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Impacts of the protective measures taken for the COVID-19 pandemic on water consumption and post meter leakages in public places

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Abstract Adequate, secure, and sustainable water supply gained utmost importance as an essential public service during the COVID-19 pandemic. The aim of this research study is to investigate impacts of the protective measures taken for the COVID-19 pandemic on water consumption and post meter leakages in public places. A total of 22 pilot study sites (PSS) representing schools, graveyards, parks, mosques, public toilets, a university building, and a sport facility were chosen to apply this study. The PSS were equipped with smart meters with different sizes that were capable of measuring the flow rates at short intervals of 15 min. The flow rates were continuously monitored at the PSS for more than 1 year before and during the COVID-19 pandemic in 2019 and 2020. Post meter leakages were determined based on the minimum night flow (MNF). The monitoring results showed a considerable decrease (42%) in the total flow rates at public places because of the lockdown measures, but excessive post meter leakages (72% of total flow rates) were also observed. Additionally, the decrease in flow rates adversely affected measuring accuracy of the meters and thereby increased the apparent water losses. Control of post meter leakages and selection of appropriate size of meters are important for efficient use of urban water. Water and energy savings besides reduction in greenhouse gas emissions are the main environmental benefits of leakage control. The use of smart technologies contributes to efficient and sustainable management of urban water demand, but raising public awareness for conservation of water is essential.

Keywords COVID-19 · Lockdowns · Meter accuracy · Post meter leakage · Public places · Smart metering

Abbreviations

CMP	COVID-19 pandemic monitoring period (April and May in 2020)
EU	European Union
GHG	Greenhouse gases
MNF	Minimum night flow (minimum flow rate measured between 00:00–05:00 in this work)
NMP	Normal monitoring period (between March and October 2019)
NRW	Non-revenue water
PSS	Pilot study sites
RLP	Reduced leakage period (between November 2019 and end of February 2020)
SWB	Standard water balance
UAC	Unbilled authorized consumption

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Introduction

The World Health Organization (WHO) declared the COVID-19 outbreak a pandemic in March 2020, and nearly 269 million COVID-19 cases have been confirmed globally as of 10 December 2021 causing more than 5.2 million deaths (WHO, 2021). The adequacy and security of water have gained an enormous importance with the outbreak of COVID-19 as personal hygiene and hand washing are highly recommended to control the spreading of the disease.

Population increase, urbanization, land use change, and climate change increased the water demand and caused water stress and scarcity in many countries. The annual global water demand was reported to increase at approximately 1% while between 4.8 and 5.7 billion people are estimated to live in water-scarce areas for 1 month per year by 2050 (UN-Water, 2019). Climate change highly affects the global water cycle and the availability of water changes spatially and temporally with major variations and uncertainties (Kanakoudis & Tsitsifli, 2019). Undeveloped countries and poor people are under high risk due to lack of access to water, sanitation, and personal hygiene especially during pandemic disease outbreaks, such as COVID-19. Prevention or suppressing of pandemics requires adequate water availability, acceptable water quality, and sustainable management of water resources (Cooper, 2020). The use of intelligent or smart equipment (sensors and meters) in smart water networks and advanced data analytics is necessary to ensure sustainable and efficient water management through digitalization of water (Di Nardo et al., 2013; Freitas et al., 2019; Fuentes & Mauricio, 2020; Liu & Mukheibir, 2018; Water Europe, 2020).

In the study of Eastman et al. (2020), the effects of COVID-19 on urban water consumption were investigated for eight water utilities for the period between March and June 2020. Total water consumption showed reductions (−3.4% to −12.2% difference) in March and April 2020 in some of the investigated utilities compared to the 3-year historical average for those months. However, some utilities experienced double digit increases (6.3% to 17.7% difference) in total water consumption in May and June 2020. The total water consumption showed variations in between the utilities due to different climatic conditions, local, state, and federal policies adopted for the pandemic. Additionally, the non-residential consumption was noticed to reduce in almost all the utilities in the early months of the pandemic (March and April 2020), but it returned to normal levels in some utilities by June 2020. In another case study in Joinville, Southern Brazil, the impacts of COVID-19 spread prevention actions on water consumption were compared before and after the governmental actions of quarantine and social isolation. Nonparametric analyses and regression models were applied to compare the commercial, industrial, public, and residential water consumption. There were significant differences between the analyzed periods with decreases in the water consumption of commercial, industrial, and public areas and an increase in the residential use (Kalbusch et al., 2020). Similarly, in Germany, the residential water increased by about 14.3% with higher morning and evening peak demands in 2020 than the two previous years (Lüdtke et al., 2021). The effects of COVID-19 safety measures (frequent hand washing and disinfection) on drinking water consumption and wastewater generation were analyzed in the study of Quintuña (2020) where 20% increase in consumption of drinking water and 15 to 18% increase in wastewater volumes were reported.

The first case of COVID-19 in Turkey was reported on March 11, 2020, and the number of daily new cases exceeded 13,000 after 1 month. In order to prevent the spreading of COVID-19, immediate drastic measures were taken starting from March 13, 2020, until the end of May 2020, and they were effective to reduce daily new cases below 3000. Specifically, all onsite classes at schools and universities were closed, the residents over the age of 65 and under 18 were asked to stay at their homes, crowded events such as weddings and all sorts of meetings were banned, and some public places and shops (such as parks, mosques, hotels, sports centers, shopping centers, restaurants, coffee shops, coiffeurs, and entertainment areas) were closed. Lockdown measures, social restrictions, banning of group activities, and increase in home working caused significant changes in water consumption patterns globally. This research study aims to examine the post meter leakages in public places during the COVID-19 pandemic and to assess the impacts of the taken measures on the consumption and leakage rates of water. A previous study conducted by the authors before the COVID-19 pandemic showed significant volumes of post meter leakages in public places (Muhammetoglu et al., 2020). This

paper presents a novel comparative study for water consumption and post meter leakages during the implementation of COVID-19 prevention measures at public places using smart metering. Moreover, the environmental benefits of post meter leakage control (water and energy saving, reduction in greenhouse gas emissions) are also presented and discussed.

Materials and methods

The study was conducted at Antalya City of Turkey which is located along the Mediterranean Sea coast. The population of the city is estimated at 1,420,166 persons in 2020. The city is an important destination for national and international tourists where the number of tourists visiting Antalya was approximately 15 million in 2019. The methods to achieve the aim of this study include the continuous online monitoring of the flow rates at 22 different public places for more than 1 year before and during the COVID-19 pandemic using smart metering. Figure 1 depicts the data collection, transfer, and analysis stages of the monitoring system using smart water meters. The monitored flow rates passing through the meters (consumptions) are analyzed, and leakages are determined at three different periods to investigate the impacts of the protective measures for COVID-19 on water consumption and post meter leakages.

Non-revenue water (NRW) in Antalya

The standard water balance (SWB) required by the Turkish water losses control regulation (MFWA, 2014) is slightly modified from the SWB of the International Water Association (IWA) and American Water Works Association (AWWA) (Alegre et al., 2000; Hirner & Lambert, 2000) by combining the leakages on transmission and distribution mains and service connections in one component. All municipalities are required to fill in and submit the yearly SWB table to the related ministry in Turkey every year since 2015 to show the performance of urban water losses management (Gungor et al., 2019). The yearly SWB for Antalya City in 2019 is given in Table S1 (given in Supplementary Material) which indicates that NRW in the city was calculated as 45.35% while water losses were calculated as 44.98% (ASAT, 2020). The use of percent metric is misleading, but this is the only performance indicator required by the related Turkish regulation (MFWA, 2014) although unbiased performance indicators such as Infrastructure Leakage Index (ILI) (Lambert et al., 1999) should be used. The percent of unbilled authorized consumption (UAC) in Antalya City was 0.37% in 2019 which

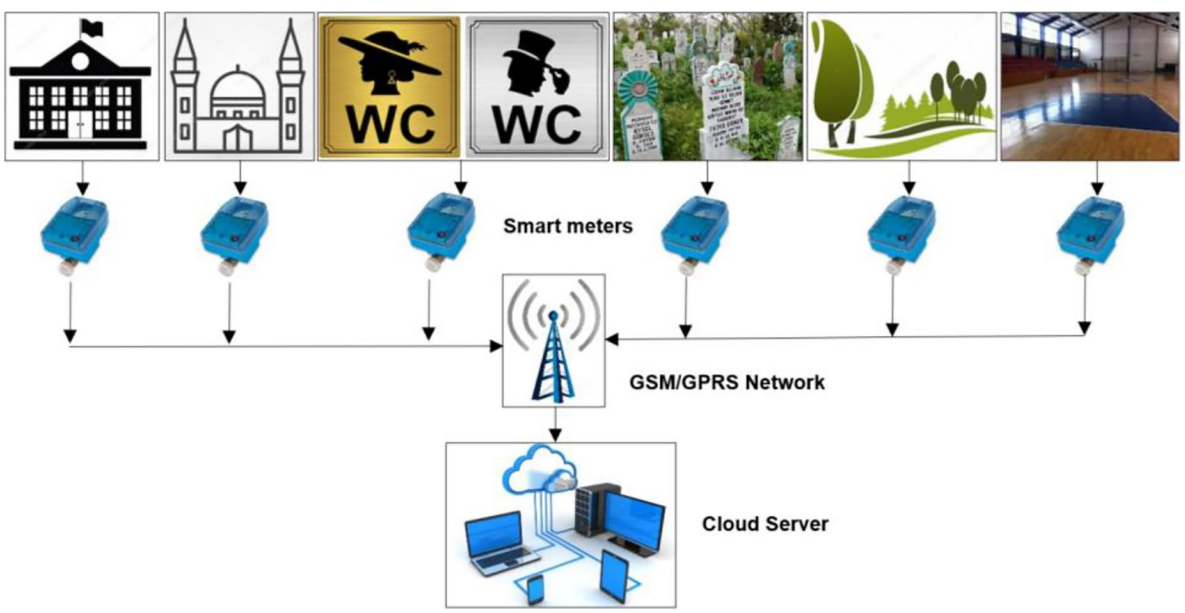


Fig. 1 Data collection, transfer, and analysis stages of the monitoring system

includes mainly water consumption for religious places and fire hydrants. Thus, the water consumption in public places considered in this study is not included in UAC except for mosques. Also, post meter leakages are not included in water losses or NRW components because they are recorded by the meters and consequently included in the authorized consumption. However, high levels of post meter leakages cause pressure on the water resources, water supply system, wastewater collection system, and treatment and disposal facilities. Additionally, leakages increase energy demand which implies much more greenhouse gas emissions.

The investigated public places

Common public places in Antalya were chosen as pilot study sites (PSS) for this research study. The reason for choosing public places instead of residential areas is that the cost of consumed water is not paid directly by the users. Instead, the responsible municipality, water authority, ministry, university, or school pays for the cost of consumed water. Consequently, the water is usually used unconsciously and wastage of water is frequent. Moreover, the district municipalities or other governmental offices in Turkey usually postpone or even ignore the payment of the water bills of public areas (such as parks, public toilets, and graveyards) to the water authorities that collect the payments of water bills. In fact, this ignorance is also accepted by the water authorities and hence there is little attention to reduce leakages and wastage of water at public areas.

A total of 22 PSS was chosen including two schools, two graveyards, three parks, four mosques, four public toilets, four toilet blocks at different floors of a faculty building, two toilet blocks at university campus shopping areas, and one sports facility (Fig. 2). Smart water meters with many powerful tools were installed to the PSS. The characteristics of the PSS and size of the installed smart water meters are given inTable 1. In the table, “medium scale” describes a typical public place in Antalya City that covers an average size of land and serves for an average number of people, whereas “small scale” or “large scale” indicates relatively smaller and larger places than the typical ones. Additionally, “free of charge” term describes that public toilet is owned and operated by the local municipality and that the people do not pay for the toilet use. All the installed meters are volumetric and C-type. The flow characteristics (minimum (Q1), transitional (Q2), nominal (Q3), and maximum (Q4) flow rates) of the installed smart water meters are presented in Table 2, whereas further details and technical aspects of the meters are given elsewhere (Muhammetoglu et al., 2020).

Monitoring the flow rates

The flow rate passing through each smart meter was measured online continuously at intervals of 15 min at each PSS. The leakage level at each site was calculated on a daily basis as the leakage level may change from one day to another. The methodology used to separate the leakage part from the flow rate is based mainly on minimum night flow (MNF) as most of the PSS used to have no or very low water consumption at night between 00.00 and 05:00. Consequently, the level of post meter leakage at each site was equal to the MNF that was extracted from the flow rate measurements between 00:00 and 05:00. The flow rates passing through the meters were monitored for three different periods as follows:

1. Normal monitoring period (NMP): This period lasted 6 months and it was between March and August 2019 for meters with the size of DN20 and between May and October 2019 for the other meters. The purpose of this period was to investigate the flow rates and leakages at the PSS without any intervention. Consequently, no one was informed about neither the monitoring activities nor the aim of monitoring.
2. Reduced leakage period (RLP): This period followed the NMP period, and it was between November 2019 and February 2020. In this period, the administrators of the public places were informed about the findings of the research study including the frequent occurrence of high leakage levels. They were also informed about the reasons of leakages and were asked to take actions to reduce leakages.
3. COVID-19 pandemic monitoring period (CMP): This period includes monitoring of flow rates and leakages at all sites during the COVID-19 pandemic in April and May 2020. The measures to combat with COVID-19 were very strict and efficient during April and May 2020 in Turkey. Therefore, this period is used to study the impacts



Fig. 2 The locations of PSS where smart water meters were installed

of the taken protective measures on the levels of flow rates and leakages.

Results and discussion

Monitoring results

In the first period of monitoring, NMP, extremely high levels of flow rates were measured at all the investigated PSS. The reason is the frequently occurring high volumes of leakages which usually continued for long periods. Figure 3a depicts the monitored flow rates at a mosque (Mosque-2, as an example) for 1 week in June 2019 starting from Monday to Sunday (the last two days are weekend) where a different color is used for each day, whereas Fig. 3b depicts the separation of leakage from flow rate for the same site. This figure clearly shows that the flow rates never reached to zero during the whole week and there was a continuous leakage with daily variations. The total flow rate and leakage are calculated as 42.87 and 23.83 m^3/week, respectively, for the presented period of 1 week in June 2019 during NMP for that mosque. In case of mosques, the flow rates are usually expected to reach maximum on Fridays at noon

Table 1 Characteristics of the selected PSS

Category	Description of site	Meter size	Water consumption purpose
Mosques	Medium scale	DN20	All purposes such as ablution, toilets, washing, and irrigation of the small green areas
Mosque-1	Medium scale	DN20	
Mosque-2	Medium scale	DN20	
Mosque-3	Medium scale	DN20	
Mosque-4			
Graveyards	Medium scale	DN20	Irrigation of the green areas and construction of graves
Graveyard-1	Medium scale	DN20	
Graveyard-2			
Public toilets	Free of charge	DN20	Classical toilet water usage
Toilet-1	Free of charge	DN20	
Toilet-2	Free of charge	DN20	
Toilet-3	Free of charge	DN25	
Toilet-4			
Campus toilets	Inside the university campus shopping area	DN20	Mainly for toilet usage
Campus toilet-1		DN20	
Campus toilet-2			
Faculty building	Open for everybody	DN32	Mainly for toilet usage
Entrance floor WC	Open for everybody	DN32	
1st floor WC	Open for everybody	DN32	
2nd floor WC	Open only for staff	DN25	
3rd floor WC			
Parks	Large scale	DN40	All purposes such as drinking, washing, and toilets while irrigation is supplied from onsite groundwater wells
Park-1	Large scale	DN40	
Park-2	Small scale	DN20	
Park-3			
Sports facility	Medium scale	DN40	Several sports activities except swimming
Schools	Private school	DN50	All purposes except irrigation which is supplied from onsite groundwater wells
School-1	Governmental school	DN50	
School-2			

time as this is a holy day for Muslims and the people are collected at mosques for Friday praying. This was also the case for our monitoring site as the flow rates were maximum on Friday (14 June 2019). Additionally, peak flow rates may occur in the other days of the week and mostly in the afternoons for the occasion of funeral meetings and praying at mosques.

Table 2 The characteristics of the installed smart water meters

Meter size	Starting flow rate (L/h)	Q1 (L/h)	Q2 (L/h)	Q3 (L/h)	Q4 (L/h)
DN20	1.5	15.6	25	2500	3125
DN25	10	39.4	63	6300	7900
DN32	12	62.5	100	10,000	13,000
DN40	22	253	406	16,000	20,000
DN50	32	313	500	25,000	31,250

Figure 4a shows the monitored flow rates at a school (School-1) for 1 week during RLP in February 2020, as an example. In this school, the flow rates were reduced after informing the school administration about the level of leakages. The total flow rate and leakage are calculated as 215.58 and 68.44 m^3/week, respectively, for the presented period of 1 week. The flow rates were usually high in the weekdays in comparison to the weekend since there are limited activities at the school at the weekend. However, the monitored flow rates were always equal or higher than 200 L/h during the whole RLP. First investigations at this school showed no sources of leakage where all the taps and toilets were in excellent condition. However, further investigations showed that the reason beyond the considerable leakages was the leaks from the swimming pool where the school administration was informed about the detected leakages.

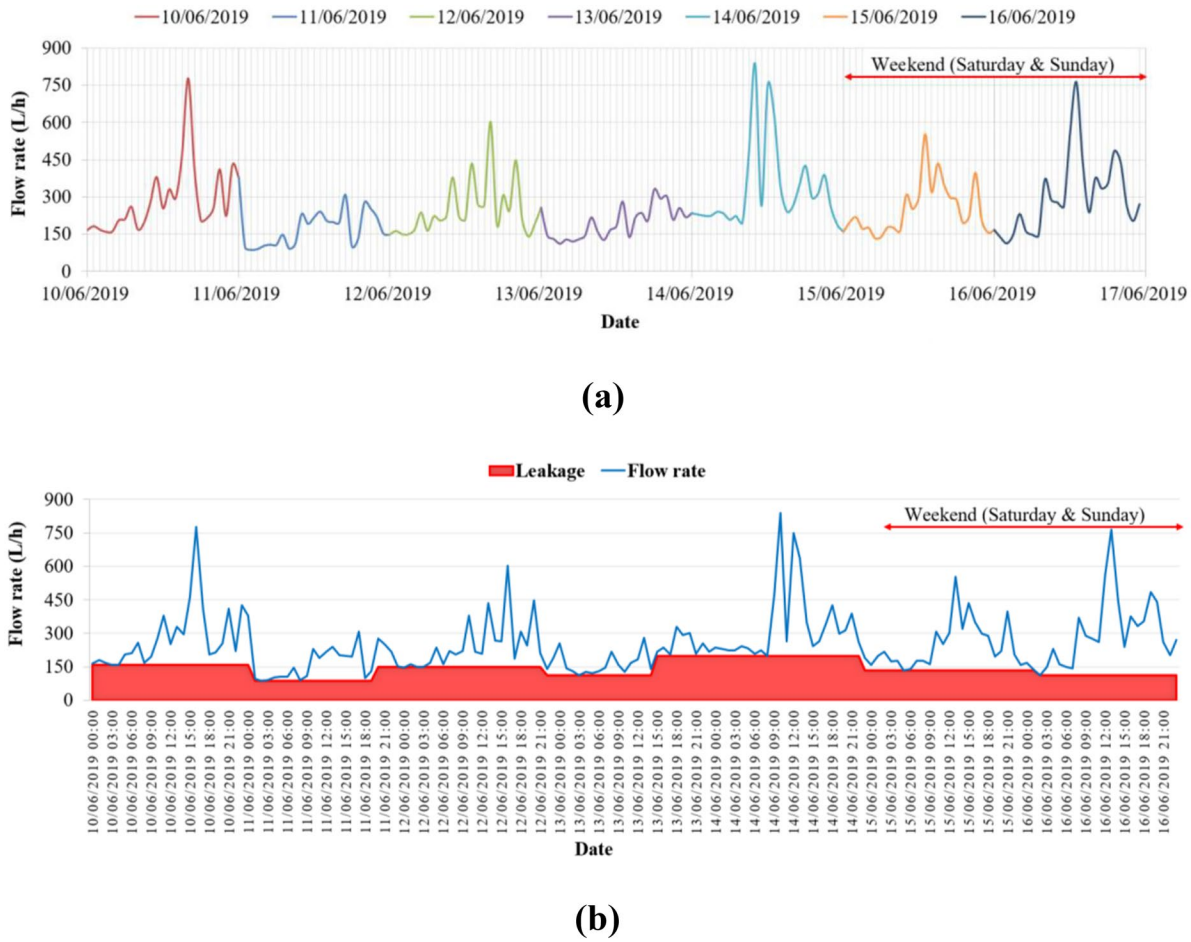


Fig. 3 **a** The monitored flow rates at Mosque-2 during NMP in June 2019, **b** separation of leakage from flow rate for the same site.

Figure 4b shows the monitored flow rates at a small park (Park-3) for 1 week during the COVID-19 pandemic in April 2020, defined as CMP. Although the protective measures at that month included the closure of all parks in Turkey, the flow rates in this park were considerably high and even continuous for days. In the presented period of 1 week, the last two days showed the weekend, and there was a lockdown order to stay at home for the whole weekend. Actually, the monitored flow rates were all leakages due to unfixed taps and toilets and leaks in the old pipes which transfer and distribute the water from the water meter to different parts in the park. The reduction of leakages in the weekend is most probably due to controlling one of the leaking sources such as closing an open water tap. In Fig. 4b, the total flow rate is calculated as 96.11 m^3/week which was completely post meter leakages.

A different leakage analysis was necessary for two public toilets which were open only at daytime, where the operators of these toilets used to close the main water valves at night (non-working hours) to avoid excess leakage from the unfixed taps and toilets which usually leak continuously during the open hours. Figure 5a depicts the monitored flow rates for such a public toilet (Public toilet-2) for 1 week, while Fig. 5b presents the separation of leakage from the flow rate. As a result, post meter leakage is none during the closed hours but actually there is excessive leakage during the open hours. As the smart meter reading frequency is 15 min, it was possible to determine the leakage level even in such a complex

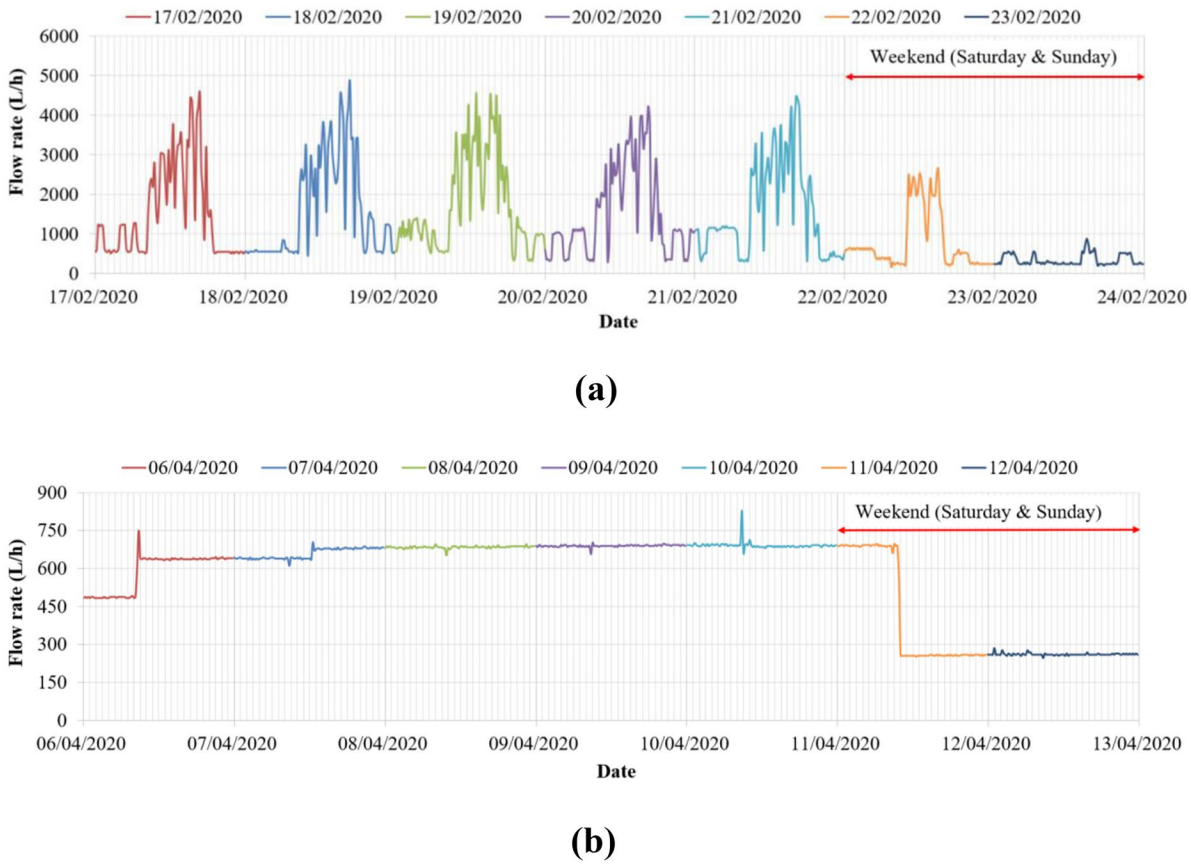


Fig. 4 The monitored flow rates for 1 week **a** at School-1 during RLP in February 2020, **b** at Park-3 during CMP in April 2020

and unusual case. This public toilet was investigated on site for the frequency of usage, and it was observed that there was always no usage of the toilet for more than 15 min especially during the first hour after opening and the last hour before closure. Consequently, the minimum flow rate during the open hours was used as the minimum leakage for that day. The leakage analysis is carried out on a daily basis as the leakage levels showed daily variations. The total flow rate and leakage are calculated as 82.05 and 40.37 m^3/week, respectively, for the presented period of 1 week in October 2019 during NMP for this site.

The monitoring results of the flow rates and leakages are presented in Table 3 for all the investigated periods and the different categories of the PSS along with the totals of each category and the totals of all the PSS. One of the main results of the monitoring activity is that excessive and high leakages occurred during the three periods of investigation, namely NMP, RLP, and CMP. Looking at the totals of flow rates and leakages, the monthly total leakage at all the PSS was 3705 m^3/month during NMP which represents approximately 55% of the total flow rate (6730 m^3/month). The monthly total flow rate reduced to 5395 m^3/month during RLP which implies a reduction of nearly 20% when compared to NMP. However, the monthly total leakage during RLP (3192 m^3/month) was reduced by only 14% when compared to NMP. Although very firm restrictions and protective measures were applied during CMP, considerable flow rates and leakages were observed. The monthly total flow rate during CMP was 3149 m^3/month at all the PSS which is approximately 58% of the total flow rate during RLP (5395 m^3/month). Additionally, approximately 72% of the total flow rate is calculated as leakage (2277 m^3/month) during CMP.

The most successful site during RLP was the governmental school (School-2) where the school

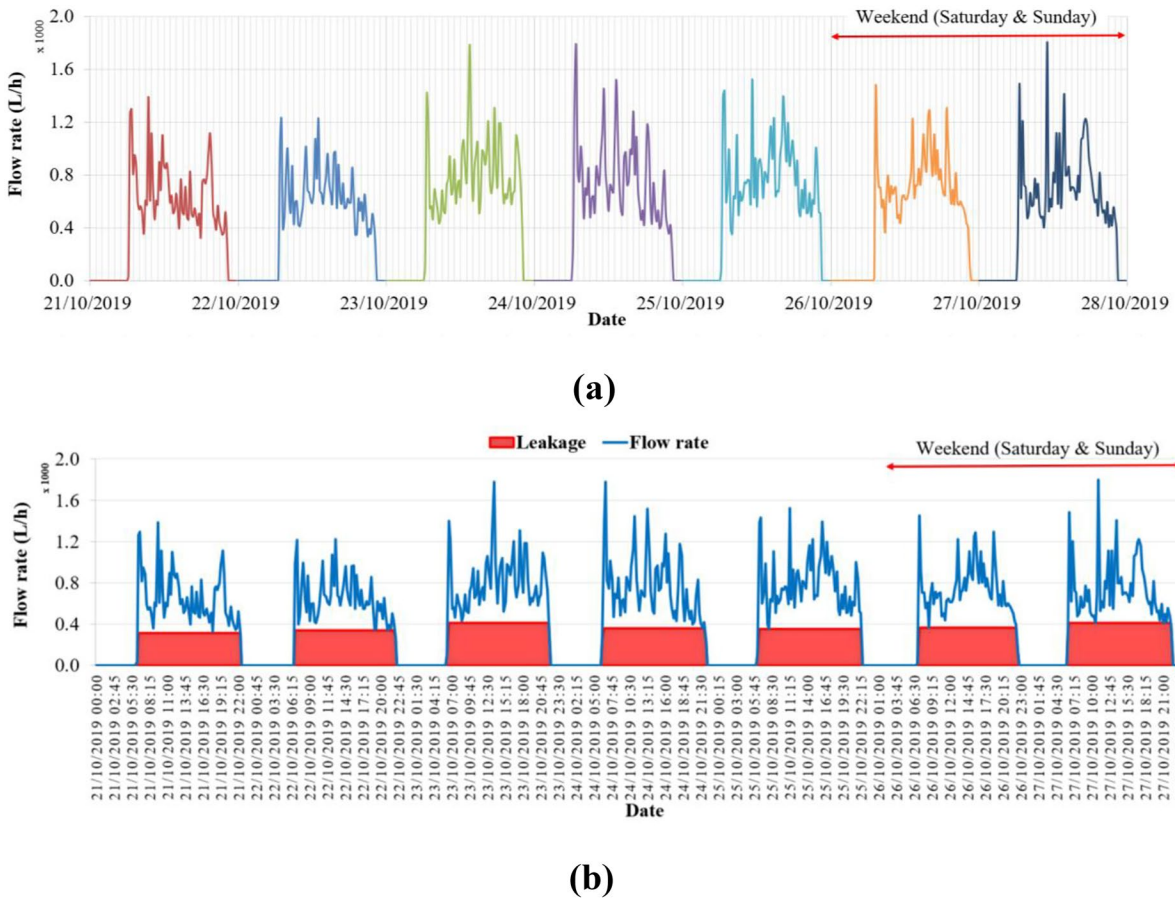


Fig. 5 **a** The monitored flow rates at Public toilet-2 during NMP in October 2019 where main water valve is closed at night, **b** separation of leakage from flow rate.

administration was very careful to reduce leakages. The success was due to prompt actions to fix leaking toilets and taps and their efforts to increase the awareness of students for conservation of water. Unfortunately, some of the investigated PSS did not show enough improvements to reduce leakages such as all investigated parks and the private school (School-1).

The reason for the high leakages in the parks is mainly due to the cracks in the low-quality water distribution pipes inside the parks which are usually harmed by the vehicles and machines used in plantation and other activities in the parks. A part of the pipe cracks was repaired at Park-3 during RLP that led to reducing the leakages. Similar leakage situation exists in the graveyards where excessive leakages are observed from the water distribution pipes inside the graveyard areas. Frequently, the public illegally install low-quality pipes by themselves in graveyards to bring water close to the graves, but these pipes usually cause excessive leakage. The faculty building and campus toilets in the university exhibited high flow rates and leakages during RLP although the administrative staff was well informed about the leakages as the research team of this study works at the same institute. Finally, the dean of the faculty decided to renovate all the old toilet blocks to have new and high-quality units. Still, raising awareness among the students is a real need. According to the research results of Willis et al. (2011) and Fielding et al. (2013), positive environmental and water conservation attitudes and interventions were effective to reduce household water consumption.

Table 3 Flow rate and leakage values of the PSS for the three different monitoring periods

Category	Site name	Normal monitoring period (NMP)		Reduced leakage period (RLP)		COVID-19 pandemic monitoring period (CMP)	
		Flow rate (m^3/month)	Leakage (m^3/month)	Flow rate (m^3/month)	Leakage (m^3/month)	Flow rate (m^3/month)	Leakage (m^3/month)
Mosques	Mosque-1	123	29	92	30	51	9.5
	Mosque-2	194	51	82	45	71	23
	Mosque-3	96	31	83	31	67	17
	Mosque-4	193	58	132	31	76	43
	Total	606	169	389	137	265	92.5
Graveyards	Graveyard-1	186	107	111	102	138	91
	Graveyard-2	128	81	59	51	74	41
	Total	314	188	170	153	212	132
Public toilets	Public toilet-1	154	92	92	63	18	5.5
	Public toilet-2	304	113	254	38	150	37.5
	Public toilet-3	196	82	140	31	27	4.5
	Public toilet-4	172	110	135	60	135	103
	Total	826	397	621	192	330	150.5
Campus area	Campus toilet-1	346	262	319	162	Closed	0
	Campus toilet-2	93	21	77	34	8	3
	Faculty building-entrance floor	130	100	122	82	67	66
	Faculty building-1st floor	51	25	63	31	6	4
	Faculty building-2nd floor	62	27	89	43	12	8
	Faculty building-3rd floor	36	10	39	9	8	1
	Total	718	445	709	361	101	82
Parks	Park-1	313	272	236	225	324	317
	Park-2	1204	641	1071	882	1070	923
	Park-3	1168	734	789	644	324	272
	Total	2685	1647	2096	1751	1718	1512
Sports facility	Sports facility	536	326	487	233	211	75
Schools	School-1	880	457	809	340	295	234
	School-2	165	76	114	25	17	0
	Total	1045	533	923	365	312	234
Totals		6730	3705	5395	3192	3149	2278

Impacts of the COVID-19 pandemic on water consumption and leakage rates

Among the three monitoring periods, CMP, the monitoring period during COVID-19 pandemic, is the most interesting one. In this monitoring period, many strict prevention measures were active (closure of schools, universities, parks, mosques, intense lockdowns for all social places etc.). Consequently, the flow rates were expected to reduce sharply and even reach nearly zero during CMP especially in parks, schools, sports facilities, and campus area. However, most of the PSS exhibited high flow rates during CMP. The most interesting category among the PSS is the parks where considerable flow rates and leakages were monitored during CMP. The monitored total flow rate of the three parks during CMP was 1718 m^3/month which represented nearly 55% of the total flow rates of all PSS at that period. On the other hand, the calculated leakage in the parks during CMP (1512 m^3/month) represents

more than 66% of the total leakages of all PSS during the same period.

Schools were closed during CMP and only a few personnel visited the schools from time to time. However, School-1 which is a private school exhibited high leakage rates during CMP although the flow rates were reduced due to the absence of students. The reason for high leakage rates is the leaking swimming pool although the pool was not used during CMP. Approximately 79% of the flow rate is calculated as leakage (234 m^3/month) during CMP for School-1. On the contrary, School-2 which is a governmental school exhibited very low flow rate and zero leakage during CMP. Figure 6 shows the monthly variations of flow rates and leakages at School-2 during the three monitoring periods. Although there were very few activities during the summer holiday (July and August 2019), flow rates and leakages were very high at School-2 because tap water was illegally used to irrigate the school garden. With the start of fall semester education in September 2019, leakage reduction interventions and raising student awareness toward water saving were effective to reduce the flow rates and leakages considerably during RLP. Figure 6 clearly displays the impacts of leakage reduction efforts and the preventive measures of COVID-19 on the monitored flow rates and leakages although this is not the rule for the other PSS.

In addition to School-2, the flow and leakage rates were considerably reduced during CMP for some of the investigated PSS such as Mosques-1 and 3, Public toilets-1 and 3, and campus area. The flow rates and/or leakages were only moderately reduced at some of the PSS such as Mosques-2 and 4, Public toilet-2, Park-3, Sports facility, and School-1. Surprisingly, there are even some PSS such as graveyards, Public toilet-4, and Parks-1 and 2 where the flow rates and/or leakages were higher than the RLP despite the intense lockdowns during CMP.

The monitoring results confirmed that the very strict protective measures against COVID-19 pandemic were not enough to achieve considerable reductions in post meter leakages at most of the PSS. However, these protective measures caused considerable reductions in the flow rates during CMP, as presented in Table 3. The flow rates were generally reduced as less people visited the religious places, graveyards, parks, schools, university, sports facilities, and public toilets. The frequencies of the flow rates are investigated for the period before COVID-19 (during NMP and RLP) and during COVID-19 (CMP) for Mosque-1, as an example. The results of frequency analysis, as depicted in Fig. 7, showed that the occurrence of high flow rates (> 180 L/h) was reduced during COVID-19 due to reduced intensity and number of users. Additionally, the results showed a general increase in the frequency of low flow rates (< 72 L/h) during COVID-19 because of undetected and unrepaired leakages which lasted for long periods.

Impacts of the COVID-19 pandemic on the meter measurement accuracy

It is well known that the measurement accuracy of the flow passing through new meters depends on the meter size, meter properties, and the level of flow rates (Al-Washali et al., 2020). Therefore, the measurement accuracy of meters significantly reduces when the flow rates

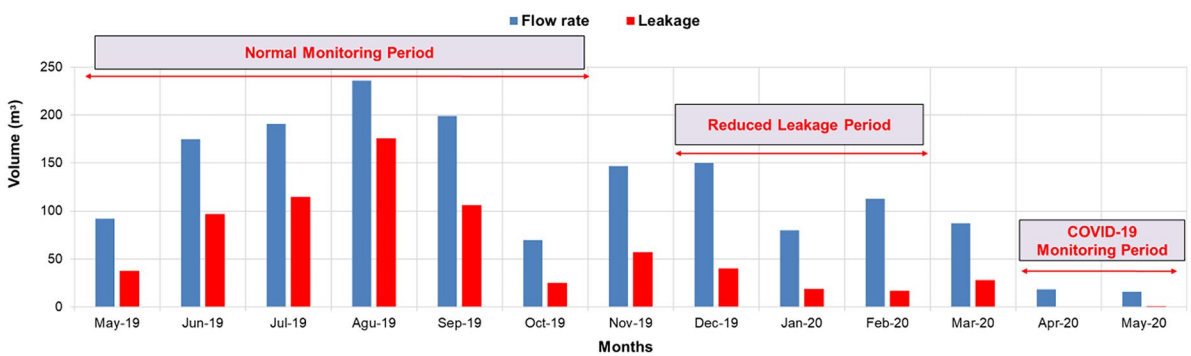


Fig. 6 The flow rates and leakages during the whole monitoring periods for School-2

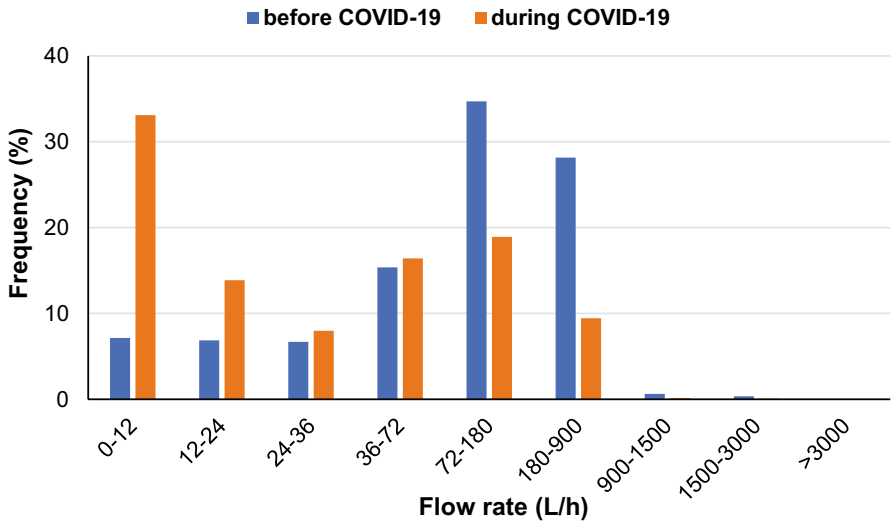


Fig. 7 Comparison of frequencies of flow rates before and during COVID-19 for Mosque-1

are below the minimum flow rate "Q1." In the previous section, it was shown that the protective measures for COVID-19 caused considerable changes in flow rates where the rates were generally reduced during CMP. Consequently, changes in the measurement accuracy of the meters are expected. Accordingly, a frequency analysis of the flow rates is conducted for the four smart meters installed at the faculty building, as an example. Table 4 presents the results of flow rate frequency analysis where it can be seen that the percent of flow rates below Q1 increased considerably during CMP in comparison to the flow rates in NMP and RLP. This in turn implies reduction in the measurement accuracy of the meters and thereby an increase in apparent water losses during CMP.

Reasons of high leakages at public areas

Post meter leakages at PSS were online monitored and investigated on site for more than one year. The main reasons beyond excess leakages can be classified under three items, namely (i) physical aspects, (ii) administrative aspects, and (iii) lack of awareness. The physical aspects include unfixed old taps and toilets besides the cracks in the piping system that transmits the water from the meters to different points inside the PSS, as previously discussed. Administrative aspects are due to the lack of leakage follow-up activities by the personnel responsible for PSS. In many cases, a tap in a park is left open for days although there is a number of personnel allocated only to look after the safety of that park. Moreover, there are no guidance values for the monthly water consumption in the PSS although the water meters are read monthly. Furthermore, there is no mechanism to control if the monthly water volumes at the PSS lie within the normal ranges or not. Lack of awareness is the most important aspect as the public can usually stop the leakages by simple actions such as tightly closing the taps but unfortunately, they usually do not attempt to do that. There is a need for an effective feedback method about

Table 4 Frequency analyses of the flow rates at the faculty building

Site name/meter size	$0 \le Q \le Q_1$		$Q_1 \le Q \le Q_2$		$Q_2 \le Q \le Q_3$	
	During NMP and RLP	During CMP	During NMP and RLP	During CMP	During NMP and RLP	During CMP
Entrance/DN32	38.06	43.31	8.02	26.96	53.92	29.73
1st floor/DN32	70.98	87.54	5.85	0.22	23.17	12.24
2nd floor/DN32	40.01	85.51	6.70	7.97	53.29	6.52
3rd floor/DN25	46.87	77.16	6.53	6.42	46.60	16.42

Table 5 Evaluation of monthly environmental impacts of leakages for the PSS

Category	Environmental benefits of leakage reduction during RLP			Environmental losses due to leakages during CMP		
	Water saving (m^3/month)	Energy saving (kWh/month)	GHG emission reduction (kg CO_2 /month)	Leakage rate (m^3/month)	Energy losses (kWh/month)	GHG emission (kg CO_2 /month)
Mosques	217	145	78	92	62	33
Graveyards	144	96	52	132	88	47
Public toilets	205	137	73	150	101	54
Campus area	9	6	3	82	55	29
Parks	589	395	211	1512	1013	541
Sports facility	49	33	18	75	50	27
Schools	122	82	44	234	157	84
Total	1335	894	479	2277	1526	815

community water consumption for water conservation (Otaki et al., 2017), as there is a serious lack of awareness toward water saving among most of the public, managers, and decision-makers.

Evaluation of environmental impacts of leakage

Impacts of leakage are evaluated for RLP and CMP considering environmental benefits and losses. For RLP, the environmental benefits of post meter flow reduction were considered under three main headings: water saving, energy saving, and greenhouse gas emission (GHG) reduction. Water saving is determined by calculating the difference of flow rates between NMP and RLP. In case of energy saving, the amount of energy consumed for supplying 1 m^3 of water from the source to the PSS for Antalya City is considered, and it is reported as approximately 0.67 kWh/m^3 (ASAT, 2013). Consequently, the amount of energy saving is calculated based on water savings. For GHG emission reduction, the estimated value of CO_2 emission for energy production in Turkey (0.53426 kg CO_2/kWh) is considered (Can, 2007). For CMP, the environmental losses due to post meter leakages were considered under three main headings: leakage rate, energy losses, and GHG emissions. The environmental benefits of leakage reduction during RLP and the environmental losses due to leakages during CMP are summarized in Table 5 for the investigated categories of the PSS on a monthly basis. Additionally, reducing leakages and/or water saving directly reduces wastewater volumes that need treatment and disposal. The presented results imply that reduction of post meter leakages supports sustainable management of urban water supply and resource conservation.

Conclusion

This study presented the impacts of the protective measures taken for the COVID-19 pandemic on water consumption and post meter leakages in public places. The flow rates were continuously monitored at the selected 22 PSS for more than 1 year before and during the COVID-19 pandemic and the post meter leakages were determined using MNF measurements. The monitoring results showed that the very strict protective measures against the COVID-19 pandemic were not enough to achieve considerable reductions in post meter leakages at most of the PSS but these protective measures caused considerable reductions in the flow rates. The monitoring results showed a considerable decrease (42%) in the total flow rates at public places because of the lockdown measures, but excessive post meter leakages (72% of total flow rates) were also observed. Public places such as universities, schools, graveyards, parks, mosques, public toilets, and sport facilities are very vulnerable to excessive post meter leakages even during the COVID-19 lockdowns and even if leakage occurrence is known. Although many public areas were shut down during the period of protective measures for COVID-19, high and continuous leakages were observed at many public places. Raising public awareness toward water saving is crucial to reduce post meter leakages in public areas. Moreover, the personnel responsible for public places should monitor leakages on site and check the level of periodic meter readings. Old and low-quality water taps, toilets, plumbing systems, and network pipes post the meters should be replaced with durable ones. Changing the flow rate profiles may lead to a considerable change in the measurement accuracy of water meters.

As presented in this study, the flow rates were generally reduced because of the protective measures for COVID-19 which reduced the measurement accuracy of water meters and thereby increased the apparent water losses. Control of post meter leakages leads to water and energy savings in addition to reductions in GHG emissions and wastewater volumes that need treatment and disposal. Therefore, control of post meter leakages and use of smart technologies greatly contribute to sustainable and efficient management of urban water.

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Declarations

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