Article title: The Impacts of Covid-19 Pandemic and Weather Conditions on Water Environment, a Case Study in Istanbul and London/South-east England
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Dear Editors,

We are delighted to submit our manuscript titled "***The Impacts of Covid-19 Pandemic and Weather Conditions on Water Environment, a Case Study in Istanbul and London/South-east England***" for publication in the UCL Open: Environment.

This manuscript corresponds to a research article as outlined in your list of accepted article types and we believe it falls within the scope of the special series "***COVID-19 interactions with our Environment***".

The article discusses how aspects of water resources and water use changed in the municipality of Istanbul during the early period of the Covid-19 pandemic. Some comparisons are made with London and the south-east of England in the same period. It is the first use of a DPSIR Framework to examine the compound effects of Covid-19 and Climate Change on water consumption by people. As people were advised to stay at home as much as possible during lockdowns, the demand for water would be expected to increase in domestic settings and decrease in many business settings and in schools and universities (falling close to zero in many cases). Figure 15, our final DPSIR Framework, shows how the Covid-19 and Climate may have affected water consumption and water reserves (in the form of reservoirs). We believe our findings to be of interest to large conurbations dealing with a range of risks linked to the environment.

We look forward to your response to this submission and we hope the opportunity to respond to review comments.

Yours sincerely,

Ferhat Yilmaz

Public Interest Statement

Water is essential and water resources are under pressure from increased urbanisation and from the impacts of a changing climate on both the long-term trends in precipitation patterns and via weather extremes such as drought. Water systems serving large conurbations need to be developed that are resilient to these pressures and water consumption needs to be managed to help ensure that the use of water resources is sustainable. In addition, sustainable water systems need to be able to cope not only with known pressures but also be able to deal with emergency situations such as droughts, floods and pandemics which can put pressure on both physical and human resources. To design more resilient and sustainable systems, one early step must be to scope how water systems that support major urban centres respond in circumstances where compound risks arise from a combination of long- and short-term influences such as, for example, more frequently occurring droughts (arising from climate change) and pandemics or migrations so that future risks can be fully accounted for in planning future water usage infrastructure and management options.

In this paper we examine how aspects of water resources and water use changed in the Turkish municipality of Istanbul during the early period of the Covid-19 pandemic. Some comparisons are made with events in London and the south-east of England in the same period as there were some commonalities and some differences. Figure 1 sets out the factors we have examined in this paper which includes some unexpected uses of water in the Covid-19 period, in this case street disinfection (illustrated in Figure 5 and the Bolu Municipality Instagram post). Water use in Istanbul has increased over time and seasonal variation in water supply demand has become more apparent. Figure 2 provides a new way of visualising this. In addition, using a similar visualisation approach we show reservoir levels decreased with increased consumption and during periods of drought (as in the years around 2007) or low rainfall. The ongoing increase in water use and change of the pattern of use in emergency situations could cause local water shortages in future due to either infrastructure failure or capacity limitations. Figure 15 expands Figure 1 and shows the factors we believe may need to be taken account of in developing future resilient water systems and management approaches.

The Impacts of Covid-19 Pandemic and Weather Conditions on Water Environment, a Case Study in Istanbul and London/South-east England

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Abstract

The Covid-19 Pandemic affects not only populations around the world but also the environment and natural resources. Lockdowns and restricted new lifestyles have had wide ranging impacts on the environment (e.g., on air quality in cities). Although hygiene and disinfection procedures and precautions are effective ways to protect people from Covid-19, they have important consequences for water usage and resources especially given the increasing impacts of climate change on rainfall patterns, water use and resources. Climate change and public health issues may compound one another and so we used a DPSIR Framework to scope the main factors that may interact to affect water use and resources (in the form of reservoirs) using evidence from Istanbul, Turkey with some discussion of the comparative situation in the UK and elsewhere. We modified initial views on the framework to account for the regional, city and community level experiences. We noted water consumption in Istanbul has been increasing over the last two decades (except, it appears, in times of very low rainfall/drought); that there were increases in water consumption in the early stages of the Covid-19 pandemic; and, despite some increase in rainfall, water levels in reservoirs appeared to decrease during lockdowns (for a range of reasons). We also noted, through a new simple way of visualising the data, that a low resource capacity might be recurring every 6 or 7 years in Istanbul. We made no attempt in this paper to quantify the relative contribution that climate change, population growth etc are making to water consumption and reservoir levels as we were focused here on scoping those social, environmental and economic factors that appear to play a role in potential water stress and on developing a DPSIR Framework that could aid both subsequent quantitative studies and the development of policy and adaptive management options for Istanbul and other large complex conurbations (such as London and south-east England). If there are periodic water resource issues and temperatures rise as expected in climate projections with an accompanying increase in the duration of hot spells the subsequent additional stress on water systems might make managing future public health emergencies, such as a pandemic, even more difficult.

Keywords: *water, covid-19, climate, patterns of use, water management, adaptive management*

Introduction

Water is a fundamental part of life in any society. It is vital for people's health and well-being, agriculture, businesses, and the environment. Water use patterns change on a daily, seasonal, and annual basis. Resource levels and water use in different parts of any country can be affected by many factors: for example, normal variations in rainfall that affect river flows (that might be used for abstraction); changes in reservoir and aquifer levels due to recharge or draw down; and changes in the amount of irrigation needed for commercial crops or the maintenance of private and public gardens during periods of hot weather.

Water management must ensure that water remains at sufficient levels to sustain the environment in the long term so as to guarantee the prosperity of future generations. It is expected that maintaining water needs for drinking, industrial, agricultural and other usages will be one of the most important challenge for societies, as is already apparent in some parts of the world (Bensoussan & Farhi, 2010). Enhanced vulnerabilities from climate change such as might arise from more intense and frequent storms, heatwaves, and sea-level rise, could increase water-related stresses on society, the economy (including food production) and the environment (IPCC, 2012).

Climate change puts established patterns of resource management and usage at risk because of long run and often gradual trends in overall temperatures and rainfall patterns, that can be difficult for people and professionals to recognise, and because of changes in the frequency or intensity of extreme events such as flooding and drought (Sheridan & Allen, 2015). Both trends and extremes will affect the way water resources and usage need to be managed in the short and medium term and in future. Managing these changes can be made more difficult if other trends, such as changes in population levels or demographics, need incorporating into planning. Extreme events also have to be allowed for when planning (a) to meet legal or policy criteria requiring that resource levels always are sufficient to meet demand or (b) there is a need to provide supply in areas where no or inadequate supply exists at present (as is the case for many 100s of millions of people worldwide, and, often, when new housing or industrial development is required).

The Covid-19 pandemic[1] is an extreme event of a particular kind, a global health emergency, that might affect water usage patterns or wastewater management because of public health concerns, if nothing else, and, thereby, available water resources over a period of at least one or two years. This period would be longer if the pandemic could not be controlled and/or it led to long-term shifts in water use as might be the case if, say, working and travel patterns changed permanently. In such circumstances the impact on water consumption and thereby the resilience of resources might be difficult to predict and quantify.

The combination of risks from a pandemic and from climate change represent a compounding of risks that might challenge established patterns of water use and management. Frameworks for the management of compound risks of these kinds of combinations of events (components of which are

[1] On 31 December 2019, a novel coronavirus was identified in Wuhan, China. Globalization facilitated the rapid spread of this Covid-19 virus. First confirmed case outside of China was recorded in Thailand on 13 January 2020. Alarming levels of spreading and severity obliged the World Health Organization (WHO) to characterize the Covid-19 as a pandemic. As of 22 June 2021, there have been around 178 million confirmed cases of COVID-19, and around 3.8 million deaths globally. Daily cases are still around 300k, and almost 2.5 billion vaccine doses have been administered. Weekly confirmed cases in the week of 2 November almost doubled the cases occurred in the summer weeks (WHO, 2020).

often thought of as low frequency but high impact) are needed, especially as extreme events linked to climate change are occurring more regularly.

In this paper we examine how unexpected situations such as the Covid-19 pandemic might affect water usage and availability. We focused on events in 2020 and compared these with situations in previous years. We used Istanbul as a case study of compound risk issues (public health x climate change) as this is Turkey's largest centre of population and because Istanbul experienced drought conditions in the recent past in the period around 2007. We quantified the changes in water use and water reserves during the period in which Turkey went into and emerged from the initial lockdown state. While people are advised to stay at home as much as possible, the demand for water might be expected to increase in domestic settings and decrease in many business settings and in schools, for example. This could have consequences for water supply for domestic use, due to infrastructure failure or capacity limitations, both consequent on changes in the pattern of demand for water. Instances of this may have occurred in both Turkey and elsewhere, such as in the United Kingdom, in local areas during the pandemic period.

We examined the situation in Istanbul through a DPSIR lens (Figure 1) because we are interested in identifying, as part of our wider studies, the factors that influence the level of risks that need to be managed in different municipalities. While previous studies have used the DPSIR approach to analyse water related problems, and identify the factors involved (Ashfaq et al., 2019; Gari et al., 2018), there is no previous use of a DPSIR framework to examine the impacts of Covid-19 and climate change on water consumption and resources. Figure 1 shows a range of climate and pandemic factors that, at the outset, we believed could affect water resources, water consumption and the supply system of Istanbul. We then looked for evidence of the influence of such factors on the water resources and water consumption in Istanbul. We hoped that by gathering evidence from a range of sources we would be able to modify this diagram so that it could provide a Framework for thinking through what kind of influences on water supply and consumption patterns needed to be incorporated into future water management planning for this, and other, major urban centres. The water system might then be more resilient so as to ensure water was available to support people's lives because it had been designed in a manner that recognised the impacts of (i) trends in climate change impacts, (ii) extreme events, (iii) the importance of all aspects of the infrastructure system and (iv) the importance of human behaviour in water use.

To complete this study, we used information gathered from news and social media as well as information issued by local government bodies or published in authoritative reports (e.g., from water utilities and consultancies) as well as material in the academic literature. We used this range of sources to try to capture the fast-changing circumstances of a pandemic.

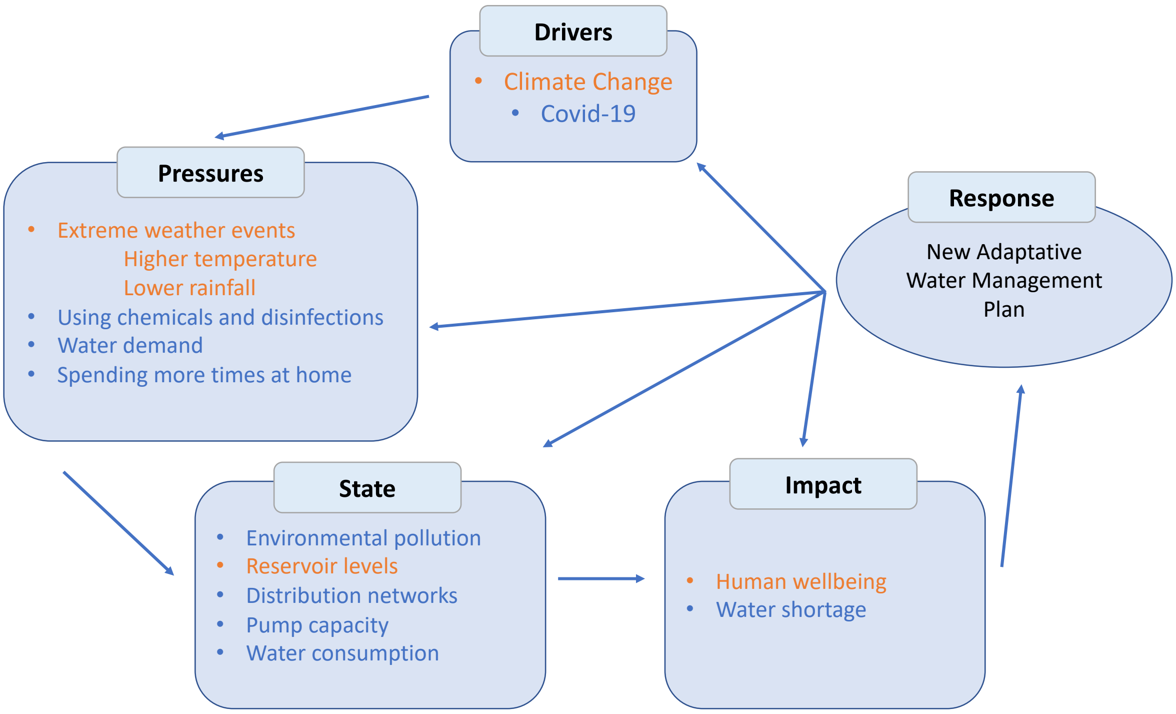


Figure 1. DPSIR Framework: Overview of factors likely to be involved in changing water consumption in pandemic circumstances that might lead to supply challenges (blue text) with the equivalent climate change factors (orange text). Pandemic and climate factors co-located in the sectors of the model might amount to interacting or compound risks. We assume in this that governmental bodies would want to respond to issues by developing and adaptive management plan to deal with at least the climate change aspects of the hazards and risks.

This study is part of a wider one into water issues in Turkey linked to extreme events related to climate change, such as drought. The wider study covers the impacts of climate change on water management in Turkey and how Turkey might adapt to any impacts on its water resources (Yilmaz et al., 2020) and water management. In a set of case studies, we have been examining impacts of climate change and in particular the resourcing and management of water in Turkish municipalities as these are the effective governance level. We believe our findings could be generalised to other large conurbations as Istanbul is one of the world's largest and still developing cities.

Case study: Water Use and Resources in Istanbul

Figure 2 indicates the way water use in Istanbul has varied month by month over the recent past. This form of visualisation allows for easy comparison of variations in monthly water use over a twenty-year period. Water consumption in Istanbul has gradually increased since the 2000s (as shown by the shift from green to blue and darker blue) from an average of 1,600,000 m^3/day to an average of 3,100,000 m^3/day. Water use is always higher in the summer with a marked increase in this effect being apparent after 2012. This seasonal effect is well known. The overall increase in water use may be attributed to population increase, industrialization, and rising standards of living and/or lifestyle choices (such as leisure uses) that go alongside increasing levels of consumption in general.

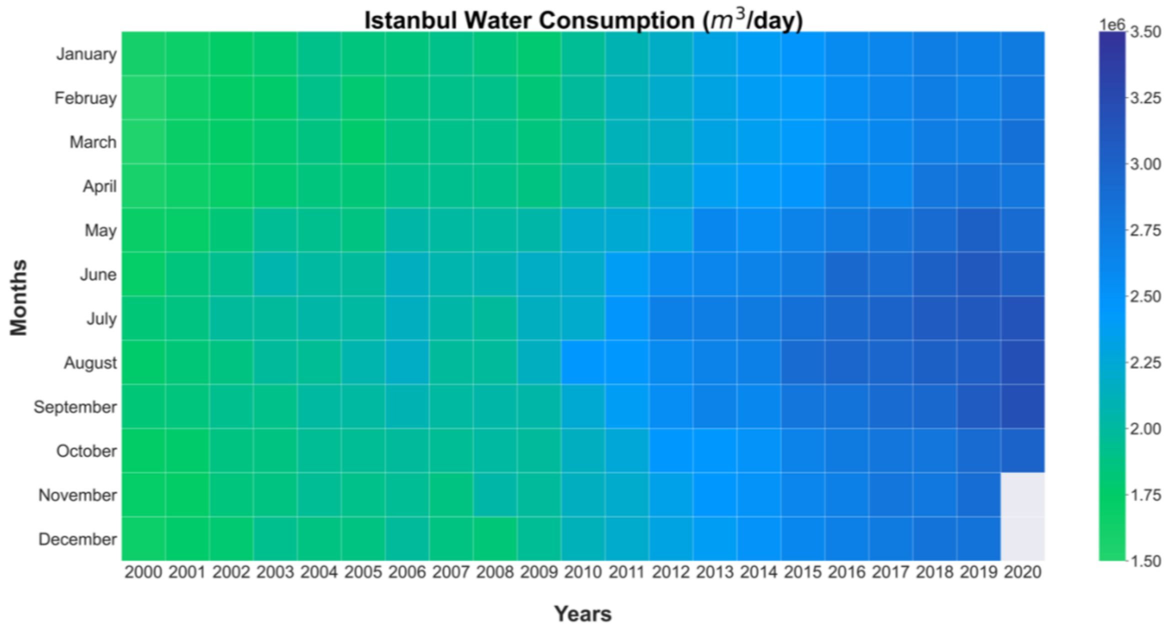


Figure 2. Monthly water consumption (m³/day) in Istanbul from January 2000 to October 2020. The final column covers the pandemic period's early stages.

Figure 3 shows that over the 20 years period of interest the population increased by about 40%, while water consumption rose by 73%.

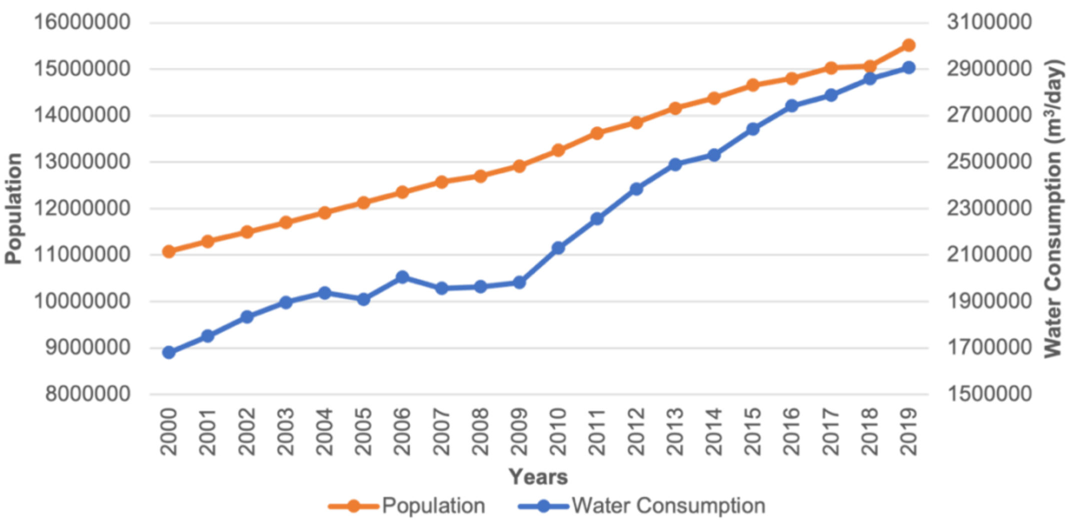


Figure 3. The comparison of population (Turkish Statistical Institute [TURKSTAT], 2020) *and water consumption in Istanbul from 2000 to 2019.*

Although population and water consumption both increase over time (and therefore show a strong Pearson correlation of r = 0.98, n = 20, p< 0.001) there have been periods when water consumption grew little, for example, between 2005 and 2007-2009. This slow or negligible growth in this period is linked to low rainfall and drought periods in 2005 and 2007 (Unalan, 2011) with people and businesses adjusting their behaviour to reduce consumption following communication from governmental bodies and the media about water shortages.

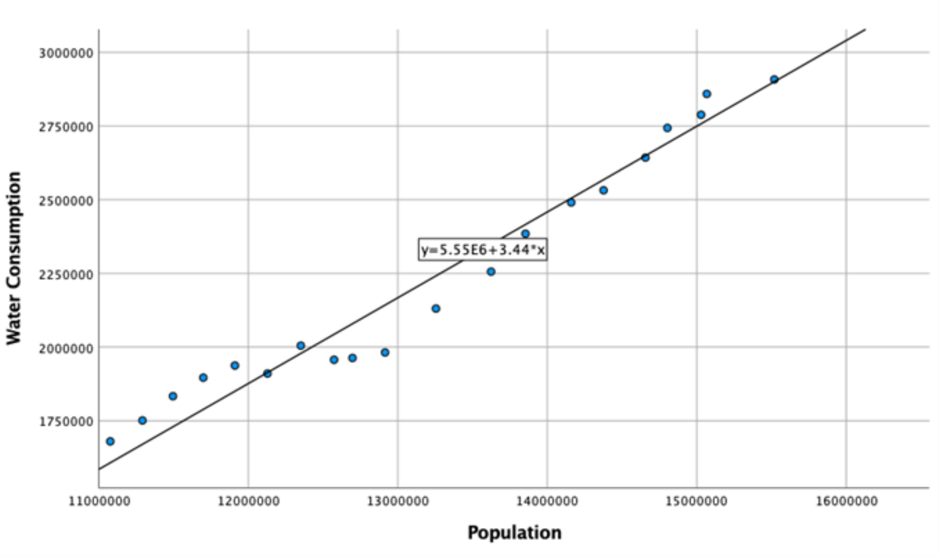


Figure 4. The relationship between population and water consumption (m^3/day) from 2000 to 2019 in Istanbul. Overall, in this period water consumption per head of population moved from about 150 litres/day to 190 litres/day, an increase of over 25%.

In order to get some separate evidence that the pandemic restrictions affected human activity in Istanbul we examined air quality parameters, and these suggest air pollution in Istanbul was lower in 2020 than in 2019 indicating decreased human activity consistent with Covid-19 restrictions. Air quality parameters such as PM_{10}, SO_2, and CO are a good evidence of these changes (IBB, 2020). Annex – I shows how the levels of these parameters decreased in Istanbul. After confirmation of the first cases in Turkey in March, air quality parameters started to change negatively from late March when national restrictions (working remotely, closing restaurants, and full lockdowns) were announced and applied.

Changes in Water Use and Resources during the Covid 19 pandemic in Istanbul

Water consumption

Looking at the total water consumption for 2020 as shown in Figure 2 it appears consumption in March, when Covid-19 started to spread in Turkey, is higher than March 2019 from (from 2,853,000 to 2,763,000 to m^3/day). This increase of about 90,000 cubic metres per day (or about 3%) on average could reflect additional water use due to the increased emphasis on hygiene measures such as hand washing or street disinfection. In March and April, when the Turkish government decided to move to lockdown in big cities, including Istanbul, people didn't want to stay in a highly populated city and went to their home town or summer house. This temporary migration was intense. For example, the Mayor of Bodrum in Muğla stated 'Please do not come to Bodrum, Bodrum is totally full', and it was noted that many cars entered Bodrum that were registered in Istanbul or Ankara (Yenicag, 2020). The first Covid-19 case in Bodrum was confirmed in a person coming from Istanbul before the start of travel restrictions between the big cities in Turkey (NTV, 2020). These temporary migrations probably explain why consumption in Istanbul fell back in April by an average of 42,210 m^3/day.

Since June, when Covid-19 cases started to decrease in Turkey as a whole, people began returning to Istanbul, and water consumption gradually increased by 141,609 m^3/day to the end of the summer in August (see below for more detail on this). Public health measures such as an increased emphasis on hand washing and the sanitisation of public space with water-based disinfectants (Figure 5) could all be expected to lead to increased water consumption.

Figure 5. Street disinfection photos from Turkey and Ethiopia during the Covid-19 Pandemic (Tessema, 2020; Usak Bel, 2020). In addition to street photos, the Municipality of Bolu, a small city in Turkey, posted a video on its official social media account (Instagram): https://www.instagram.com/p/CIao9VJJJC0/?igshid=1irbte6t7xd5j with the caption: 'You are at home, we are on duty, wish everyone good health' on 5 December 2020. Although Bolu was exceptionally and extremely dry according to the Standardized Precipitation Index (SPI) from October to December 2020 (TSMS, 2021), the municipality used lots of water and chemicals to clean its main streets.

Expressing the resource use data in terms of consumption per head per day as in Figure 6 creates further insights especially when the first Covid pandemic year of 2020 is compared to the same data for the 3 years preceding the pandemic.

Water use in 2020 (green line) was higher than the average of 2017-2019 (black dashed line) for several months between March and October (extra 2.56 litres per person per day was consumed across year as a whole). Any increase was likely due to the greater emphasis on hygiene measures from March onwards when the first virus case was found in Turkey. A similar effect was found in other countries (see Discussion). Water use was lower than the 2017-2019 average for during the period people left Istanbul on a temporary internal migration to home villages or country houses. As indicated above, since the people movement was intense and many left Istanbul for their hometowns and summer houses, there was a decrease in water consumption in April by 2.73 litres per person per day from the March if constant population figure is assumed. As people gradually returned to Istanbul from the second quarter of 2020 there was a steady increase in water consumption with consumption in July – October higher than the 2017 – 2019 average. In the pandemic year of 2020, along with rising summer temperatures, which normally cause additional water usage in any case (note the average annual pattern for 2017-2019), water consumption continued to climb above the three-year average right through until September when normally consumption would have fallen back. This suggests that the Covid-19 pandemic placed an additional call on Istanbul's water resources (perhaps about 2% greater across the year as a whole). Perhaps the most striking finding was that water consumption per head in

Istanbul did not decline with falling Q3 temperatures as it has in earlier years. The difference in this period (July, August, and September) between 2020 consumption and the three-year average was about 10 litres per person per day. In addition, the last 3 years' religious holidays (Islam) were in August and September due to the Islamic calendar (consists of 12 months in a year of 354 or 355 days). It might have an impact on water consumption as people went on holiday or to their home town during the religious holiday.

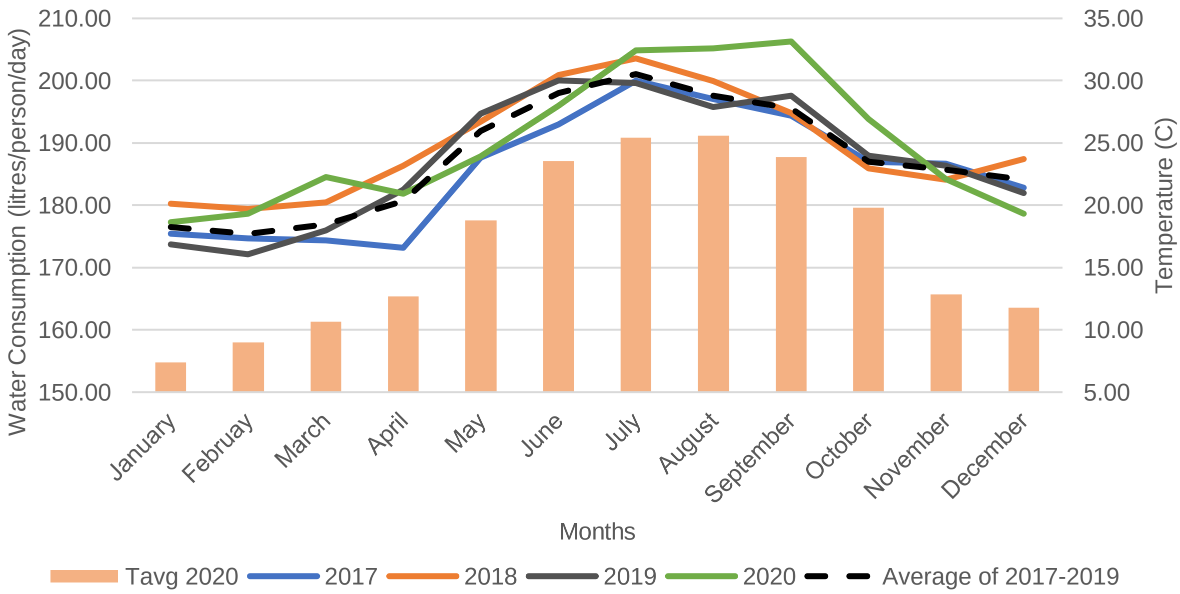


Figure 6. Water consumption (litres/person/day) and 2020 monthly temperature average in Istanbul. During the pandemic period daily water consumption per head was above both the average and range of consumption in the previous three years and did not fall back as temperatures fell as it had done in previous years suggesting that the higher consumption of water seen for July – September was due to the pandemic and not to other factors (such as an extended period of high summer temperatures).

Water resources of Istanbul

Yilmaz et al., (2020) provide information on the water resources of Istanbul which are largely reservoir-based. Periodically, reservoir levels are low suggesting that from time-to-time Istanbul is close to experiencing drought conditions should rainfall levels be low. Monthly water reservoir levels (as % of live capacity) from 2005 are given in Figure 6. In most years, reservoirs are at their highest levels in late-Winter and Spring months, and lowest in the Autumn because of the increased consumption during the summer and lower rainfall together lead to resource depletion. Reservoir levels were at their lowest level in this record in 2007, 2008, and 2014. These years show clearly in the visualisation of Figure 6. In the pandemic year of 2020 the highest reservoir level (a relatively low 69%) was observed in April. Normally, an increase in reservoir levels is expected with increased rainfall through the end of the year. However, the decreases in reservoir capacity that started in the spring months of 2011, 2013, 2019, and 2020 saw limited recovery. In the last two years (2019-2020) capacity did not recover throughout the year (Figure 7), so even without the impact of Covid-19 there was a case to be made for taking a precautionary approach and encouraging water saving. There are indications in this limited dataset that, effectively, near drought conditions impacting Istanbul may occur every 6-7 years (see Figure 8). Within the data for our limited time period: a severe drought occurred in 2007/8, and not dissimilar conditions in 2014/15, and late 2019 and 2020 into perhaps 2021. Figure 8 suggest that there may be a similar periodicity in periods where temperatures are anomalously high.

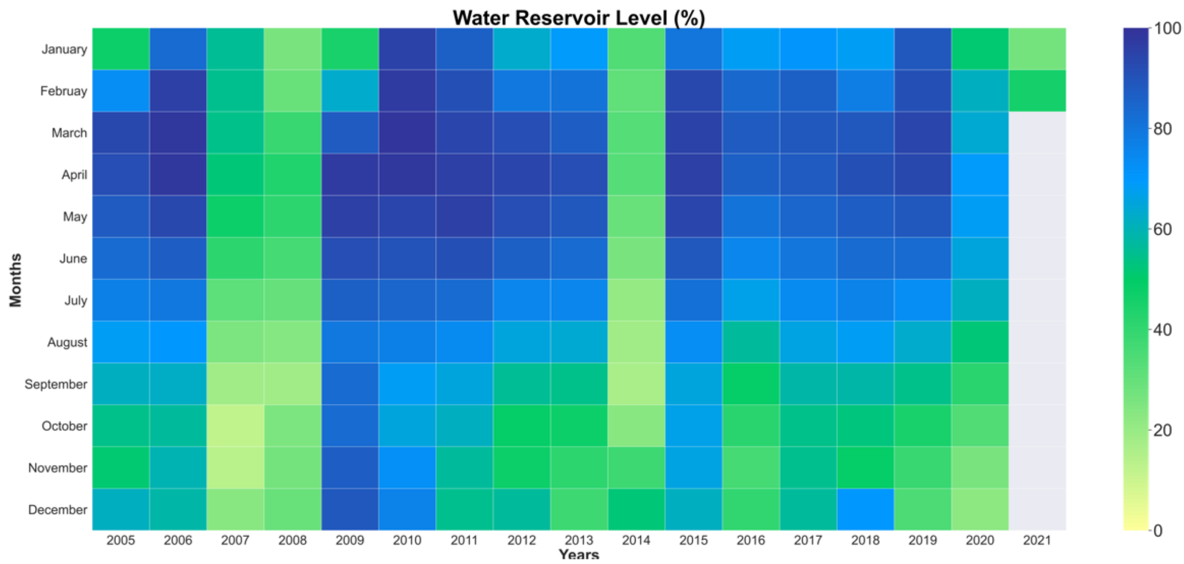


Figure 6. Monthly water reservoir levels (as % of capacity) in Istanbul

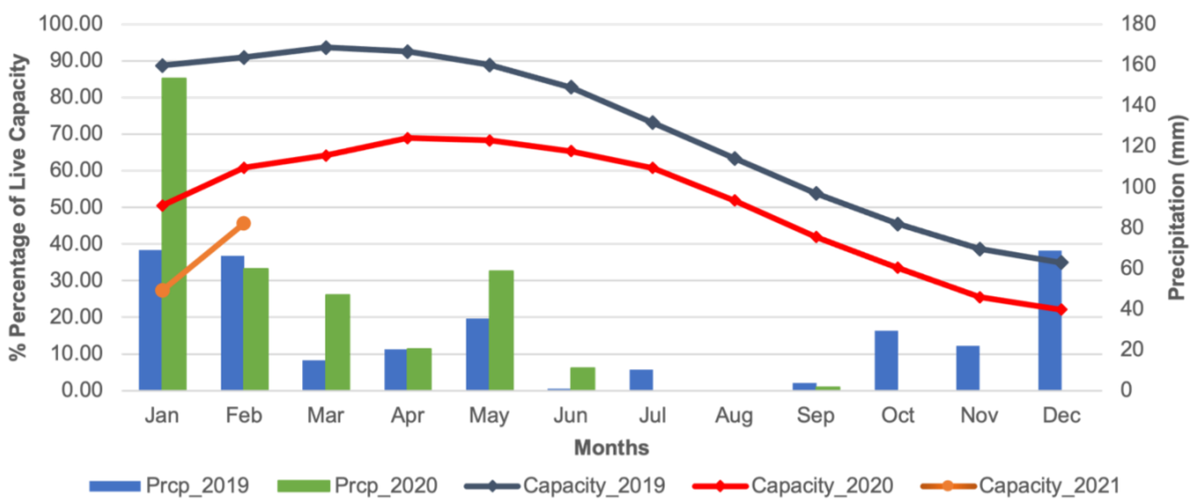


Figure 7. Comparison of water reservoirs live capacity (%) and total monthly precipitation (mm) in Istanbul in 2019 and 2020. Live capacity in 2020 did not reach 2019 levels and were already close to the minimum level for 2019 (December) in August. Water resources were not replenished to 2019 levels in 2020 despite higher rainfall in early 2020 than 2019. This indicates higher water use, some of which, say for the cleaning of public spaces, might not have been recorded in the standard figures given their emergency nature.

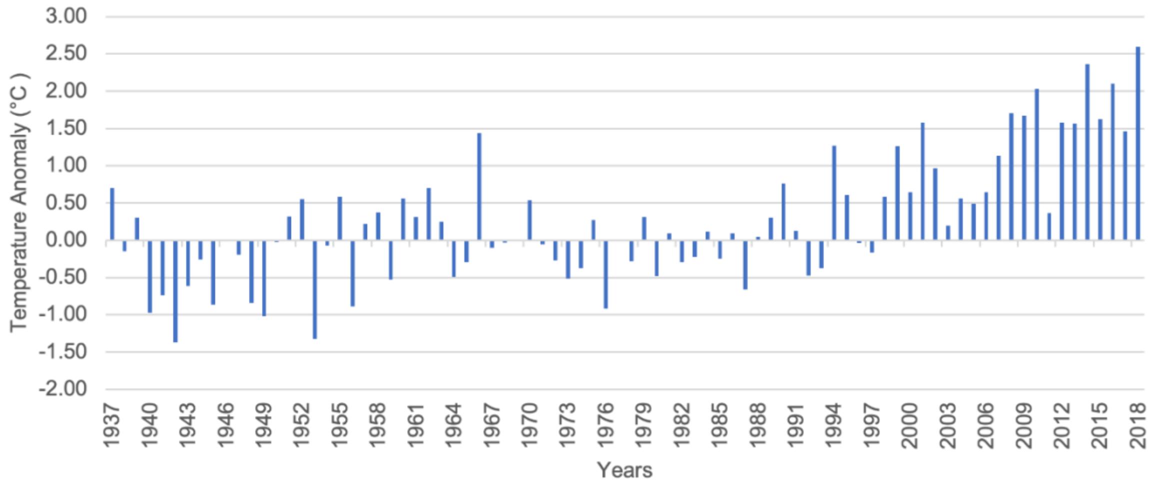


Figure 8. Istanbul temperature °C anomaly. This figure plots the average temperature anomaly data from 1937 to 2018 relative to 1961 to 1990 values in Florya Met Station, Istanbul. It is clearly seen that there is increasing trend in Istanbul especially after 1990s. Since 1990s, higher temperatures have occurred every 6-7 years (1990/1, 1995/6, 2000/1, 2007/8, and 2014/5) indicating that low reservoir levels occur when temperatures are anomalously high.

Implications for future water consumption and resources under climate change

Projected temperature and rainfall under climate change scenarios RCP 2.6 and RCP 8.5

Given the evidence above in (Figure 7 and Figure 8) that Istanbul may be subject to drought like conditions relatively frequently, we examined two climate change emission scenarios to scope, for the DPSIR Framework, whether such events might become more frequent of more intense in future. We chose RCP 2.6 as a low emission scenario (one where the Paris Agreement was met) and the higher RCP 8.5 scenario which would occur if Paris were not successful at reducing global emissions. In order to look at the specific location of Istanbul, the outcomes of CIMP5 ensemble model for RCP 2.6 and RCP 8.5 were used and extracted from the World Bank Climate Change Knowledge Portal (CCKP, 2021). We used this Portal as it is one that policy makers and government agencies can get ready access to and might use for planning adaptations to climate change.

Under the low emission scenario (RCP2.6), Figure 9 shows the projected temperature and rainfall patterns compared to the reference period (1986-2005). For the period 2020-2039; between 0.5 and 1.7°C per month increase is expected for all the months, with potential increase up to 3°C, in August. and rainfall seems to be same as the baseline values in all months with potential changes up to ± 20 mm per month during winter months. For the period 2080-2099; between 1 and 2°C per month increase is expected for all the months, with potential increase up to 4°C, in August, and rainfall seems to be same as the baseline values in all months with significant changes up to ± 20 mm per month especially during winter months.

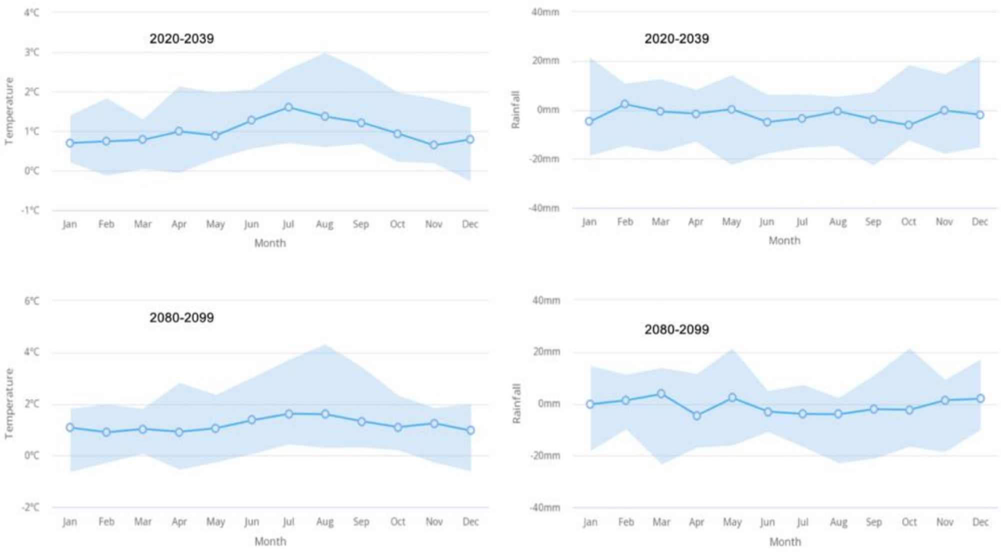


Figure 9. Temperature and rainfall projections for 2020-2039 and 2080-2099 under RCP 2.6. Output obtained from the World Bank portal (CCKP, 2021). The reference period here is 1986 – 2005. Blue shaded areas show the 10-90th percentile range of ensemble model outputs.

Under the high emission scenario (RCP8.5), Figure 10 shows the projected temperature and rainfall patterns compared to the reference period (1986-2005). For the period 2020-2039; between 1 and 2°C per month increase is expected for all the months, with potential increase up to 3.2°C, in August, and rainfall seems to be same as the baseline values in all months with potential changes up to ± 20 mm per month during winter months. For the period 2080-2099; between 3 and 6°C per month increase is expected for all the months, with potential increase up to 10.2°C, in August, and rainfall is lower than the baseline values in all months with significant changes up to - 30 mm per month especially during winter months.

Figure 10. Temperature and rainfall projections for 2020-2039 and 2080-2099 under RCP 8.5 The reference period here is 1986 – 2005. Blue shaded areas show the 10-90th percentile range of ensemble model outputs.

Overall, the climate projections suggest temperatures will rise in Istanbul but rainfall will not increase, indeed it may decline most under those scenarios where temperatures move to potentially very high values (the mid or even high 40s °C). With current pressures and limited water resources, the above locally expected trends in temperatures and rainfall may have significant impacts on water availability over the upcoming decades especially if there is lower rainfall at times of the year when reservoirs currently recharge. Given the long-term implications for increased water use in Istanbul as a result of higher temperatures and given that the population might increase further, dealing with the public health aspects of a future pandemic might become even more challenging, especially if it occurred in a drought year. Much may depend on how long warm and/or dry spells last in future.

Projections of future warm spells in Istanbul

The Warm Spell Duration Index (WSDI) is defined as count of days with at least 6 consecutive days when daily T_{max} > 90th percentile of the reference period (1986-2005) (CCKP, 2018). Figure 11 shows historical Turkey WSDI for 1986-2005 and projected WSDI by 2060 under four emission scenarios. Even in low emission scenario (RCP2.6), warmer periods seem likely to last about 9 times longer than in the historical records (1986-2005), which will cause more pressure on water resources where people, under the pressure of higher temperature, tend to use more water for recreational activities and other activities.

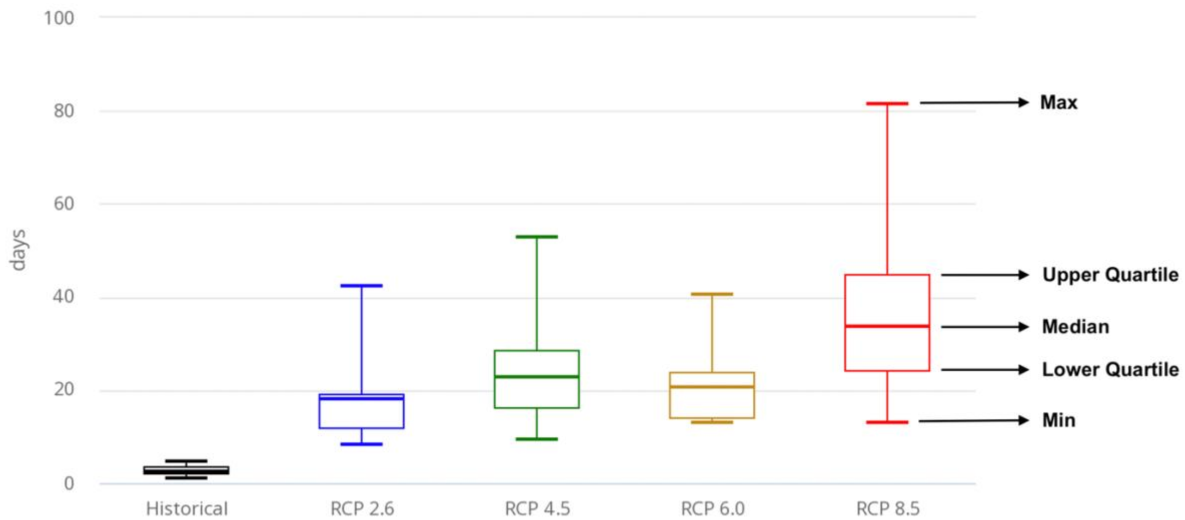


Figure 11. Warm Spell Duration Index in Turkey for period 2040-2059, the only time period available in CCKP (2018) for the reference period 1986-2005.

Main findings for Istanbul

The main findings from the case study were:

As Istanbul has developed the population has increased. Not surprisingly then, water consumption has increased, and water resources have only just kept pace with demand. Water resources seem at risk in dry periods such as those present in the mid to late 2000s.

Some changes in water consumption were noted during the early period of the pandemic coincident with changes in temporary migration away from large conurbations (such as Istanbul and Ankara) to smaller population centres (such as Bodrum) and increased water use for public health reasons.

Although water consumption figures varied there was a marked decline in the level of Istanbul's reservoirs during the pandemic period despite normal to high rainfall levels. This might reflect either the way resources (reservoirs) were being managed or use of water, (say for public health purposes such as street disinfection) for purposes not included within the normal reporting regime.

Several emergent water issues were identified in Istanbul. These included substantial uses of water for disinfecting streets and other public areas and the issue of potential water course contamination with cleaning agents and or Covid-19 virus. These two risks would arise from sources that had not passed through sewage treatment facilities before reaching the sea of inland waters. Water use for maintaining public and private gardens and parks seems likely to increase under climate change.

Under both climate change scenarios, Istanbul's water resources are the subject of higher levels of variability and an increase in the likelihood of hot days that may themselves promote water use. The changes suggest that drought conditions may become more likely with hot dry periods lasting up to 80 days (in effect, the whole of the summer months).

Discussion

International context to observations from the case study in Istanbul

Water use

Limited comparisons are possible between Istanbul and other countries at present due to lack of data availability. However, material is progressively becoming available on water use and water resources during the pandemic and information already exists in relation to the changing climate for countries such as the UK, USA, Netherlands, and many others.

In all examples where data was collected during the pandemic's early phases, a combination of factors contributed to some changes in daily domestic patterns of water consumption. In these other studies, we looked in particular for factors that needed to be included in the DPSIR framework that were originally omitted and for confirmation that factors included in Figure 1 were indeed of some importance.

For example, home water usage for 2,000 randomly selected USA homes with "smart meters" increased by 21% from Feb 1 to April 30, 2020 and changes in work patterns resulted in a delayed morning water consumption from 7 am to 9 am (TechRepublic, 2020). Similarly, in Germany, (Lüdtke et al., 2021) daily water consumption was 14.3% higher during the first lockdown in 2020 than in previous years at the same time period. Additionally, demand patterns over the day changed with a time shift of the morning peak and higher evening demand peaks, and something of a similar shift was observed in the UK where some higher increases in water use were found (Alda-Vidal et al., 2020). A shift in peak water use and other impacts on the pattern of water consumption was also found in the Pughlia region of southern, Italy (Balacco et al., 2020) where attempts at predicting demand were made difficult by the mix of both deterministic and stochastic factors that appeared to affect consumption, some of which were behavioural and social in origin. For example, because of progressive delay in the waking up time and delayed routines for personal and domestic usages, the maximum morning peaks for use shifted from 0800 to 1000. In Joinville, southern Brazil, Kalbusch et al., (2020) did a detailed study of different social and commercial sectors. This showed actions to prevent the spread of COVID-19 led to a decrease in commercial, industrial and public usage, and a slight increase in residential consumption. The comparison between water consumption averages in the sample shows that in areas and time periods studied it decreased by 53%, 42% and 30% in the industrial, commercial, and public categories, respectively. Average water consumption increased by 11% in the residential category with differences in use between houses and apartment blocks. Some differences between geographical locations were also identified.

Concerns about the impact of Covid-19 on water consumption in many parts of the world are apparent. For instance, Sivakumar (2021) argues that efforts to control the spread of COVID-19 will likely increase the water demand and worsen the water quality, leading to additional challenges in water planning and management and the urgent need for issues to be addressed. For Sub-Saharan Africa (SSA), Anim & Ofori-Asenso (2020) suggests that a wide range of different approaches were thought necessary. These were made more important by the rapid population growth and the impact of climate change which would increase drought risk and included: (i) increasing the efficiency of water use by implementing strategies for conservation of available resources (ii) nature-based solutions to help with water storage and supply. Such approaches have been proved to work in the case of New York, USA. The compound risks presented by climate change and other socio-economic events such as the current pandemic suggest much greater use of digital technologies may be necessary in a reimagined water infrastructure system (Poch et al., 2020).

Despite the level of concern about the impact of Covid-19 on water systems a review of governmental responses in 27 European countries (Antwi et al., 2021) revealed that COVID-19 pandemic policy measures were focused around economic measures, but water, which plays a significant role in both socio-economic and well-being, enjoyed limited interventions. Some countries had water-related interventions predominately consisting of short-term measures to ensure uninterrupted water supply and to cushion the impact of loss of income during the pandemic. This also reflected the situation in the UK where a strategic approach evolved. Thus, to understand the impacts of Covid-19 on water sector in the UK, Water UK and Ofwat decided to work collaboratively in May 2020. One report found there were many impacts on water companies including unpaid bills, consequences of raised unemployment rates, lower tariffs for many customers, more household consumption, and less office (non-household) consumption. Again, it was suggested that digital technologies might provide opportunities for companies to better manage water during such emergency situations (Frontier Economics, 2020). This would be especially important for learning about exact and up-to-date consumption. Similar issues arose in Turkey where, for example, because of restrictions on movement for public health reasons, some municipalities decided not to read meters (water, electricity, and gas) for 3 months from March 2020 (e.g. ABB, 2020; EPDK, 2021). This caused unbilled consumptions and lower revenue for the companies and also complicated understanding of patterns of water consumption in certain places in a way that has yet to be resolved.

Changes in water use patterns and the drivers for these are gradually becoming clearer in the UK, one of the countries most affected by the pandemic. In general, there was a substantial increase in water use. Some of the changes in the pattern and level of water use were driven by a range of public health, social and life-style reasons and some may become permanent post-pandemic (Alda-Vidal et al., 2020). Demand was so high a times in the UK (partly due to hot weather in the summer) that appeals were made by water companies for customers to use less water for leisure or gardening. There were substantial regional and local differences in apparent effects of the pandemic situation and some evidence that people responded to appeals for restraint on water use as consumption often fell after appeals were made (e.g., in southern England in areas supplied by southern water). This may have been especially the case in parts of southern England where commuters did not travel into London for long periods that coincided with a period of hot weather in the summer of 2020. Some examples of the highest water use coincided with periods of hot weather, but not all, with United Utilities of northern England issuing a general request to use less water on its website in Mid-2020 (BBC News, 2020b) after finding it had pumped 4.6 billion litres of extra water during the early part of the pandemic period. Welsh water also recoded peak demand levels at record levels with demand exceeding 1,000 million litres/day as opposed the more normal 800 million. Trade sources reported that in one week in June 2020 Thames water pumped a record volume of water (an extra 158 million litres per day) in parts of the Thames Valley (Smart Water Magazine, 2020). This level of demand (totalling 758 million litres in a day) was so great that it was close to exceeding the capacity to treat water for supply.

Although the main water company for the London area (Thames Water) reported no particular supply issues with outages being relatively short. This could have been aided by the absence of many 100,000s of workers staying out of London during lockdown periods or during periods when “stay at home” was the preferred behaviour required by UK government policy. It was also assisted by a strategic partnership with the UK Met Office. Despite important local variations, overall, base water consumption (effect of weather removed) in lockdown seemed to vary little on average with water consumption increasing or decreasing depending on locality (down in urban centres; up in suburbs) (Met Office, 2020). However, raw use figures were very different with increases of over 25% being almost universal amongst 10 UK water companies with some major common changes in the pattern of water use also emerging (Lee, 2020).

Changes in demand in line with pandemic lockdown regulations and advice were noted: e.g. decrease in demand in central London, increase in demand in suburban areas, (Thames Water, 2021). In the Thames Valley area, the public were told (Rice, 2020) demand increased by 158 million litres per day in the last week of May 2020, the highest level of demand for 31 years (Smith, 2020). Northumbrian Water (northern England) reported increased use during the pandemic equivalent to 29 litres extra per person per day (WWT, 2021). There were occasions when southern England water companies (where many London workers tend to live) were close their capacity to maintain supplies with so many people lockedown at home. It was challenging for some companies to pump sufficient water into the domestic mains system at certain times (e.g. Severn Trent in late May 2020 when 2,000 homes were without water temporarily: (BBC News, 2020a). Demand in the Severn Trent areas was also reported at a 30-year high.

Some communities in Sussex southern England experienced supply outages requiring use of street bowsers and bottled water (South East Water, 2020). High demand during hot weather in August 2020 led to an increased demand of 150 million litres per day across the South-East Water region. This occurred when water use was high due to a combination of high temperature (mid 30sC) and pandemic conditions (many people at home). Record demands for water (696 million litres – 150 million above the norm) may have contributed to supply failures in the area lasting a number of days that could have had implications for public health. These were addressed by providing temporary water supplies (bowsers and bottled water accompanied by advice to boil tap water before use (Goddard, 2020). Demand fell back in the following days (by some 30 million litres per day) following wide publicity about supply problems and appeals to use less water. Even with the onset of cooler weather demand was some 30 million litres per day above normal levels of 540 million litres per day, perhaps due to the pandemic. This increased demand of about 5% not unlike that seen in Istanbul.

Both the wider London area and Istanbul saw rises in water use during the pandemic but interpretation of the impact on water systems overall could only be understood when movements in population and people's behaviour in hot weather is taken into account.

Although high temperatures were a factor in water supply and demand in many cases during the pandemic exceptionally low temperatures also featured in a manner that compounded risks. For example, in Jackson, Mississippi (USA) low temperatures linked to a powerful jet stream brought Arctic air to the southern United States, with the ensuing local water crisis highlighting issues around race and poverty as well as those linked to Covid-19 as well as the type of extreme weather that is increasingly linked to climate change (Merritt, 2021).

Reservoirs levels

We have examined only reservoir data for the UK to obtain comparative information for Istanbul. Most detail is given for Thames Water as an exemplar for the London region as a comparator for Istanbul.

Contrary to the situation in Istanbul during the first few months of 2020, the month of May was the driest and hottest on record in England (Figure 12). In contrast February had been the wettest on record in some parts of the UK (NRFA CEH, 2020).

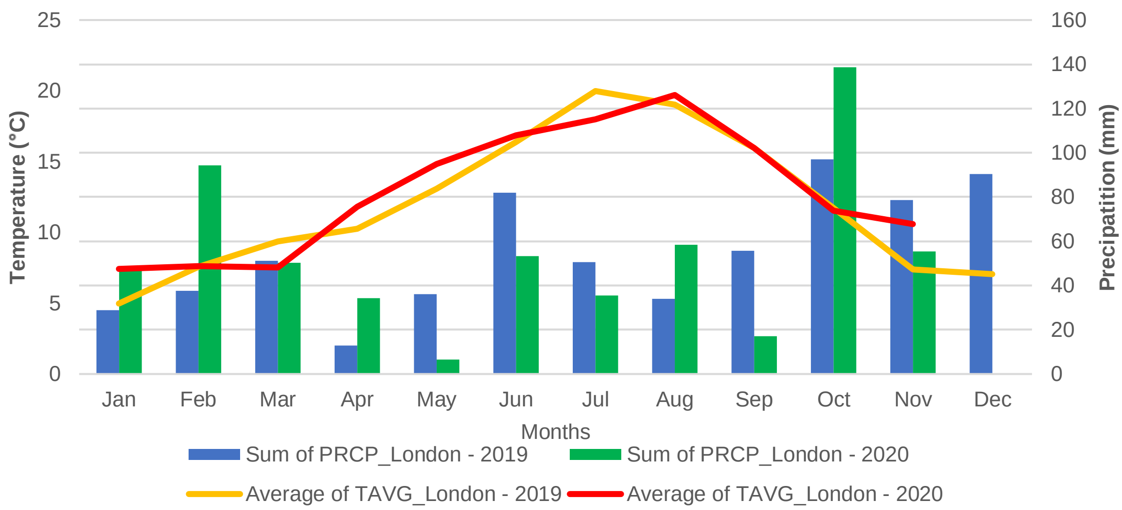


Figure 12. Monthly temperature (°C) and total precipitation (mm) in London

With the general increased demand for water during the Covid-19 pandemic, the most of reservoirs in the UK especially eight reservoirs faced their lowest levels on record in May 2020 (Figure 13). Most of reservoirs in the UK also showed a remarkable decrease in reservoir levels (NRFA CEH, 2020).

Despite different weather patterns there is evidence for a decline in reservoir-based water resources in both the UK (Figure 13) and Turkey (Figure 6) in the period of the pandemic but not all of this is necessarily due exclusively to it but perhaps, as indicated below to a combination of lack of recharge and additional demands for supply.

The increased demand for water during the Covid-19 pandemic combined with a dry spring period that was particularly acute in southern England was coincident with most reservoirs in the UK being at low levels, especially the 8 shown on Figure 13 that recorded record low values. In the area of Thames, Southern, Wessex, and South West, most of reservoir levels (May-2020) were below compared to May anomalies (the difference compared to the long-term average), and half of the reservoirs were lower than May-2019 levels (NRFA CEH, 2020)

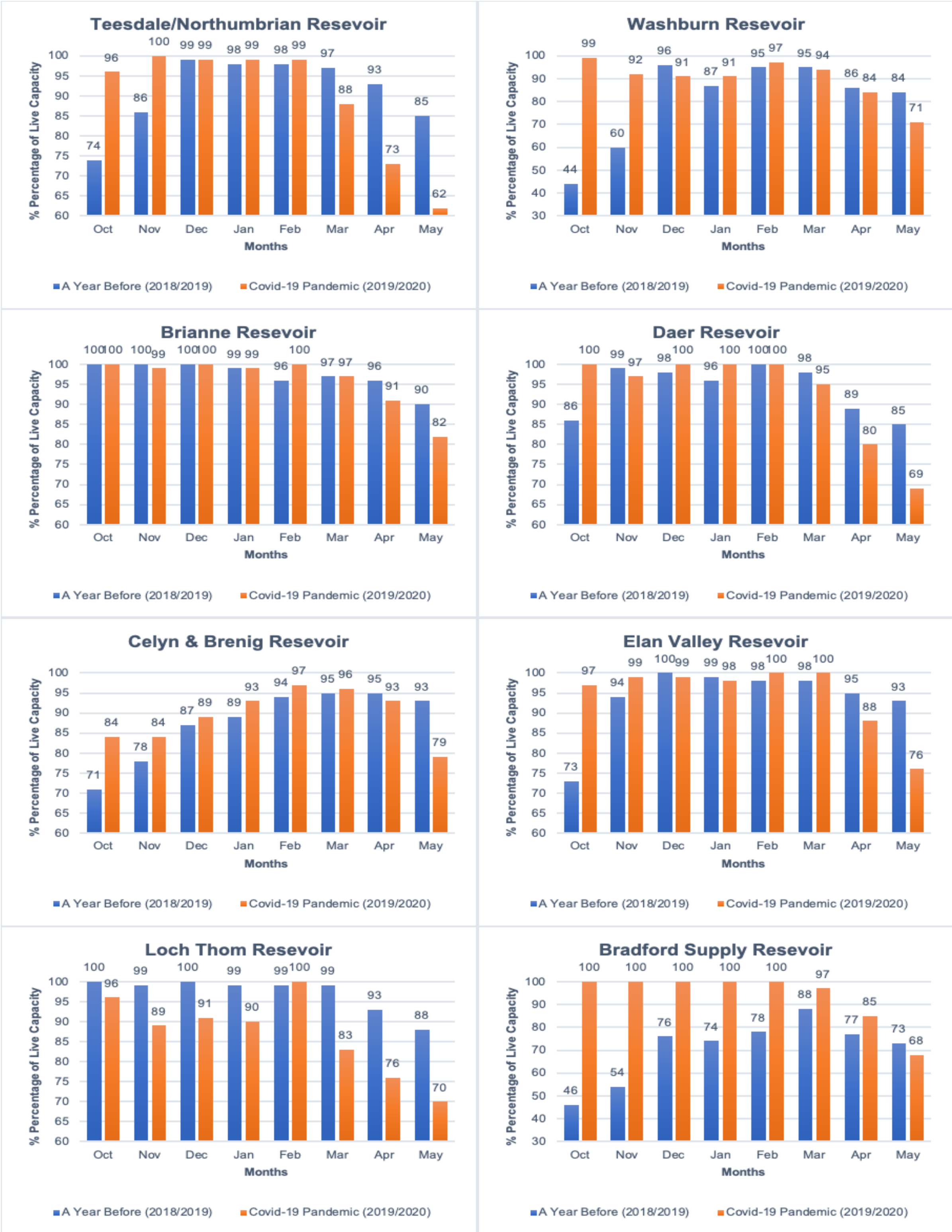
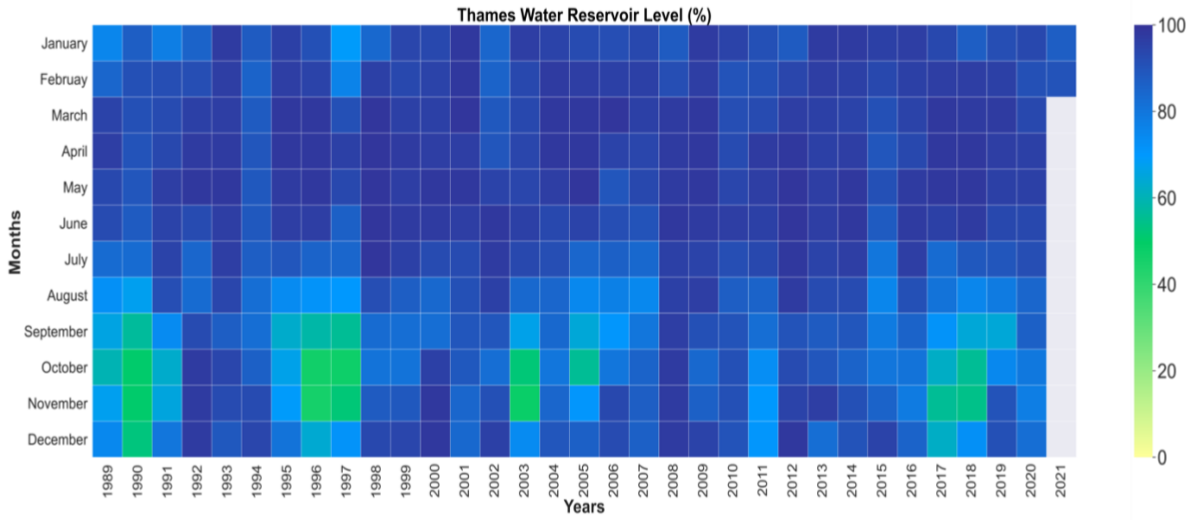


Figure 13. Capacity of the UK reservoirs where the min of May value has been observed in May 2020 (NRFA CEH, 2020)

In addition to lowest reservoir levels in May 2020, Figure 14 shows how Thames Water Reservoir Levels (%) in London changed over the period since 1989. As with Istanbul, there are indications in this dataset that, effectively, the lowest reservoir levels impacting London may occur every 6-7 years. The effect is most pronounced in 1990, with not dissimilar data for 1996/97, 2003, 2011 and 2017/18 as well.

However, one current difference between the Istanbul area and the London area is that London reservoir capacities rarely reach the low levels seen in those that serve Istanbul.



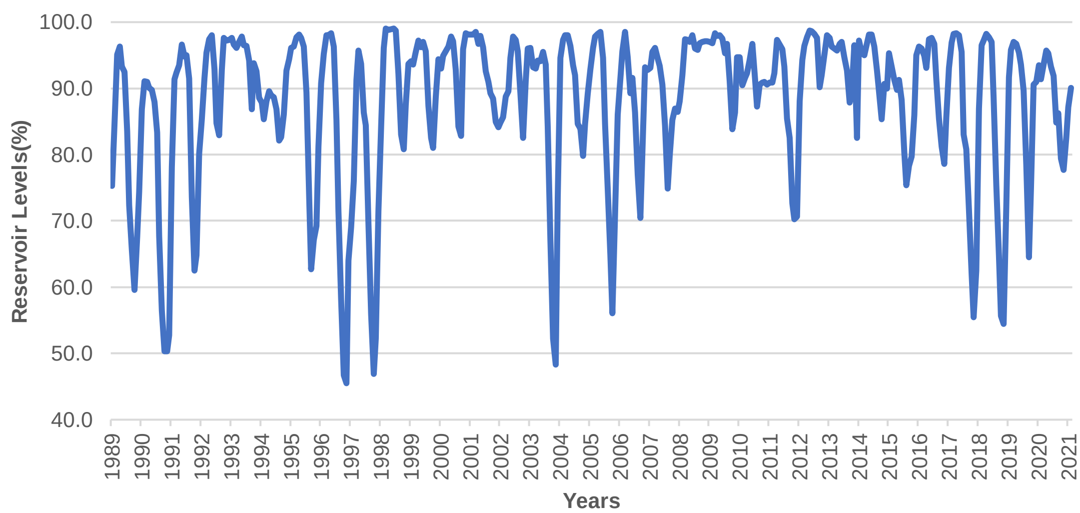


Figure 14. Monthly water reservoir levels (%) in Thames, London (Thames Water via Environement Agency, 2021)

Emergent Water Issues

In addition to issues around increase water consumption and in some place's low reservoir levels and interruptions to supply caused by a range of factors, a number of emergent issues have also been identified. These cover a range of social, economic, and environmental issues.

For example, a similarity between Istanbul and the London South-East England area is that both areas are likely to experience higher temperatures and more periods of dry weather under climate change scenarios (Lowe et al., 2019; UKCCRA, 2017, 2021a). For some parts of the UK, there are substantial concerns about water resource and supply issues due to climate change alone, especially after 2050. Potential supply shortages of between 1,220 and 3,900 million litres per day are possible – that is supply equivalent to that for between 8.3 and 19.7 million people (UKCCRA, 2021b).

The social and economic issues include factors such as problems with unpaid water bills and increased sewage system blockages. As people lost their jobs and experienced economic difficulties, they were advised to contact their water companies for help with deferring their water and sewerage payments. As people stayed at home more, increased flushing inappropriate articles through the domestic toilet systems have caused blockages in the sewerage systems (BITC, 2020; Thames Water, 2020a; Water UK, 2020). Popular news outlets carried dramatic images of the increased blockages occurring as early as April 2020 when blockages rose as a result it is thought of lockdown restrictions (Mann, 2020). Media messages to only allow permitted materials into the sewage system accompanied such images.

Increased costs of sewer blockages (costing about £3M) were only one of the economic impacts of the pandemic on Thames Water. The company posted a pre-tax loss of £246.5M in its interim report for 2020/21(Thames Water, 2020b). Many of the factors involved in this loss involved social/economic ones (help to less well-off domestic customers; loss of revenue from business customers during the pandemic; reassessment of risks partly to account for the pandemic's wider implications) as well as other cost issues linked to supply, sewage and infrastructure. Parts of this loss, such as the increase in bad debt, was attributed directly to the pandemic. Similarly, Southern Water (2021) refers to several impacts of the Covid 19 pandemic including: a 7% rise in water use from 127 to 136 litres per person per day; leakage up by about 4%; increased operating costs of £2.7M together with a redistribution in income from different customer sectors; help for vulnerable customers and a need for re-analysis of a range of business risks. The full effects of the pandemic on the water sector may not be known for some time.

The pandemic has also suggested that people need to take a wider view of water resources and act accordingly. For example, in order to act on advice to consume less water, they may need to reuse water used while cooking for houseplants, spend less leisure time in the bathroom, and, if possible, plant drought-resistant seeds in gardens and parks. (Waterwise, 2020).

As well as local and regional emergent issues there are some global ones. For example, by disrupting economies and causing thousands of deaths globally, the Covid-19 pandemic has likely had a serious impact on progress towards the Sustainable Development Goals (SDGs), and further compromised the 2030 targets. Some argue that it is important to introduce further cost-effective and innovative policies for achieving those SDGs (Barbier & Burgess, 2020). More generally, there were concerns about preventing water contamination as the virus can survive up to several days, perhaps longer in low-temperature regions. Even if sewage treatment methods and approaches such as chlorination and UV irradiation have the ability to eradicate Covid-19 in the water, the possibility of being contaminated maybe high in areas where sewage is untreated. (Bhowmick et al., 2020). Interestingly water systems can also be part of early warning systems for Covid-19 (or perhaps other types of pandemic or disease). In many parts of the world this form of monitoring for Covid-19 has been initiated (e.g. in the Netherlands) (Medema et al., 2020).

Emergencies, such as the Covid-19 pandemic (WHO, 2020) can compound the pressure on water usage and availability that are already under pressure from climate change in some parts of the world. Issues are also emerging in terms of water use in the public domain of urban areas. For example, as evidenced in Figure 5, a lot of water has been used for disinfecting public spaces. Many kinds of cleaning, disinfecting and bleaching agents were probably use during the pandemic some of which may have been used in quantities and amounts that were not expected when the national and international risk assessments were done for these materials. When released into the environment (in this case through surface water drains or directly onto soil near the areas disinfected, bleach and other chemicals can release chlorine that reacts with organic matter in soil, water, and air to form a range of organochlorine compounds. Other materials, such as detergents can have toxic effects on aquatic systems if they enter these systems at high enough concentrations. It is possible that such practices could have environmental impacts that have not yet been quantified as these compounds could be toxic to wildlife, carcinogenic or mutagenic, and accumulate in the food chain and eventually impact humans. Not all water passes through a treatment facility before entering the natural environment. Thus, the products used for hygiene purposes during Covid-19 times may end up in rivers and the sea. Additionally, the disinfection products may also infiltrate the soil, and having impacts on land, plants, and animals. Since the purification process used by most water treatment plants is achieved by bacterial action the introduction of chemicals in high concentrations (such as bleaches or disinfectants) could have a significant impact on treatment plants. More evidence is needed on these emergent issues linked to public health measures taken in the public realm of many urban areas.

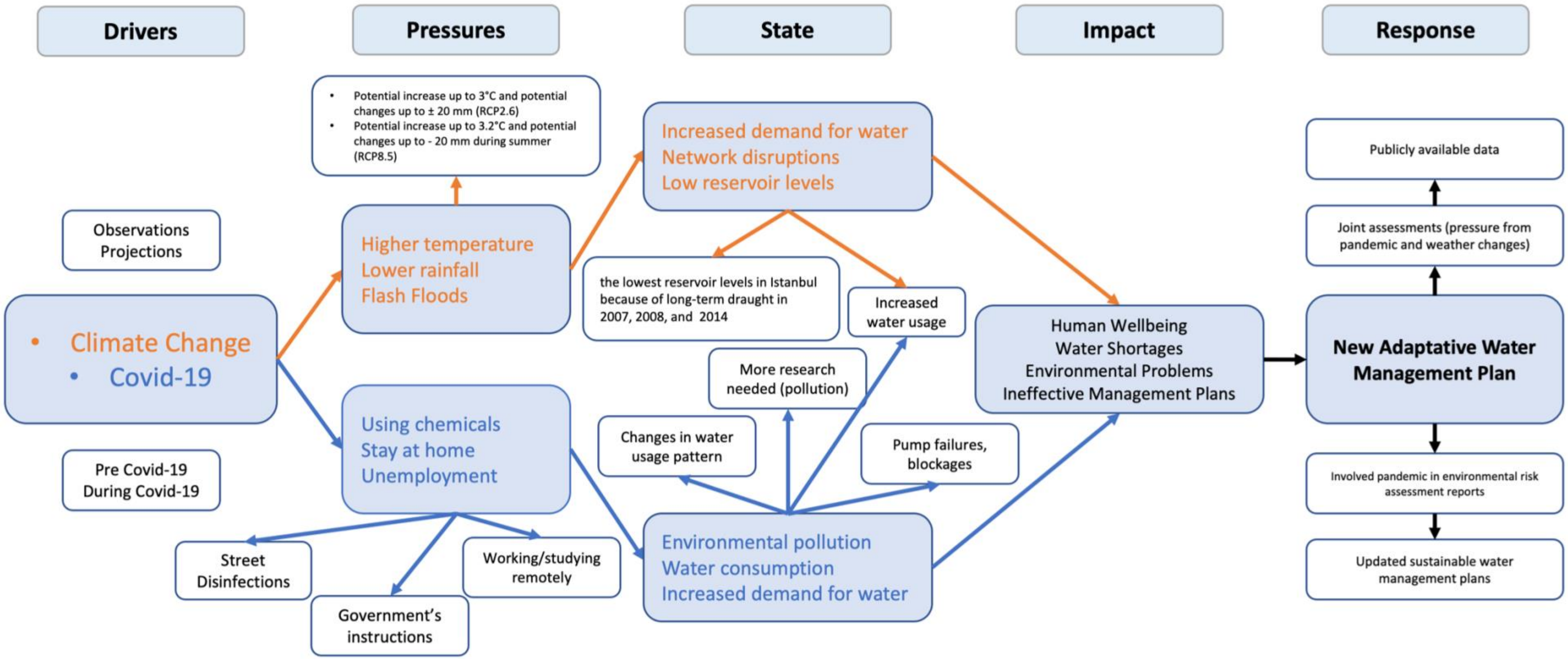
Conclusions

In this paper we have shown how a range of factors relevant to water supply and resources could be affected by the Covid-19 pandemic in several different locations (principally Istanbul and south-east England). Table 1 summarises from this evidence how different phases of the pandemic have impacts on water environment. Full lockdowns have major impacts as many people, except key workers, have to stay home, and so use more water for domestic and hygiene purposes use and perhaps also in gardens etc. The impacts of this public health emergency on the water systems of Istanbul and south-east England appear to be similar: mainly increased water use and some supply problems that were linked to high temperatures at least in parts of south-east England where London commuters were working from home under Covid restrictions. Istanbul may have been saved from supply issues by the temporary migration of people away from this centre of population. We have also identified a suggestion that periodically reservoir levels in both the London and Istanbul areas suggesting perhaps that the resilience of water systems may be at some risk from climate change given the possible association between increased water ruse and hot weather especially if near drought conditions occurred at the same time as a pandemic. This may be the current situation in Turkey where wildfires are affecting much of the countryside.

Table 1. Different factors during pandemic and their possible impacts on water environment

Factors	Impacts
Promoting hygiene	Cause additional pressure on water resources, increase water usage
Street disinfections	Increase water usage, pressure on sewage system, environmental pollution
Staying home	Change water consumption trends, increase morning water usage, pressure on sewage system
Working remotely	Increase water usage
Population movement	Increase or decrease water usage
Full lockdowns	Heavily increase water usage, more pressure on sewage system, blockages, water shortages, decrease water reservoir levels

Thus, combinations of pressures from climate change and any future pandemic leading to water shortages might present a compound risk to water resources and usage that could exacerbate the impacts of climate change on people, businesses, and agriculture. Countries, municipalities, and communities need to make adaptive management plans that take account of such compound risks. To that end and in the light of evidence gathered in this study (the first time to use a DPSIR framework to examine the impacts of Covid-19 and climate change on water consumption), Figure 1 has been modified to set out at the next level of detail the factors that may be affected by both climate change and the pandemic. This diagram perhaps relates most closely to Istanbul but may also have relevance to other places, such as the London and south-east. The modified diagram is Figure 15, which might help thinking about new adaptive management plans where there will be a need to provide publicly available data, assess actual and potential issues with affected communities and taking account of both drivers of long-term trends and shorter-term extreme events (such as pandemics or droughts). We hope a DPSIR framework may help major municipalities and their hinterlands develop such ways of manging water resources and supply in future. This study suggests the factors involved may be the same for different localities but that they need to be given different weights to account for differing environmental, social, and economic circumstances.



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620 *Figure 15. Enhanced DPSIR Framework*

Here are the main points of this study:

- Covid-19 and weather changes have impacts on water reservoirs and water consumption.
- Increased demand for water caused some problems (blockages etc.) to water sector.
- The first use of DPSIR Framework for the impacts of covid19 and climate on water environment.
- Pandemic should be involved in environmental risk assessment reports.
- Sustainable water management plans should be updated.
- Joint assessments (pressure from pandemic and weather changes) must be considered.
- All types of water data sets should be publicly available and be analysed regularly.
- Public areas should be studied for environmental pollution caused by disinfections.

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Declarations and conflict of interest

The authors declare no conflicts of interest in connection to this article.

Open data and materials availability

Data can be accessed via:

Weather data: NOAA at https://www.ncdc.noaa.gov/cdo-web/search?datasetid=GHCND and see: https://www1.ncdc.noaa.gov/pub/data/cdo/documentation/GHCND_documentation.pdf

Temperature Anomaly Data in Istanbul: Turkish State Meteorological Service at https://mevbis.mgm.gov.tr/mevbis/ui/index.html#/Workspace

Water consumption data in Istanbul: Istanbul Municipality Annual Report at https://www.iski.istanbul/web/tr-TR/kurumsal/faaliyet-raporlari1

Air quality data in Istanbul: https://havakalitesi.ibb.gov.tr/Pages/AirQualityCalendar

Water reservoir levels in Istanbul: https://www.iski.istanbul/web/tr-TR/baraj-doluluk

Water reservoir levels in London: The National Hydrological Monitoring Programme Monthly Hydrological Summaries at https://nrfa.ceh.ac.uk/monthly-hydrological-summary-uk

Local projection data: The World Bank at https://climateknowledgeportal.worldbank.org/

Istanbul population data: TURKSTAT at https://data.tuik.gov.tr/Kategori/GetKategori?p=nufus-ve-demografi-109&dil=2

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Annex – I

The impacts of Covid-19 restrictions on air quality

When looking at the other environmental concerns, air quality parameters such as PM_{10}, SO_2, and CO are demanding on people's and industrial activities, vehicles, and solid wastes (WHO, 2008). During the lockdown periods, as many people stayed at home, and many industrial actives minimized, the levels of these parameters decreased in Istanbul (Figure 1).

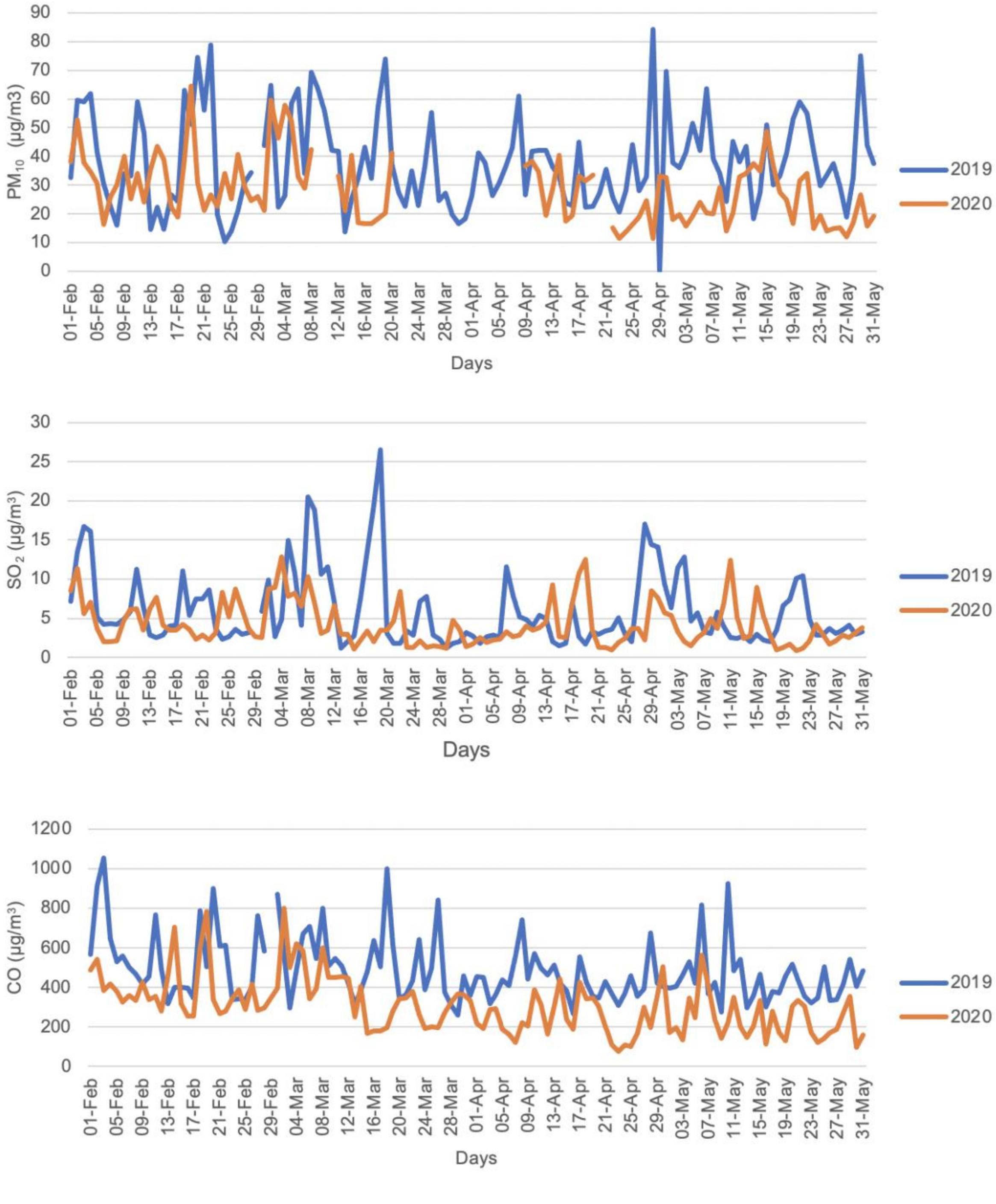

Figure 1. Daily PM_{10}, SO_2 and CO concentrations (µg/m^3) from February to May in 2019 and 2020 in Istanbul