Water Supply

Water Supply Vol 22 No 10, 7590 doi: 10.2166/ws.2022.300

The impact of COVID-19 on urban water use: a review

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ABSTRACT

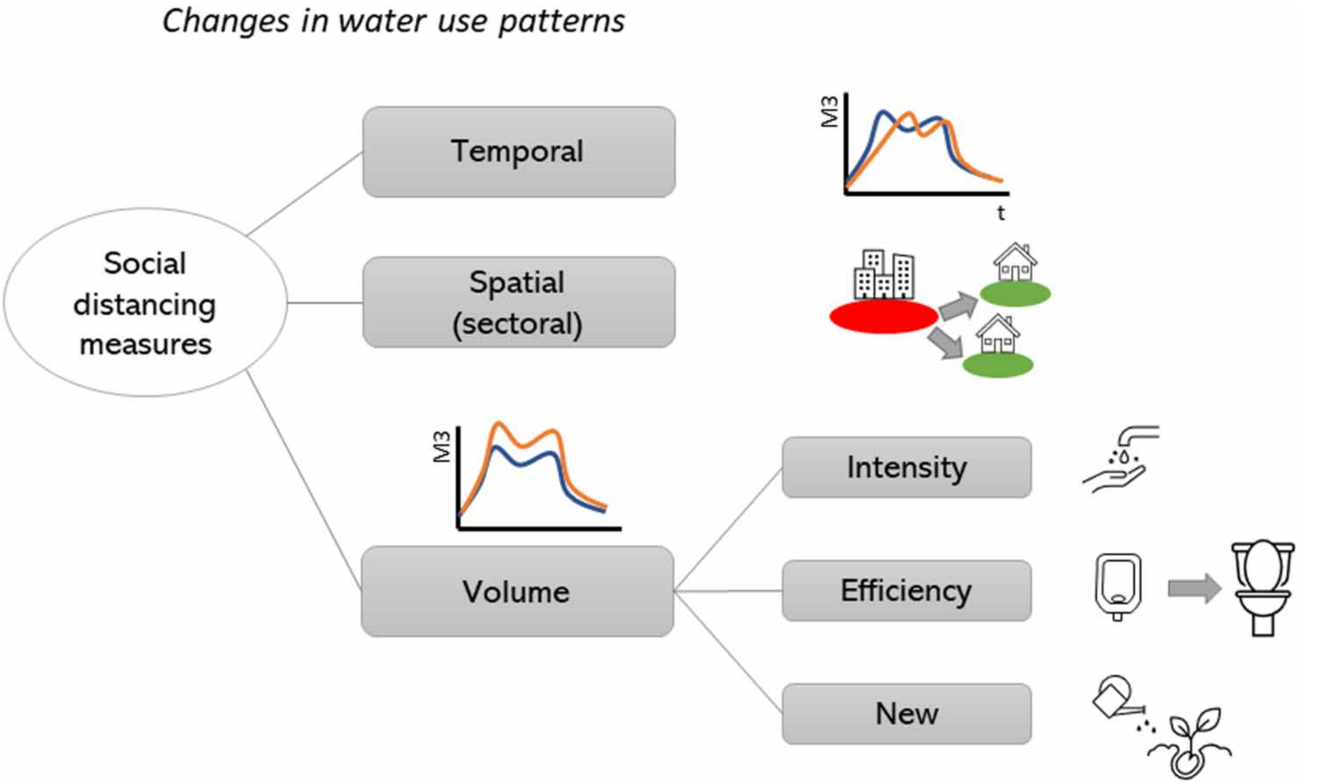
The COVID-19 pandemic had significant impact on water utilities, which had to continue providing clean water under safe-distancing measures. Water use patterns were affected, shifting peak demand and changing volumes, though changes varied from place to place. This study analyses the effects of the safe-distancing measures on water use patterns in different countries and cities with the aim of drawing general conclusions on causes and impacts of changes in water use patterns, as well as providing some insights on the impacts on finances of utilities and potential long-term implications. The analysis is based on information collected by the members of the IWA Specialist Group on Statistics and Economics for Belgium, Cyprus, Germany, Japan, Switzerland, Portugal, Romania, the Netherlands and Singapore. Temporal, spatial/sectoral and volume changes can be distinguished. The main temporal change in domestic water use was a delay in the morning peak, while commercial water use patterns changed significantly. In general, the volume of domestic water use increased between about 3% and 8%, while non-domestic water use decreased between about 2% and 11% over 2020. Indirect evidence suggests shifts have taken place between sectors and spatially. The impact on finances of utilities has likely been only short-term.

Key words: COVID-19, pandemic, water demand, water supply, water use patterns, water utilities

HIGHLIGHTS

- We give an overview of impacts of the COVID-19 pandemic on water demand.
- We look at water demand in different places globally.
- We analyse new data from nine countries supplemented with data from the literature.
- While the COVID-19 pandemic had different impacts on water use in different places, there are also some common trends.

GRAPHICAL ABSTRACT



INTRODUCTION

The global COVID-19 pandemic started on 11 March 2020 when the World Health Organisation (WHO) elevated the status of the situation caused by the SARS-CoV-2 coronavirus. In the following two years, the pandemic placed the world in an exceptional situation and had impacts on all levels, from changes in peoples' daily lives (Singh & Singh 2020), to the economic system (Khan *et al.* 2021) and even the environment (Lokhandwala & Gautam 2020; Wang & Su 2020). While some of these impacts are only short-term and will revert back to the pre-pandemic situation, other impacts may be more profound and may cause long-term changes in society, economy and the environment.

Like many other sectors, the urban water sector had to quickly adapt to the new pandemic situation. Many sectors faced restrictions or went into lockdowns, yet the urban water sector still had to provide water and sanitation services. Aside from dealing with operational restrictions, such as operating with a reduced workforce and difficulty in procuring supplies, utilities also had to deal with changes in water demand patterns, and, in some cases, impacts on finances (Cotterill *et al.* 2020; Spearing *et al.* 2021).

The pandemic had a significant effect on domestic and non-domestic water consumption patterns due to safe-distancing policies, such as lockdowns and work-from-home arrangements, while changing hygiene practices may also have had some impact. It appears, however, that there is significant variation in how patterns and total consumption were affected among different cities, towns and countries. Although on average most utilities saw an increase in domestic and a decrease in non-domestic water use (e.g. Cooley *et al.* 2020; Kazak *et al.* 2021), the magnitude of the changes and the ways patterns shifted differ from place to place.

A review of the literature shows that, so far, studies looking at changes in water use patterns due to social-distancing measures have only investigated the situation for a single city, region or country. There has been no review or overview of impacts across different places. Hence, the objective of this study is to analyse the effects of the COVID-19 pandemic on water use patterns in different countries and cities, with the objective of drawing general conclusions on impacts and their causes, as well as providing insights on the impacts on finances of utilities and long-term implications. The main source of information for this study is information on water use patterns that was collected by the members of the IWA Specialist Group on Statistics and Economics. Data and information were collected from Belgium, Cyprus, Germany, Japan, Switzerland, Portugal, Romania, Netherlands and Singapore. In addition, for Romania and Japan some financial impact data was available.

The outline of this document is as follows. The next section describes the study approach and the framework for analysis. This is followed by a review of existing studies on the impact of the pandemic on urban water use. The subsequent section analyses the information on water use patterns collected for this study. Finally, we discuss the results and draw some conclusions.

STUDY APPROACH AND FRAMEWORK FOR ANALYSIS

The COVID-19 pandemic resulted in governments around the globe taking social-distancing measures, i.e. measures that reduce interaction between people, such as closing of restaurants and shops, limiting the number of visitors that households can receive, or even restricting leaving one's home. The social-distancing measures varied significantly: while some places went into strict lockdowns with curfews for several weeks, other governments adopted a less severe approach aimed at some targeted reduction of social interaction and spread of the virus (Loewenthal *et al.* 2020). Over time, the severity of the measures also varied in regions and countries. The variation in measures and their severity should have different impacts on water use patterns.

A complicating factor in the analyses is that water use patterns are also affected by other variables, and notably by variations in weather. In many places, weather has a significant impact on water demand, with dry weather or droughts typically causing an increase in water use (Zubaidi *et al.* 2018). Another complicating factor in comparing changes in water use patterns among different places is that available data has different temporal and spatial scales. While for some places hourly data from individual consumers from smart meter systems is available, for other places only monthly billing data or consumption data provided by utilities for annual statistical data collections is available. The classification of different types of customers and the definition of the classes also differs among utilities: some utilities may have detailed classifications, while others only segment their customers based on meter size.

Hence, in view of these variations and differences, it is not possible to make direct, quantitative comparisons among different places. As such, we adopt a qualitative, descriptive approach to compare the different impacts at different temporal and spatial scales. A simple conceptual framework to identify the different impacts is used to describe and compare the different cases. This framework is based on the five dimensions of changes in water use that Lüdtke *et al.* (2021) identified.

The pandemic and resulting lockdowns had potentially three different impacts on water demand. Firstly, water consumption patterns changed over time. Water use activities took place at other times during the day or week; for instance, as people worked and studied from home and there was no need to commute, people woke up later, shifting the morning peak of domestic water use. Furthermore, people may have shifted activities, such as cleaning the house, to other days. Secondly, water consumption patterns changed over space. Water use activities took place at different locations; for instance, water demand in central business districts reduced as people worked from home, while it increased in residential areas. Spatial changes are also expressed by shifts in water demand between sectors. For instance, work from home results in increased toilet use at home, increasing residential water demand, while water demand in offices – the non-domestic sector – reduces. Thirdly, water consumption patterns changed in terms of volumes. This is the result of three separate effects: change in intensity, change in efficiency, and new water use. A change in intensity occurs as certain water use activities may happen more frequently, or use more water, or happen less. Examples are increased water use due to more and longer hand-washing, or a reduction in industrial water use as companies reduce production. A change in efficiency occurs if there is a difference in efficiency of water use of water use devices and practices, for instance urinals in commercial buildings are more efficient than toilets at home, and office lunches prepared in canteens may be more water efficient than lunches at home. An increase in volume could also occur if the pandemic or lockdown results in new water uses, e.g. for the production of new pandemic-related products or when an increasing number of households start to grow their own food or buy inflatable swimming pools for use in their gardens.

Figure 1 summarises the different impacts of social-distancing measures on water demand. We use this framework to analyse the impacts of the COVID-19 pandemic on water use patterns in the analysis below.

This study had access to data of nine locations. Table 1 gives an overview of the available data.

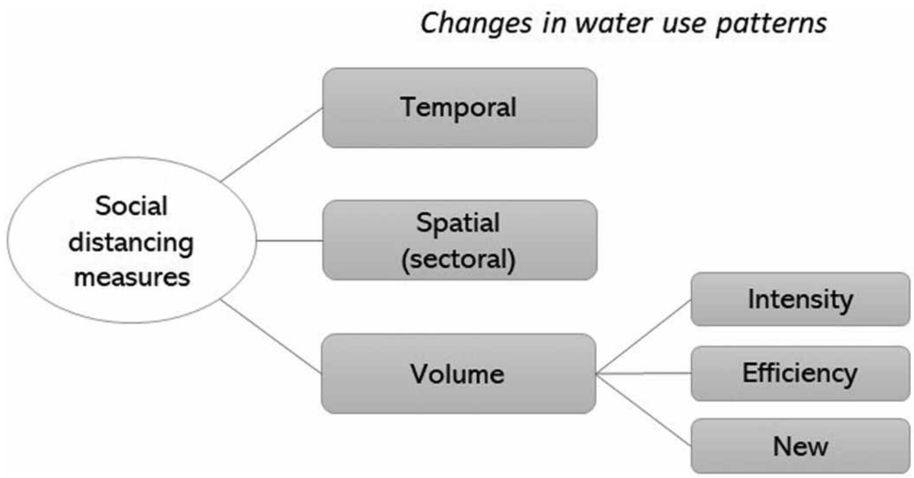


Figure 1 | Framework to analyse changes in water use patterns.

Table 1 | Overview of data

Country	Data source	Consumer classification	Temporal resolution & period	Spatial resolution
Belgium	Digital water meters	Households	Hourly, November 2019 – May 2020	330 households: 225 households in one community and 105 households of water utility staff
Cyprus	SCADA water flow data	Residential; commercial; industrial	5 minutes, 2017–2020	6 district metering areas in Limassol
Germany	Water sales data	Industry/ others; households/ small customers	Annual, 2019 & 2020	130 water utilities, split into: – large cities (>100,000 inhabitants) – suburbs of big cities – tourist areas – rural regions
Japan	Survey among water utilities	Domestic; non-domestic	Annual, comparison of 2020 with 2019	910 water utilities in Japan, corresponding to 71% of all water utilities
Netherlands	Statistical data collection	Households; business market; non-revenue	Annual, 1990–2020	Netherlands
Portugal	Billed water statistics	Households (domestic); commerce/ industry/ services (non-domestic)	Annual, 2016–2020	250 utilities, covering most of mainland Portugal
Romania	Survey data	Population; economic agents; public institutions	Monthly, 2019–2020	53 medium and large operators (covering more than 90% of the water sector)
Singapore	Meter readings & statistical data	Households & domestic; non-domestic	Weekly (with gap), Feb–Jul 2020 & yearly, 2013–2020	1,461 households & country level
Switzerland	Statistical data collection	Private households (including small businesses); commercial/ industrial	Annual, 1990/2013–2020	52 water utilities/municipalities

Note: Data was provided by members of the IWA Specialist Group on Statistics and Economics. See also Acknowledgements.

EXISTING LITERATURE

Changes in water use patterns due to social-distancing measures have been recorded and analysed in several studies. A few months after the first lockdowns, studies appeared on the impacts on water use patterns in Italy, Brazil and the USA. Balacco *et al.* (2020) found a delayed morning peak demand and absent lunchtime peak when studying aggregated flow data of five towns in southern Italy. In the larger towns, there was a clear reduction in demand due to fewer incoming commuters, while in the small, agricultural towns there was little impact on total demand. Kalbusch *et al.* (2020) analysed data from 1,178 consumers acquired with a water metering telemetry system in Joinville, southern Brazil. They found a strong water consumption drop in the commercial (–42%), industrial (–53%) and public (–30%) consumer categories, and a non-statistically-significant increase of 11% for residential consumers in the 26 days after a government decree that suspended non-essential activities. Cooley *et al.* (2020) looked at changes in water demand at 42 utilities in the USA, mainly in Massachusetts, but including a few utilities from other states, and found that residential water demand increased while non-residential demand decreased. There was significant variation in the change in total water demand among utilities, ranging from a 18% reduction to a 16.7% increase in water use. Key factors for this variation are both the relative proportion of residential and non-residential water uses and the makeup of the non-residential sectors in the communities.

In 2021, a few other studies that analysed water use patterns appeared. Abu-Bakar *et al.* (2021) applied cluster analysis to water consumption data with an hourly resolution from 11,528 smart-metered households. They identified four different clusters representing different temporal water use patterns. During the lockdown, water use increased by 10% to 46% and there was significant movement of observations among clusters. Lüdtke *et al.* (2021) analysed daily and hourly water volume rates of a utility in northern Germany. They found that daily residential water consumption was about 14% higher during the lockdown. A shifted peak for water demand in the morning hours was observed. Kazak *et al.* (2021) looked at changes in water demand patterns in Wrocław, Poland, using monthly water consumption data identifying ten different types of users in 23 zones. They found that although total demand did not change much, the lockdown of the economy caused noticeable transfers between different categories of water consumers: a 19.8% increase for housing; −17.2% for commercial users; and −38.1% for education establishments. Dzimińska *et al.* (2021) analysed automated meter readings with hourly water consumption from three apartment buildings in Bydgoszcz, northern Poland. They found that water consumption patterns of the households could be clearly clustered before but not anymore during the pandemic.

In addition to the data-analysis studies, Alda-Vidal *et al.* (2020) tried to understand changes in household water consumption associated with COVID-19 through focus-group discussions and analyses of secondary data. They concluded that changes in patterns of water use are related to changes in the organisation of life and work. Increased water use related to hygiene practices, such as more hand washing, quickly faded, while outdoor water use increased due to more intensive use of gardens. This resulted in an increase of 20% to 40% in water use. Bich-Ngoc & Teller (2020) developed a model that showed that impact of dry weather has a much stronger impact on water demand in the Liège (Belgium) conurbation (up to a 19% surge for extreme dry weather) than a reduction in outbound tourism (increase of 2% to 5% under the most extreme reduction) due to pandemic measures. Finally, the only study conducted in a developing country showed that most Ugandan households had an increase in quantity of water utilised after March 2020, based on household survey data (Sempewo *et al.* 2021).

COVID-19 IMPACTS ON WATER USE PATTERNS

Temporal changes

In this section we will discuss the impact of social-distancing measures on water use following the conceptual framework presented in Figure 1. First, we will look at temporal changes in water use patterns. Temporal changes, i.e. changes in water use patterns that occur over a day or multiple days, can only be investigated with data that has a high temporal resolution. The data from Limassol, Cyprus, was recorded at five-minute intervals and the data from Belgium was recorded at hourly intervals. In Limassol, the first social-distancing measures, comprising the closing of commercial buildings and public places, were implemented on 15 March 2020 and from 31 March to 21 May a full lockdown was in place. From mid-November 2020 onwards, a new partial lockdown was in place, with a night curfew and closing of commercial and government buildings. Figure 2 shows that the social-distancing measures from March to May caused a shift in the residential consumption of about 1.5 hours in the morning in the month of April as compared with the months of April in the preceding three years, while the evening peak was slightly earlier and water use declined slightly earlier. For industrial consumption

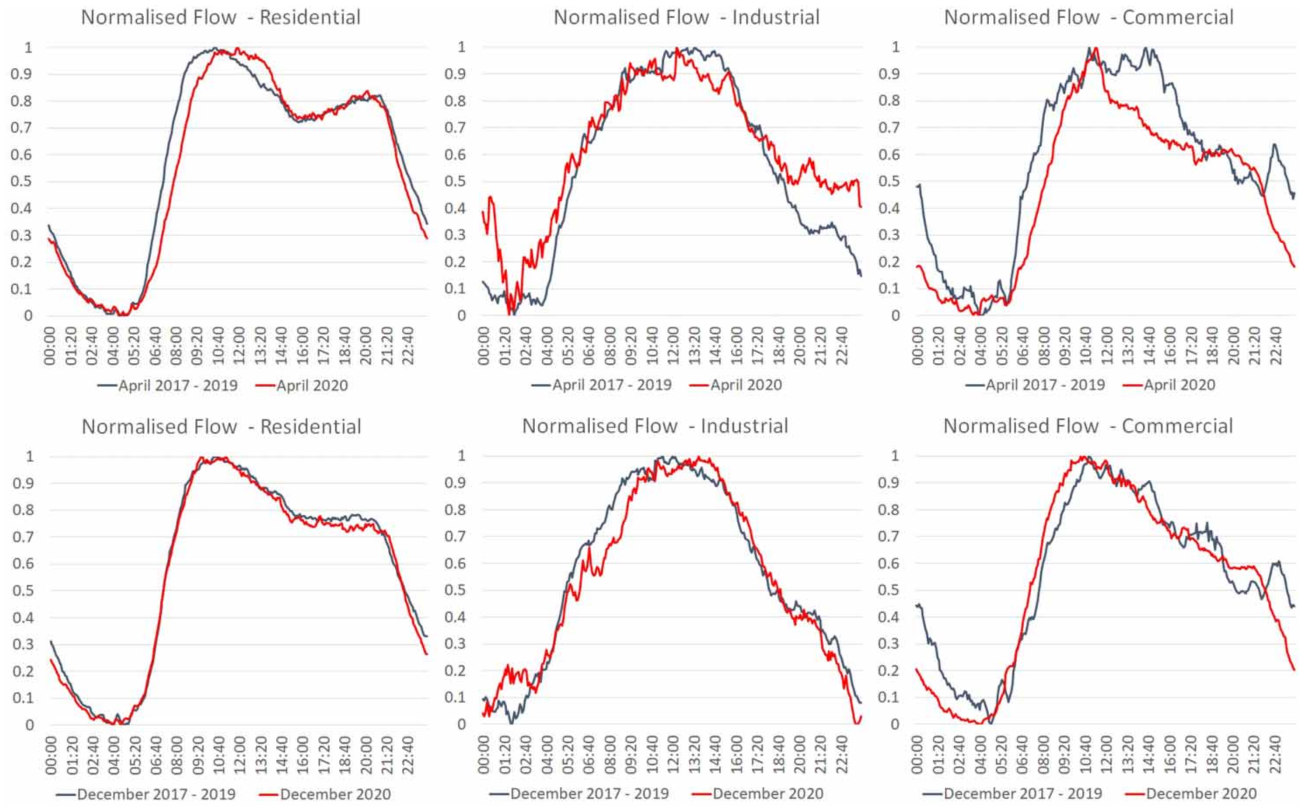


Figure 2 | Normalised flow pattern for Limassol in April (top) and December (bottom).

there was no noticeable shift; the higher consumption at night was also seen in the months before the social-distancing measures, hence it has another reason not related to the pandemic. For commercial consumption, the change in hours of operation in combination with the closure of certain types of commercial buildings results in a different consumption pattern altogether compared with before the pandemic. The partial lockdown measures at the end of 2020 had no impact on the residential water use pattern, even though travel restrictions forced most people to spend the December holidays at home. Industries also operated almost normally, while the night curfew lowered the water use of commercial buildings during that time. A shift in the morning peak of about two hours was also observed in the residential water consumption data from Belgium when comparing pre-lockdown months (November 2019–February 2020) with the first lockdown period (March 2020–May 2020). There was no change in the evening peak.

In the literature, the studies of Balacco *et al.* (2020), Abu-Bakar *et al.* (2021), Lüdtke *et al.* (2021) and Dzimińska *et al.* (2021) looked at temporal changes in water use patterns, though none of them made a distinction between different types of users. Balacco *et al.* (2020) analysed hourly water use patterns for one week during a lockdown using aqueduct flow data to towns and a city. Water use in the towns typically shows a morning, lunchtime and evening peak, but during the lockdown, the morning peak was shifted to about two to 2.5 hours later, the lunch peak was absent, while the evening peak remained largely the same. Abu-Bakar *et al.* (2021) distinguished four types of patterns in household water use: evening peak (EP), late morning (LM), early morning (EM), and multiple peak (MP). During the lockdown the number of households in the EM and EP clusters reduced from 26% to 14% and 30% to 25% of the households respectively, while the LM cluster grew from 30% to 37% and the MP from 14% to 24%. This also indicates a delayed morning peak, and people doing their activities at different times. Similarly, Lüdtke *et al.* (2021) found a delayed morning peak of about one to two hours, but no change in the timing of the evening peak. Dzimińska *et al.* (2021) found more variation in water use during the day during the lockdown period.

Based on our data and these studies, one can say that, in general, the main temporal change in residential water use due to social-distancing measures was a delay in the morning peak, most likely as people woke up later as they did not have to travel to work or school and be there at a fixed time. There was little change in the timing of the evening peak, though in some places it may have become less pronounced as people spread their water use activities over a longer time while they were at home the whole day. Based on the data from Limassol, the industrial temporal water use pattern did not change, while the commercial water use pattern changed significantly due to closures of many commercial sectors.

Volume changes

When analysing water use measurements, one can either observe changes in patterns over time, such as shifts in peak flow, or increases and decreases in volume. Spatial or sectoral changes can only be inferred from changes in water use of different types of users. Similarly, the breakdown of volume changes in efficiency, intensity and new use effects can only be inferred from secondary data as it cannot be directly observed from water use measurements. Hence, below we focus on changes in volume as evidenced by water use data and infer spatial and sectoral changes, as well as changes in intensity, efficiency and new water use from secondary sources.

Table 2 gives an overview of the annual changes in water use in 2020 as compared with 2019. When looking at the numbers one should keep in mind that even without social-distancing measures, water use can vary significantly from year to year due to changes in weather, changes in how water use is measured, etc. This is clearly visible for Cyprus, which is the only place where domestic consumption decreased over the year. In Limassol a leakage reduction programme was being executed. The domestic water consumption reduced by 16% in the month of April, during the lockdown, compared with the three previous years. It is estimated that for domestic consumers, there had been no significant volume change during the first lockdown period (April), while during the second period (December) water consumption increased, similar to the observation in other places. Travel restrictions forcing people to spend the holiday season at home, improved remote-working conditions, and weather conditions can explain an increase in December and no change in April.

The average increase in domestic water use in 2020 compared with the reference year(s) of all countries except Cyprus and the city of Lisbon in Portugal ranges between 2.7% and 7.8%. In the same period, the range of non-domestic water use decreasesd by 1.9% to 10.9% for these places. As these numbers are averaged over a year in which different social-distancing measures were in effect, the changes are expected to be larger during months that countries experienced more severe social-distancing measures, such as lockdowns. The lower part of Table 2 indeed shows larger changes for all but the domestic consumption in Romania and Lisbon. These numbers are in the same order of magnitude as the 11% increase in residential water use reported for Joinville, Brazil (Kalbusch *et al.* 2020) and the 14.3% increase in northern Germany (Lüdtke *et al.* 2021).

The case of Lisbon is peculiar as during the lockdown months domestic water consumption decreased significantly. This can likely be explained by two reasons. First, from anecdotal evidence it seems that many people left the city at the beginning of the lockdown to go to their holiday or family homes in rural areas for teleworking. Second, the change is calculated from aggregate consumption; while aggregate consumption declined, individual households that stayed in Lisbon may have used more. This points towards a spatial change in water use.

Though the water use measured in Romania is based on invoicing, the fact that the annual and lockdown increase in water use is similar is not due to collection problems, but mainly because many social-distancing measures in Romania lasted for large parts of the year. Most countries experienced strict and less strict social-distancing measures throughout 2020. For Switzerland, for instance, severity of lockdown measures was estimated in a water use model to be from 100% during a 1.5-month lockdown to 20% during a four-month period from summer to autumn. Only the first two months of 2020 were without measures. In Singapore, domestic water use during the lockdown increased by 9.5% while over the entire year it increased by 7.8%. In the weeks immediately after the lockdown, water use was still 5% to 6% higher, as many people kept working from home and other social-distancing measures, such as partial closure of restaurants, were still in place. In fact, in 2021 household water use was still significantly higher in Singapore than before the pandemic. Water use had been declining from 151 litres per capita per day (lpcd) in 2015 to 141 lpcd in 2019, mainly due to the government's water demand management policies (Tan 2022). In 2020, during the first year of the pandemic, water demand increased to 154 lpcd and in 2021 it increased further to 158 lpcd, as a large part of the population worked from home throughout the year and many social-distancing measures were still in place – or reactivated – such as home-based learning for primary and secondary students when schools emerged as COVID-19 hotspots, and disallowing dining-in in restaurants.

As social-distancing measures are reduced or completely abolished, some of the new water use behaviours may persist in the future. Alda-Vidal *et al.* (2020) concluded from focus-group discussions that the main changes in domestic water use

Table 2 | Changes in water use

Year-on-year change 2019–2020

Country	Unit (of measured data)	Domestic consumption: Reference 2019	Domestic consumption: Change 2020 Absolute	Domestic consumption: Change 2020 Percentage	Non-domestic consumption: Reference 2019	Non-domestic consumption: Change 2020 Absolute	Non-domestic consumption: Change 2020 Percentage
Belgium	l/conn./day	–	–	–	–	–	–
Cyprus (Limassol)[a]	m^3	902,398	−91,393	−10%	373,608 (ind.) 824,533 (comm.)	−10,174 (ind.) −81,112 (comm.)	−2.7% (ind.) −9.8% (comm.)
Germany	m^3 (water sales)	–	–	2.7%	–	–	−3.7%
Japan[b]	m^3 (revenue volume)	–	–	3.6%	–	–	−8.4%
Netherlands[c]	mil. m^3	818	37	4.5%	309	−6	−1.9%
Portugal	l/conn./day	221	11.7	5.3%	–	–	–
Lisbon	mil. m^3 (invoiced)	27.102	0.219	0.8%	23.477	−5.265	−22.4%
Romania	m^3 (invoiced)	–	–	6.6%	–	–	−6.9%
Singapore	mil. m^3	297.6	23.1	7.8%	202.6	−22.1	−10.9%
Switzerland	l/inh./day	142[d]	7[e]	5%	98 (country ave.) 49 (average of analysed municip.)	−3[e]	−3% −6%
Lockdown months							
Belgium[f]	l/conn./day	198	38	19.2%	–	–	–
Cyprus (Limassol)[g]	m^3/day	–	–	−5% (Apr) 8% (Dec)	–	–	> −20% (ind.; Apr) ~4% (ind; Dec) >−30% (comm.; Apr) ~−20% (comm.; Dec)
Portugal (Lisbon)	mil. m^3 (invoiced)	4.421	−0.183	−4.1%	3.075	−0.278	−8.3%
Romania	m^3 (invoiced)	–	–	6.4%	–	–	−8.7% (ind.) −14.7% (publ.)
Singapore[h]	mil. m^3	2,455	232	9.5%	–	–	–
Switzerland	l/inh·/day	142[d]	18.7[i]	13%	98 (country ave.) 49 (average of analysed municip.)	−8[i]	−8% −16%

Notes:
[a]In Cyprus (Limassol) water use in 2020 deviated from the previous years. In particular, a programme to reduce non-revenue water reduced consumption in the domestic district metering areas considerably from 2019 to 2020. Taking into account leakages the change is estimated to be −1.3%. Without taking into account leakages, domestic consumption increased by 10% in 2020 as compared with 2019.
[b]The percentage for Japan was based on reported increase/decrease categories from a survey by taking the weighted average of counts and mid-points of the categories.
[c]Netherlands faced a very high precipitation deficit in early spring 2020 (while nature had not recovered yet from the drought in previous years), while population growth also contributed to domestic consumption increase.
[d]For Switzerland, the reference year is 2015 instead of 2019.
[e]These figures are based on a linear regression model using data from 2013 to 2019.
[f]This increase is not corrected for seasonal influences (winter versus spring) and hence over-estimates the increase due to the lockdown.
[g]These figures are estimates based on preceding months' water use and the assumed impact of the non-revenue water reduction programme.
[h]These figures are based on data from 1,461 households in Singapore.
[i]These figures are obtained by estimation of 'full lockdown equivalents', weighing the different grades of pandemic measures in 2020.

patterns result from changes in the organisation of life and work. As people work from home, they have a more flexible schedule and more time for activities that use water, such as taking longer baths, gardening, cooking, and cleaning the house or car, in addition to some water use that is transferred from work or leisure locations to home. These changes are gradually returning back to pre-pandemic water use patterns, but as flexible working arrangements continue to be part of post-pandemic life, some new water use behaviours will also be part of post-pandemic life.

Intensity

Intensity of water use means that some water use activities are conducted either more or less due to social-distancing measures. Part of the increase in domestic consumption and a large part of the reduction in non-domestic consumption can be attributed to a change in water use intensity. Hand washing and other water-using hygiene measures are often mentioned as having a significant impact on water use intensity (e.g. Sivakumar 2021). While this may have been the case in the initial stages of the pandemic, Alda-Vidal *et al.* (2020) showed that in the UK, most of these hygiene practices quickly faded as people were getting used to living with the virus. Moreover, hand washing constitutes, at least in high-income countries, a small part of total water use in households; for instance, in the Netherlands water use in wash basins (which is not all hand washing) was 4% of total daily water use in 2016, compared with 41% for showering (VEWIN 2022). Yet, staying at home may lead to more intensive water use behaviours, such as cleaning the house more often, taking longer showers, and spending more time – and water – on gardening.

The water use intensity in the non-domestic sector decreased as there were less economic activities due to social-distancing measures. In the commercial sector, shops, hotels, hairdressers, etc. had to close during lockdowns and hence their water use decreased, in the industrial sector production decreased as employees were under lockdown, and in the public sector schools and public buildings were closed. Figure 3 shows the correlation between non-domestic water use in Lisbon, the month-on-month growth rate of the number of guest-stays in hotels in Lisbon Metropolitan Area and the month-on-month production growth rate in Portugal (the latter two are both min–max scaled in the graph). It clearly shows that lower production and near-zero tourism in April led to a much lower water intensity (based on billed water use) in May (as meter-reading and bill payment is done monthly and hence has a lag of one month), while in July/August water use rebounded along with an increase in hotel guests and production.

Efficiency

The impact of changes in water use efficiency due to the pandemic is difficult to show with the data that is available. It is assumed that some of the increase in water use is due to a reduction in water use efficiency at home as compared with at office or school. For instance, urinals in commercial and public buildings are more water-efficient than flush toilets at home, and meals prepared at canteens and restaurants may have economies of scale in water use compared with individual meals prepared at home. This may have contributed to some increase in water use. For instance, based on Singapore's Water Efficiency Labelling Scheme (PUB 2021) an efficient urinal uses less than 0.5 litres of water per flush, while an efficient toilet

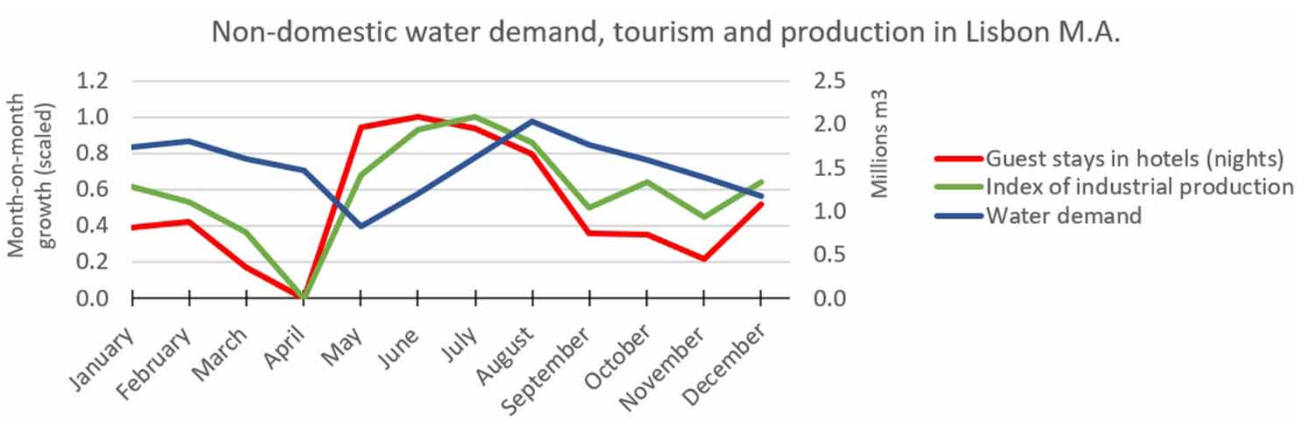


Figure 3 | Non-domestic water use and production/hotel stays.

with a reduced flush uses 2.5 litres or less. Assuming men go four times to the toilet during working hours, working from home would result in eight litres more water used per work day. This could then be broken down in a spatial/sectoral change of two litres and an efficiency change contributing to increased water use at home of six litres.

New water use

Similar to the impact of changes in water use efficiency, the impact of new water use is also difficult to show with the data, and it is very similar to increased water intensity. There is some scant evidence of new water use in the literature and from other sources. Alda-Vidal *et al.* (2020) report an increased interest in gardening, and for some people this could be new water use, as they took up gardening as a new hobby. The Dutch media reported a strong increase in the sales of pop-up swimming pools for use in gardens (Baneke & Cloin 2020) and the Belgian media reported a 30% increase in the construction of private swimming pools (HLN 2021).

Spatial and sectoral changes

While spatial and sectoral changes cannot be directly observed in changed water use patterns, the increase in domestic water use and decrease in non-domestic water use that can be observed in Table 2 can be partly explained by a shift in water use between areas and sectors. Table 2 shows that non-domestic water use declined generally somewhat more than domestic water use increased over 2020. Impact during the lockdown months seems, however, much more variable, with non-domestic water use reductions up to 30% in Cyprus and reductions of 8% to 16% in Romania and Switzerland. Kalbusch *et al.* (2020) also showed stronger declines in non-domestic water use during the lockdown: commercial water use decreased by 42%, industrial water use by 53% and public water use by 30%. This indicates that the water used in the non-domestic sector may have partly shifted to domestic use, but also declined significantly because of the closures, as discussed above.

Due to social-distancing measures, large parts of populations worked or studied from home, shifting water use from study and work locations to homes, and from the non-domestic sector to the domestic sector. A significant part of the shift in water use is likely due to toilet flushing. For instance, for the Singapore example discussed in the 'Efficiency' section above, assuming four toilet visits during work hours would increase domestic consumption by ten litres per person per day, if each flush were 2.5 litres, this would explain more than 75% of the increase in per capita consumption from 141 to 154 lpcd.

The composition of different types of water users determines the impact on overall water use in a district, city or region. The analysis of Balacco *et al.* (2020) shows that larger towns have a higher reduction in total water use than smaller towns during the lockdown period, which can be explained by the higher number of incoming commuters and larger share of commercial and industrial water use in the larger cities. In Germany (Table 3), water use by households and small customers in tourist areas decreased by 5.2%, while it increased in other areas due to the social-distancing measures in the tourism sector. The increase in water use in suburbs was significantly above the average of Germany due to the impact of working from home and the residential character of suburbs. In Portugal, a difference can be seen between predominantly urban, moderately urban and predominantly rural areas where domestic water use increased respectively 5.7%, 5.4% and 4.8%, and the case of Lisbon where domestic water use even declined. In predominantly rural areas people may already do more of their water activities at home, for instance as the population has jobs that are not done in offices (e.g. farming) and spend more time at home as there are fewer possibilities for leisure and entertainment outside the house. The Netherlands also saw large differences in water use between regions during the lockdown, which coincided with a severe drought (VEWIN 2020). In the capital Amsterdam water use reduced due to a sharp decline in the number of tourists and closure of restaurants and the entertainment industry. In the northern city of Groningen there was a decline of water use in the city and an increase

Table 3 | Changes in water use in Germany in 2020 as compared with 2019 based on water sales data

Type of area	No. obs.	Households/small customers	Industry/others
Large cities	23	+3.3%	−7.8%
Suburbs	45	+6.9%	−6.2%
Tourist areas	25	−5.2%	−5.5%
Rural regions	37	+3.9%	−4.6%
Germany total	844	+2.7%	−3.7%

in the rest of the province due to the absence of students and office workers in the city and more work from home, while in the eastern part of the Netherlands there was an extreme peak of water use during public holidays in combination with the effect of drought.

Impacts on billing and water utility finances

Lastly, we will take a look at how the changes in water use and the impacts of the pandemic affected billing and water utility finances, based on data from Japan and Romania. Aside from changes in billed water use, the pandemic had several impacts on revenues and expenditures of water utilities. For instance, costs increased due to additional costs related to COVID-19 (e.g. purchase of disinfectants, protection masks, special measures, etc.), billing cycles may have been affected as meters could not be read, or governments may have changed regulations for non-payment of bills. The shift from non-domestic to domestic water use may also have affected revenues when tariffs for different types of users are different.

In Romania, the total quantity of water invoiced increased by 2.6%. Correspondingly, the median operating revenues of all utilities increased by 2.03% and 1.45% in March and April respectively as compared with February 2020. The median operating costs recorded a sharp increase of 5.13% in March 2020, but they decreased to the normal level from April onwards due to more prudent policies regarding expenditures and due to a temporary decrease of cash-flow resources. The decrease in cash flow was the result of a decrease in collections of invoices, which decreased by 20% in the first four weeks (March 16–April 12, 2020) and by 9% in the next 4 weeks (April 13–May 5, 2020) after the state of national emergency was declared. This decrease was due to the tendency of domestic and non-domestic customers to protect their cash-flow resources in times of uncertainty, due to the fact that most of the domestic customers are used to paying their bills in cash at the collection points of the companies, and due to the legal provisions that did not allow the disconnection of households who did not pay their bill. This caused significant financial pressure on the water utilities and some regional operators struggled with their cash balances early in the pandemic.

In Japan, 18% of the utilities saw a decrease, 36% saw an increase, and 46% saw less than 1% variation in the volume of revenue water in 2020 as compared with 2019. On the other hand, when looking at the revenues from the water tariff, 47% of the utilities said there was a decrease in revenues, 27% said there was an increase and for 26% the difference from 2019 was less than 1%. Tariff reduction, exemption and/or postponement of payment was implemented by 36% of the utilities, often at the request of the city council or mayor. In almost two-thirds of the cases, the local government fully compensated the utilities for the tariff reduction and exemptions, while for another 15% there was a partial compensation.

Based on the experiences in Romania and Japan it seems that due to the initial shock of the lockdowns revenues decreased, and costs increased, but in the long run the impact on utilities' finances will be limited. The decrease in revenues was mainly caused by late payments and customer assistance programmes. Due to the larger share of domestic water for most utilities, total water sales, and hence revenues, increased a little. However, as Spearing *et al.* (2021) discuss for utilities in the United States, the temporary decrease in revenues may have led to postponement of investments, and planned tariff increases were postponed for some utilities, causing a longer-term impact. Hence, for individual cases there may be longer-term impacts on utilities' finances.

CONCLUSIONS

The COVID-19 pandemic had significant impacts on water utilities, which had to continue to provide clean water during lockdowns and cope with various social-distancing measures. The social-distancing measures affected the water use patterns of domestic and non-domestic customers, requiring utilities to adjust their operations under the restrictive pandemic conditions, and affecting their revenues and expenses.

The objective of this study was to compare how water use patterns in different places were affected by social-distancing measures. Lockdowns and working and studying from home changed how, when and where people used water. A first impact was a delay in the morning peak of domestic water use. Time saved on preparing for and travelling to work or school meant people woke up, bathed and took breakfast later. This is shown in the domestic water use pattern of Limassol, Cyprus, during the first lockdown and was also found in several existing studies in the literature. Domestic water uses during the remainder of the day changed less in terms of timing, though the volume of water used by households increased; around 5% over 2020 for the countries for which data was available in this study. During the stricter social-distancing measures, domestic water use increased more, to around 6% to 13%. For non-domestic temporal water use patterns less data is available, but based on the data from Limassol, industrial temporal water use patterns were not affected, while commercial water use patterns changed significantly due to closures in different subsectors, such as non-essential shops. Yet water use in both the industrial and commercial sectors decreased significantly during the lockdowns. However, as the average non-domestic water use decrease over 2020 is around 6%, which is considerably less than the decreases reported during lockdowns, non-domestic water use likely quickly returned to normal after lockdowns. Changes in water use patterns varied significantly between areas in the different countries, depending on the composition of types of water users in an area.

Finally, while the initial shock of lockdowns affected utilities' revenues and expenses – mainly due to late payments, assistance programmes and higher costs related to COVID-19 measures – long-term impact on utilities' finances is not expected.

ACKNOWLEDGEMENTS

The research in this paper resulted from discussions in the IWA Specialist Group on Statistics and Economics, of which the authors are members. The authors would like to thank the specialist group members for their contributions to this paper. The data for Romania was provided by Teodor Popa, Financial Manager, Compania Apa Brasov, Romania, and Vice-chair of the IWA Statistics and Economics Specialist Group. Data for Cyprus was extracted by the Water Board of Lemesos in cooperation with KIOS Research and Innovation Center of Excellence, University of Cyprus.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 28 May 2022; accepted in revised form 5 August 2022. Available online 16 August 2022