as well as final considerations, are discussed.

Case Study

The case study considered relates to the Commenda DMA, situated in the city of Rovigo, a provincial city in the Veneto region (northern Italy), whose number of inhabitants is about 51,000. Management of the integrated water distribution service in the city is entrusted to *acquevenete S.p.A.*, a water utility serving around 515,000 inhabitants in an overall territory of 3,200 km^2.

The Commenda DMA covers a mainly residential area near the city center and includes 301 users, 288 of which are residential users, and 13 are commercial establishments (e.g., a pharmacy, a hardware store, a homeopathic and wellness center, and a hairdresser). More in detail, this mainly residential DMA is populated with a medium-income community, ranging from single residents to couples and families with one or more children. Specifically, the average number of residents per user is about 3. Around 60% of the residential users are detached or semidetached houses, whereas around 40% are flats. Based on the authors' experiences, the Commenda DMA is representative of many residential areas in Italian and European medium-sized cities not significantly affected by urban commuting phenomena.

Starting from the end of September 2018, the Commenda water distribution network underwent a complete renovation, including the installation of new connections to users. Following the renovation of the network, all the traditional mechanical meters were replaced with Sensus iPerl smart meters, new generation electromagnetic meters also capable of logging data with hourly temporal resolution. Specifically, the meters were equipped with a radio transmitter making use of the wireless M-Bus communication protocol. The logged cumulative water consumption data are periodically collected onsite by the operator with the walk-by mode through a radio receiver kit.

Water consumption has been monitored since April 2019, which has resulted in the availability of hourly water consumption time series for each of the 301 users. Specifically, the available time series relate to the period between April 4, 2019, and May 3, 2020. Data collected in the preceding period allowed the following: (1) the analysis of residential and commercial water consumption (and profiles) throughout the period in which increasingly strict restrictions were applied to the complete lockdown due to the COVID-19 pandemic (from February 1 to May 3, 2020); and (2) the comparison of user water consumption during the lockdown period (from April 4 to May 3, 2020) with the corresponding consumption of the previous year (from April 4 to May 3, 2019).

Methodology

To assess the effects of the lockdown on water consumption in the Commenda DMA, the entire user dataset was subjected to a preliminary cleaning. From an operational standpoint, the cleaning process was developed in the following phases: (1) removal of the users with a closed meter or subjected to a contract transfer; (2) removal of the users with no water consumption due to householders' absences; (3) removal of the users, including missing or incorrect data, due to a malfunctioning in the meter; and (4) removal of the users affected by internal leakages. In particular, Set (1) of the users to remove was identified by using the water utility database and searching for the users with contract closures or transfers. Set (2) was identified by looking for users, including no water consumption for at least two weeks. Set (3) was identified by looking for users characterized by negative consumption data or with at least two days of missing data. Lastly, Set (4) was identified by looking for the users affected by internal leakages equal to or greater than 1 L/h that were, in turn, detected through the algorithm proposed by Luciani et al. (2019).

Overall, after the cleaning process, the hourly water consumption time series of a total of $NT = 216$ users ($NR = 208$ residential and $NC = 8$ commercial users) were selected for the study. For the sake of brevity, the aforementioned datasets will be subsequently identified as a total-user (TU), residential user (RU), and commercial user (CU) dataset.

In addition, analyses were carried out to ensure that water consumption changes during the lockdown period were not due to sociodemographic or climatic factors.

- Regarding sociodemographic factors, analyses of a water utility database along with the information directly provided by the technicians showed the following: (1) no substantial changes in the DMA number of users between 2019 and 2020 occurred; (2) the cost of water was not subjected to changes; and (3) no awareness-rising campaigns were carried out throughout years 2019 and 2020.
- Regarding climatic factors, temperature and rainfall data were considered. First, it was observed that monthly temperatures and rainfall of the years 2019 and 2020 were consistent with values of the previous decade (i.e., years 2010–2018) and were not characterized by anomalies or outlier values. Second, the possible existence of a correlation between the Commenda DMA water consumption and climatic factors during the lockdown period was investigated. Specifically, a significance test was conducted by assuming a 95% significance level. For both climatic factors, the correlation with water consumption was not statistically significant ($p > 0.05$)—that is to say that water consumption changes in the selected period are not attributable to them.

The cumulative water consumption data collected for each user over the monitoring period were turned into hourly water consumption (m^3/h) and analyzed at different levels of temporal and spatial aggregation. Analyses were first carried out on a daily temporal scale by considering all the users together (i.e., at the level of a whole TU set). These were followed by a more detailed examination of the daily water consumption of each individual user n ($n = 1, \ldots, NT$). Concerning the hourly temporal scale, the analysis of residential water consumption was conducted by considering both the residential users grouped together (i.e., at the level of whole RU subset) and each residential user r ($r = 1, \ldots, NR$), whereas the commercial water consumptions, given the limited sample of available data and the very different nature of each commercial user (e.g., pharmacy and hairdresser), were analyzed by considering each individual user c (i.e., for $c = 1, \ldots, NC$). Therefore, in total, four analyses were conducted, as reported in the following.

Daily Temporal Scale, Aggregate Users

The daily volume of water V^j consumed by all the users (i.e., whole TU set) during each day j of a selected period was calculated

$$V^j = \sum_{n=1}^{NT} \sum_{i=1}^{24} v_{n,i}^j \quad (1)$$

where NT = number of users in the considered dataset; and $v_{n,i}^j$ = hourly water consumption of user n ($n = 1, \ldots, NT$) at hour i ($i = 1, \ldots, 24$) of day j.

Daily Temporal Scale, Individual Users

The difference between the daily average volume of water consumed by each individual user n ($n = 1, \ldots, NT$) during the lockdown period and its corresponding period of 2019 were calculated

$$\overline{\Delta v}_n = \left(\frac{1}{J}\sum_{j=1}^{J}\sum_{i=1}^{24} v_{n,i}^j\right)_{2020} - \left(\frac{1}{J}\sum_{j=1}^{J}\sum_{i=1}^{24} v_{n,i}^j\right)_{2019} \quad (2)$$

where $(\ldots)_{2020}$ and $(\ldots)_{2019}$ mean that all the variables within the brackets refer to data pertaining to the considered lockdown period 2020 and to its corresponding period of 2019, respectively (i.e., April 2020 and April 2019); and J = number of days included in each period.

Hourly Temporal Scale, Aggregate Users

The hourly consumption coefficients $C_{h,i}$ ($i = 1, \ldots, 24$) making up the daily residential water use profile for weekdays and weekends/holidays were calculated

$$C_{h,i} = \frac{\frac{1}{T}\sum_{j=1}^{T}\sum_{r=1}^{NR} v_{r,i}^j}{\frac{1}{T}\frac{1}{24}\sum_{j=1}^{T}\sum_{r=1}^{NR}\sum_{i=1}^{24} v_{r,i}^j} \quad (3)$$

In the preceding equation, $v_{r,i}^j$ is the hourly water consumption of the residential user r at hour i of day j; and T is the number of weekdays or weekends/holidays occurring in the selected period. Specifically, the numerator defines the average volume of water consumed by all the residential users at hour i during weekdays or weekends/holidays, while the denominator represents the average over the day of the hourly volume of water consumed by all the residential users during weekdays, or weekends/holidays [i.e., Saturdays, Sundays, Easter Monday, the Anniversary of Italy's Liberation (April 25), and the International Workers' Day (May 1)]. The assumption of considering two classes was numerically verified through cluster analysis as detailed in the "Results and Discussion" section.

Hourly Temporal Scale, Individual Users

With reference to each residential user r ($r = 1, \ldots, NR$), two analyses were conducted at the hourly temporal scale. First, the difference between the hourly average water consumption during the lockdown period and its corresponding period of 2019 was calculated

$$\overline{\Delta v}_{r,i} = \left(\frac{1}{J}\sum_{j=1}^{J} v_{r,i}^j\right)_{2020} - \left(\frac{1}{J}\sum_{j=1}^{J} v_{r,i}^j\right)_{2019} \quad (4)$$

Second, recurrent water use profiles (clusters) were searched, and users were classified based on the cluster closest to their own water use profile. For this purpose, the K-means algorithm (Lloyd 1982) was applied to the set of hourly water use profiles assessed for each individual user r ($r = 1, \cdots,$) with reference to the average weekday. In detail, a definition of the clusters was obtained starting from a space of $2NR = 416$ objects (i.e., NR-water use profiles for the period preceding the lockdown and NR-water use profiles for the lockdown period), each of which was made up of 24 attributes (i.e., the 24-hourly consumption coefficients $C_{h,i}$). The objects were partitioned into classes (i.e., K) based on a preliminary silhouette curve analysis (Rousseeuw 1987). Both the cluster and the silhouette curve analysis were performed by choosing the squared Euclidean distance to assess the proximity between objects and clusters. Moreover, the optimal number of partitioning classes was chosen by selecting the K-value corresponding to the highest average value of the silhouette parameter. Details about the results of the analyses are provided in the following section.

Results and Discussion

Daily Temporal Scale, Aggregate Users

As far as it regards the daily temporal scale and considering the NT-users grouped together, a positive trend over time in the total daily water consumption (i.e., V^j) (m^3/d) was observed in the period between February 1 and May 3, 2020 (Fig. 1). Specifically, V^j rose from about 61.4 m^3/d in the period preceding the school closures (February 1–23, 2020) to about 64.5 m^3/d in the period of transition toward the complete lockdown (February 24–March 10, 2020), and ultimately to 70.2 m^3/d during the actual lockdown period (March 11–May 3, 2020). Moreover, a comparison between the daily average water consumption in the month of April 2020 (April 4–May 3) and the water consumption in the same period of 2019 (Table 1) revealed that the increase—not ascribable to sociodemographic factors or anomalous climatic conditions but mainly due to the restrictions and lockdown imposed—was of approximately 18%.

More specifically, it emerged that the increase in the overall consumption was mainly tied to residential users (RU subset), as also observed in the case study reported by Kalbusch et al. (2020). In particular, the RU subset, including over 96% of the users of the DMA, showed an overall increase of 19% in daily average water consumption (rising from 59.4 m^3/d in 2019 to 70.8 m^3/d in 2020) because of social distancing, which forced residents to stay at home.

In contrast, the CU subset, representing a modest number of users, reduced the daily average water consumption by 25% during the lockdown compared to the same period of the previous year. The 25% reduction is mainly ascribable to few commercial users whose consumption fell to zero due to the forced closure of businesses imposed by the Italian government.

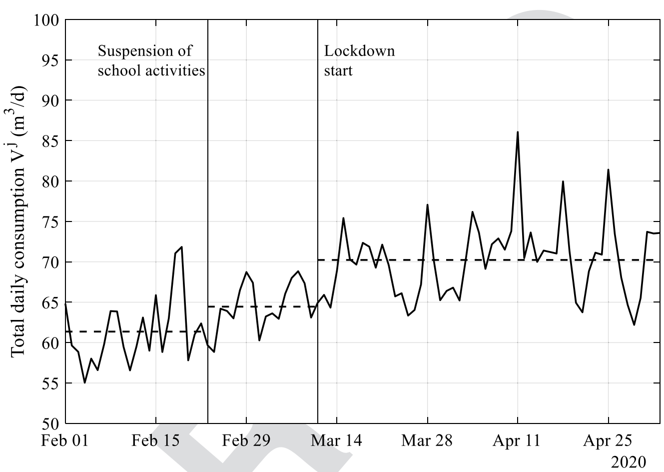

Fig. 1. Trend over time of the daily water consumption of the TU set (V^j, m^3/d) in the period between February 1 and May 3, 2020.

Table 1. Comparison between the daily average water consumption V^j (m^3/d) of TU, RU, and CU sets in April 2019 versus April 2020

Dataset	Number of users	Average water consumption V (m^3/d) April 2019	Average water consumption V (m^3/d) April 2020	Variation (%)
Total (TU)	216	60.6	71.7	+18.3
Residential (RU)	208	59.4	70.8	+19.2
Commercial (CU)	8	1.2	0.9	−25.0

Daily Temporal Scale, Individual Users

Considering the daily volumes consumed by each individual user n ($n = 1, \ldots, NT$) (L/d), it emerged that the majority of users (around 75%) increased their daily average water consumption during the month of April 2020 versus the month of April 2019 (Fig. 2). In about 51% of the cases, the increase was in the range of 0 to 100 L/d, whereas a smaller percentage of users manifested increases exceeding 200 L/d or a decrease. This increase is mainly tied to residential users, representing almost the totality of the set, while the majority of commercial users registered no changes or a decrease in the daily average water consumption due to the closure imposed on some of them. Considering the whole TU set, the mean increase was 51.5 L/d with a standard deviation of 107.5 L/d.

Hourly Temporal Scale, Aggregate Users

Considering the hourly consumption coefficients $C_{h,i}$ of the whole RU subset, the division in two classes was verified through cluster analysis, and to this end, the K-means clustering algorithm was applied to daily water use profiles by ranging the K-value from 2 to 10 and calculating the average silhouette value in turn. The highest value was observed for $K = 2$, highlighting that residential users tend to consume water in two different ways throughout the week. Specifically, a comparison based on the Italian calendar demonstrated that the two clusters correspond to weekdays and weekends/holidays.

In the case of weekdays [Fig. 3(a)], the peak morning consumption in April 2019 occurred between 7:00 a.m. and 8:00 a.m. (with $C_{h,i} = 2.13$), while, during the lockdown, a significant reduction in its entity, as well as a delay of about 2 h (equivalent to a $C_{h,i}$ of 1.70 between 9:00 a.m. and 10:00 a.m.) was observed. This delay, also pointed out in the case study reported by Balacco et al. (2020), is ascribable to the fact that, on weekdays during the lockdown period, users tended to get up later than in the month of April 2019. With reference to daytime hours, a general increase in $C_{h,i}$ values was observed during the lockdown. This new profile suggests the presence of a larger number of users confined to their respective homes as a result of the forced closure of schools and workplaces.

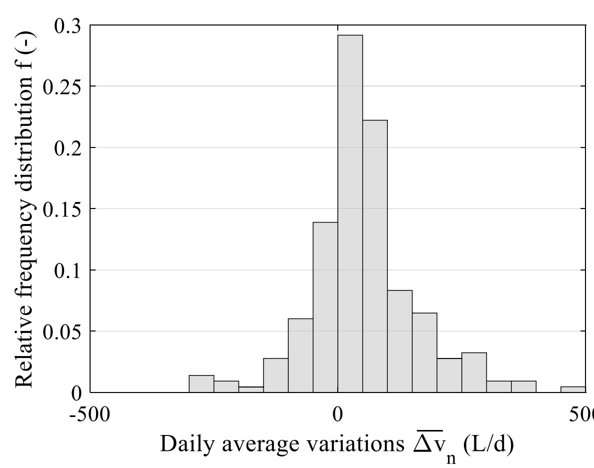

Fig. 2. Relative frequency distribution (f) of the variation in the daily average water consumption of each user between the months of April 2019 and April 2020 ($\overline{\Delta v}_n$, L/d).

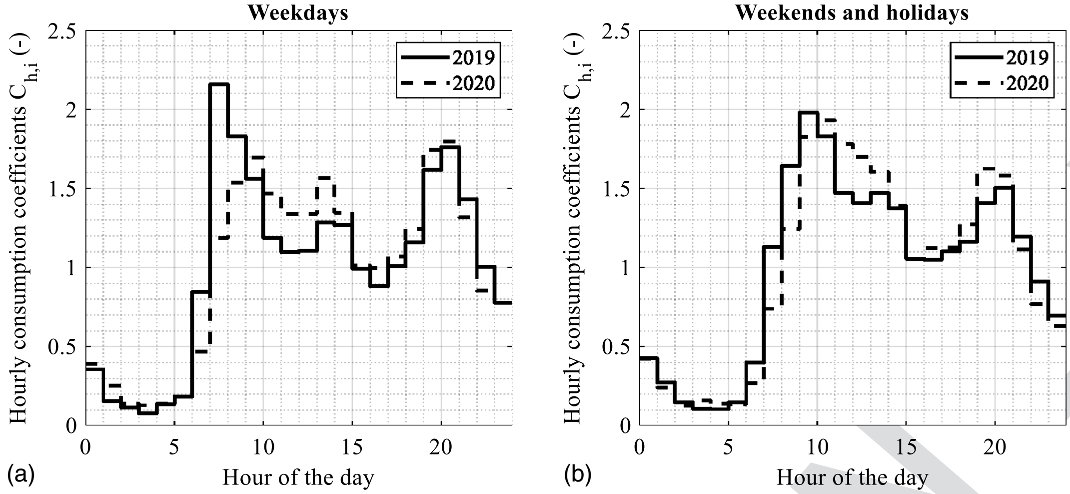

Fig. 3. Hourly consumption coefficients ($C_{h,i}$) in the months of April 2019 (solid line) and April 2020 (broken line) for the whole *RU* subset: (a) on weekdays; and (b) on weekends/holidays.

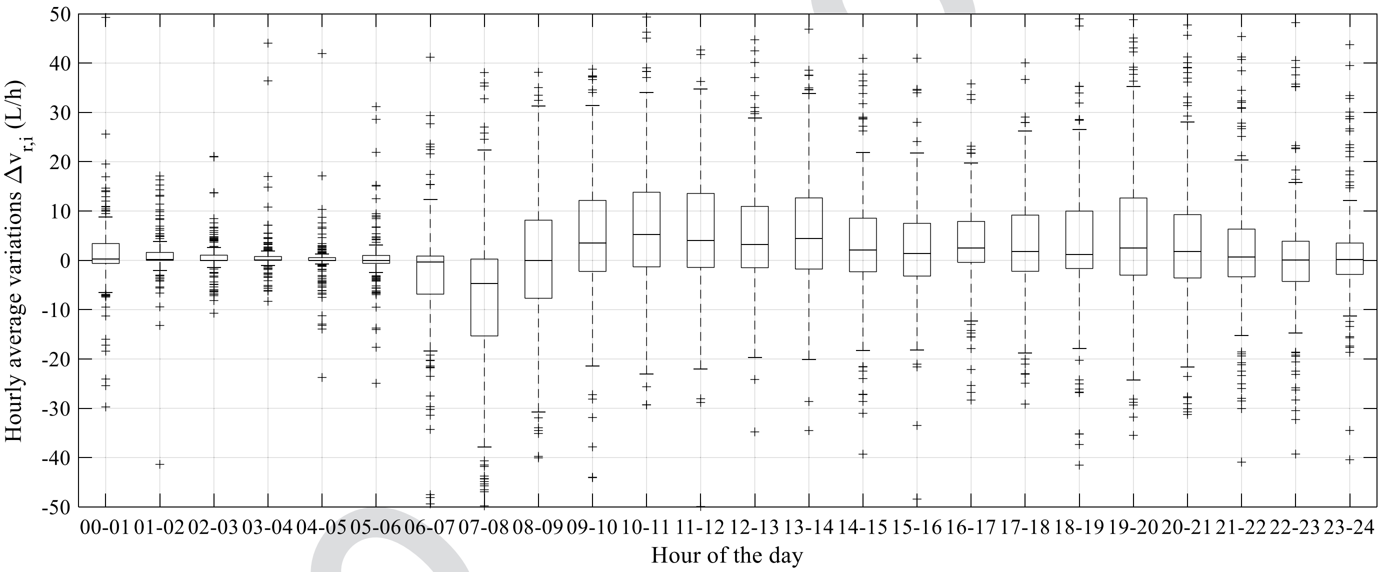

Fig. 4. Box plots of the difference ($\overline{\Delta v}_{r,i}$, L/h) between the hourly average water consumption on weekdays in April 2020 versus April 2019 for users of the RU dataset.

Similar considerations partially apply to the weekends/holidays water use profile [Fig. 3(b)]. In fact, during the lockdown period, a slight delay in the morning peak occurred, as the highest value of $C_{h,i}$ was shifted forward by 1 h, and a general increase in water consumption was observed during diurnal hours.

Hourly Temporal Scale, Individual Users

Fig. 4 includes the box plot of the difference between the average water consumption of April 2020 and 2019 for weekdays [Eq. (4)]. The boxes show values tightly packed around zero between 2:00 a.m. and 5:00 a.m., meaning that, on average, there were no differences in water use from 2019 to 2020 during the nighttime. In contrast, user changes were more heterogeneous after 6:00 a.m. Specifically, between 6:00 a.m. and 8:00 a.m., 75% of the users showed a reduction in the average water consumption during the lockdown compared to 2019. In the daytime hours after 9:00 a.m., 75% of the users showed an increase in the average water consumption during the lockdown compared to 2019. Analogous results, even though less marked, were obtained for weekends/holidays.

Most of the preceding considerations about residential water use profiles on weekdays were further supported by cluster analysis through the K-means algorithm. The preliminary silhouette curve analysis conducted to identify the optimal number of partitioning classes (i.e., optimal K-value) showed that the average silhouette was the highest for $K = 4$. The four clusters that emerged from the K-means analyses (Fig. 5) were different in terms of the daily distribution of water consumption and the time of occurrence of the peak consumption: (1) a profile with limited consumption during the day and a significant peak in the morning ($K = 1$); (2) a profile with moderate consumption during the day and a peak in the

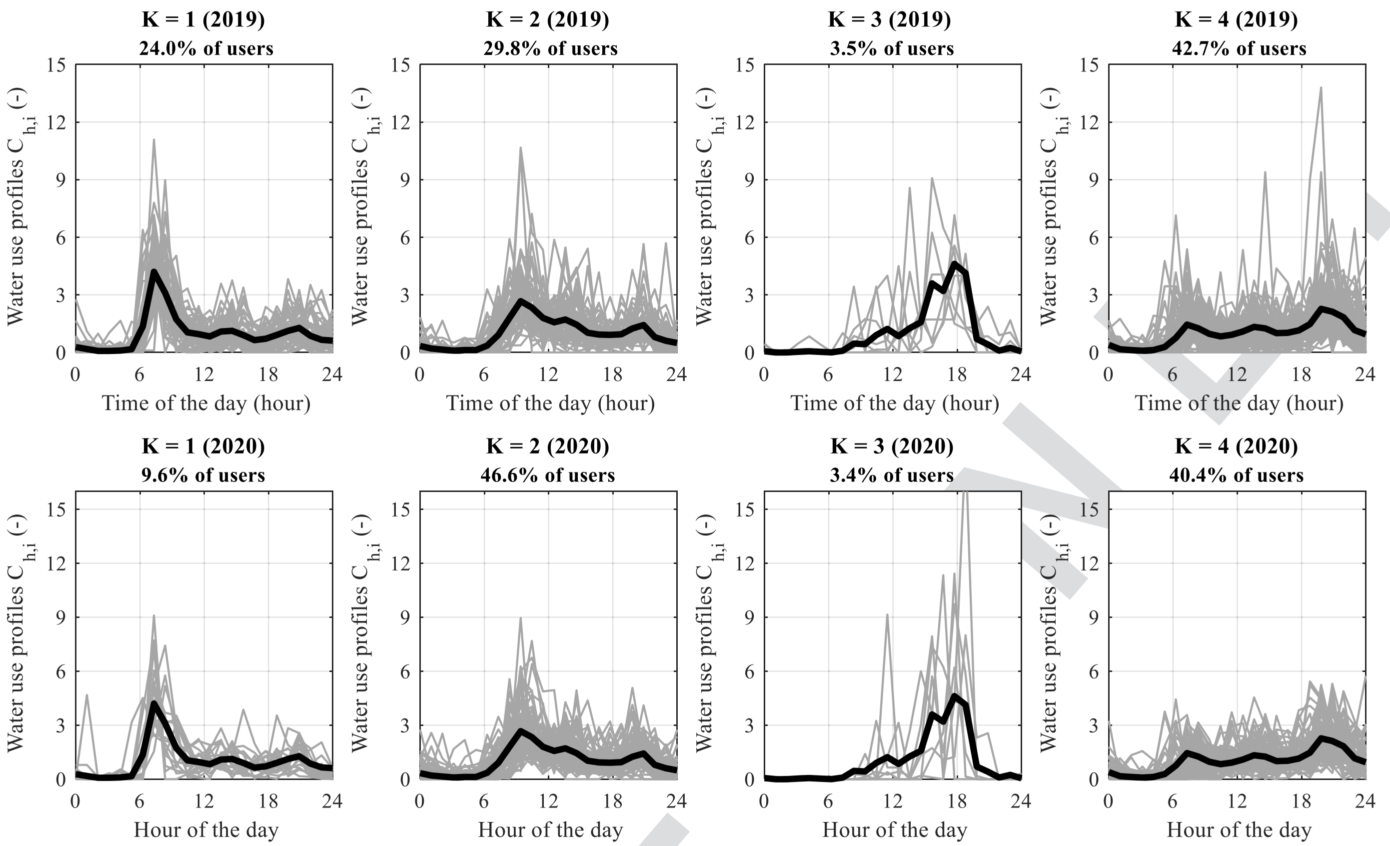

Fig. 5. K-means algorithm results. Every panel includes the 2019 and 2020 weekday residential water use profiles ($C_{h,i}$, in grey) for the given partition classes and the cluster (in black) associated with each partition class.

morning ($K = 2$); (3) a profile with limited consumption during the day and a significant peak in the evening ($K = 3$); and (4) a profile with moderate consumption during the day and a peak in the evening ($K = 4$).

Table 2 provides the percentages of users assigned to each class in April 2019 and in April 2020, and it is worth noting that 45% of users changed their partition class with the advent of the lockdown. A high percentage of users (i.e., 16.3%) switched from the first to the second, third, or fourth class, whereas only a small part (i.e., 1.9%) switched from the second, third, or fourth class to the first. Therefore, the results of the K-means algorithm application confirmed a general change in the weekday behavior of residential users during the lockdown period due to social distancing and the obligation of working from home. There was a greater tendency to use water in a more evenly distributed manner during the day, with attenuation in the morning peak of consumption.

Table 2. Percentages of residential users assigned to each of the four partition classes in April 2019 (prelockdown period) and in April 2020 (lockdown period)

		April 2020				
—	—	$K = 1$	$K = 2$	$K = 3$	$K = 4$	Total
April 2019	$K = 1$	7.7%	9.1%	0.0%	7.2%	24.0%
	$K = 2$	0.5%	22.1%	1.4%	5.8%	29.8%
	$K = 3$	0.0%	0.5%	0.6%	2.4%	3.5%
	$K = 4$	1.4%	14.9%	1.4%	25.0%	42.7%
	Total	9.6%	46.6%	3.4%	40.4%	—

Note: K = partition class.

Concerning commercial users, it emerged that, during the lockdown, the ones providing essential goods (i.e., pharmacies and hardware stores) did not change their water consumption behavior compared to the same period of the previous year. In contrast, other users (i.e., homeopathic and wellness centers and hairdressers) completely changed their consumption profile and did not consume water at all during the period of forced closure of their businesses (Fig. 6).

The preceding considerations about the tendency of some nonresidential users to reduce or stop water consumption during the lockdown period were further supported by considering the daily inflow (m^3/d) of the Abano Terme DMA, which is around 30 km north of the Commenda DMA, supplying a total of around 10,000 users. The Abano Terme DMA is characterized by a high nonresidential water consumption (around 60% of the total) due to the presence of a natural thermal site conferring touristic and commercial value to the area. Specifically, compared to April 2019, an overall decrease of 30% in average daily inflow was registered in the Abano Terme DMA for April 2020, being the average difference between the 2019 and the 2020 daily inflow of about 1,000 m^3/d. Although the authors acknowledge that, in general, inflow changes can be affected by other factors beyond water consumption (e.g., leak formation/repair and valve settings), it is worth noting that no anomalies due to leak phenomena or changes in operational controls, or anomalous climatic conditions, were reported in the two periods. Therefore, it was reasonable to assume that the 30% reduction in the Abano Terme DMA daily inflow was mainly due to the closure of commercial activities and the interruption of tourist services.

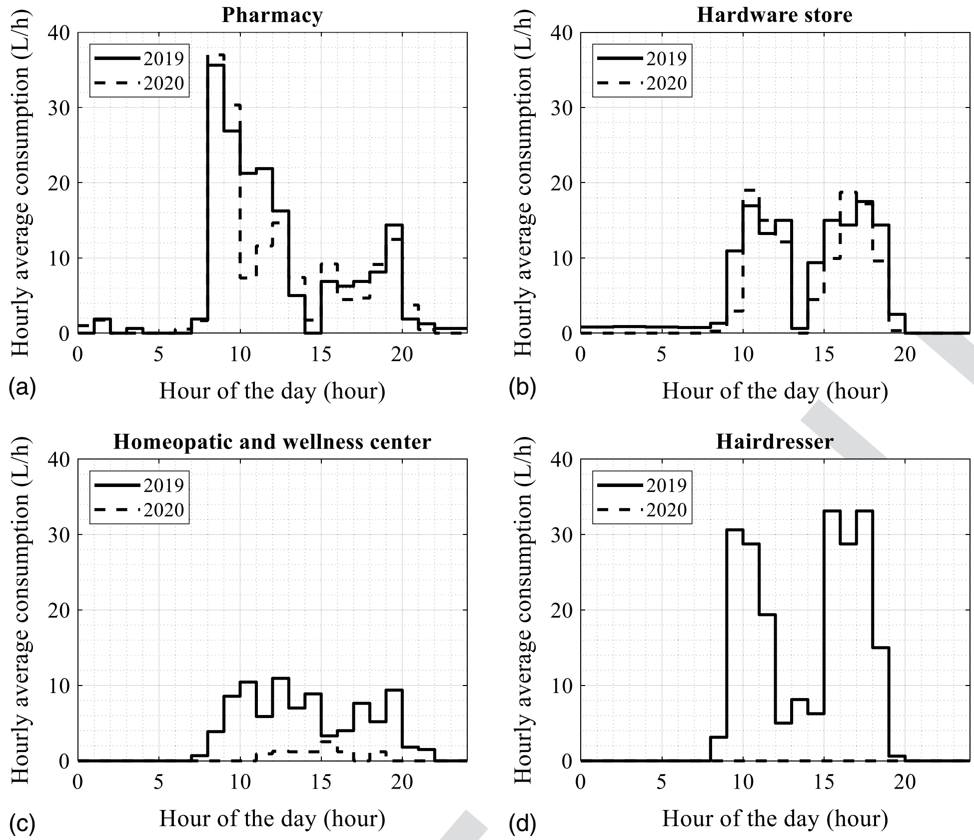

Fig. 6. Weekday hourly average water consumption (L/h) in the months of April 2019 (solid line) and April 2020 (broken line) of (a) a pharmacy; (b) a hardware store; (c) a homeopathic and wellness center; and (d) a hairdresser.

Implications and Limitations of Study

Outcomes of the analyses performed can hint at some considerations of interest for water utilities and system management but are also affected by some limitations. Indeed, on the one hand, it is worth recalling that changes in water consumption generally result in the need to rethink water distribution network operational criteria with the aim of adapting them to new conditions (Berglund et al. 2021). This was confirmed by the water utility responsible for water supply in the case study considered, which adopted new management strategies during the lockdown (e.g., modifications in the pump operation) to adapt the system to water consumption changes, providing larger volumes but with reduced peak discharge in the residential district and lower volumes in the commercial district. Furthermore, it is worth highlighting the advantages brought to the water utility by smart meters for water consumption monitoring. Indeed, thanks to the monitoring systems, water consumption data could be collected despite the emergency condition and with respect to social distancing.

On the other hand, it is worth noting that the case study considered is a mainly residential DMA of a medium-sized, provincial city, and therefore, the results obtained may not be applicable to different scenarios (large metropolitan areas, commuter towns, or industrial zones). Moreover, it was not possible to investigate the correlation between water consumption changes and sociodemographic factors such as family size, family income, or household characteristics, and because user monitoring has been ongoing since April 2019, a comparison between the year 2020 water consumption and one of the years prior to 2019 was not possible.

Conclusions

The current study analyzed the effects of the lockdown due to the COVID-19 spread on water consumption, with reference to the Commenda DMA in Rovigo, Italy.

The results highlight the following:

- the measures to contain the spread of COVID-19 implemented in the month of April 2020 had the effect of increasing water consumption across the entire DMA by about 18% compared to the same period of the previous year;
- the increase in the total consumption is mainly ascribable to residential users;
- a clear delay in the morning peak and a general increase in water consumption during diurnal hours were observed in residential water use profiles on weekdays, which is understandable given the fact that the suspension of school and job activities and the incentivization of homeworking induced users to consume water in a more distributed manner during the day; and
- with reference to the few commercial users belonging to the DMA in question, considerable changes in water consumption were observed in the case of activities for which a forced closure was imposed.

In conclusion, this study demonstrated that the adoption of restrictive measures to contain the COVID-19 pandemic largely influenced people's water consumption habits in the DMA analyzed. It is believed that the results of the analyses could be transferred to additional similar contexts (i.e., residential DMAs of medium-sized cities) and used to improve the understanding of the network and to validate water distribution system models better, as also reported by Berglund et al. (2021).

Data Availability Statement

The data and codes generated and used during the study are available in an online repository in accordance with funder data retention policies (Alvisi et al. 2020).

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