Article title: The influence of Covid-19 Pandemic and Climate Change on Water Use and Supply: Experiences of Istanbul and London Area
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The influence of Covid-19 Pandemic and Climate Change on Water Use and Supply: Experiences of Istanbul and London Area

Public Interest Statement

Water is essential, and water resources are under pressure from increased urbanisation and the impacts of a changing climate on both the long-term trends in precipitation patterns and 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 with known pressures and be able to deal with emergencies 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 southeast of England in the same period as there were some commonalities and some differences. **Figure 4** sets out the factors we have examined in this paper, including some unexpected uses of water in the Covid-19 period, in this case, street disinfection (illustrated in **Figure 8** 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 5** 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 in the pattern of use in emergency situations could cause local water shortages in future due to either infrastructure failure or capacity limitations. **Figure 16** the expanded version of **Figure 4** shows the factors we believe may need to be considered in developing future resilient water systems and management approaches.

The influence of Covid-19 Pandemic and Climate Change on Water Use and Supply: Experiences of Istanbul and London Area

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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., air quality in cities). Although hygiene and disinfection procedures and precautions are effective ways to protect people from Covid-19, they have significant 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 that 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). Through a new simple way of visualising the data, we also noted that a low resource capacity might be recurring every 6 or 7 years in Istanbul (same finding from Thames Reservoir in London). 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

1. Introduction

Water is a fundamental part of life in any society, and 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 drawdown; 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 to guarantee future generations' prosperity. Maintaining water needs for drinking, industrial, agricultural, and other usages are expected to be one of the most important challenges for societies, as is already apparent in some parts of the world (Bensoussan and 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 and changes in the frequency or intensity of extreme events such as flooding and drought (Sheridan and Allen, 2015). Managing these changes can be more difficult if other trends, such as those in population levels or demographics, need incorporation into planning. Public health emergencies, like pandemics, may complicate matters further.

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 climate change represents a compounding of risks that might alter established water use patterns and challenge management approaches. Frameworks are needed to manage compound risks (components of which are often thought of as low frequency but high impact), mainly as extreme events linked to climate change are occurring more regularly.

[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 23 May 2022, there have been around 522 million confirmed cases of COVID-19, and around 6.27 million deaths globally. Daily cases are still around 200k, and over 12 billion vaccine doses have been administered. (WHO, 2022).*

In this paper, we examine how pandemics like the Covid-19 pandemic might affect water usage and availability and how this might add to existing and future water management issues in Istanbul, Turkey, and consider how such impacts are likely to be affected by climate change. We focused on events in 2020 and compared these with situations in previous years. We used Istanbul as a case study of compound risk 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 Covid-19 lockdown state in 2020. When people were 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 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 water demand.

We examined the situation in Istanbul through a DPSIR (drivers, pressures, state, impact, and response) lens (**Figure 4**) 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 (Gari *et al.*, 2018; Ashfaq *et al.*, 2019), there has been no previous use of a DPSIR framework to examine the actual and potential impacts of Covid-19 and climate change on water consumption and resources. **Figure 4** 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, some of which are set out in Yilmaz et al. (2020). We then looked for evidence of the influence of such factors on 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 adaptive water management planning for this, and other, major urban centres. The water system of a large municipality might then be more resilient because it had been designed in a manner that recognised and allowed adaptation to the impacts of (i) trends in climate change impacts, and (ii) extreme events of different kinds, which considered the importance of (iii) all aspects of the infrastructure system and (iv) human behaviour in water use.

In this study, we used information gathered from the 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 the pandemic. To increase the likelihood that our findings might be generalised, we drew on information from other areas, including the USA, Germany, Italy and Brazil.

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 and water management. In a set of case studies, we have been examining the impacts of climate change and 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.

2. Approach and Methodology

2.1. Study areas and environmental conditions prevailing in Istanbul and London in 2020

In this study, the cases of Istanbul and London (**Figure 1**) (amongst the largest conurbations in the world) have been considered in most detail due to similarities in lifestyles and commuting patterns. While over 15 million people live in Istanbul (5,343 km^2), which is the most populous city in Turkey, just over nine million people live in London (1,572 km^2). A population similar to that of Istanbul lives in the wider area of south-east England that is within commuting distance of London

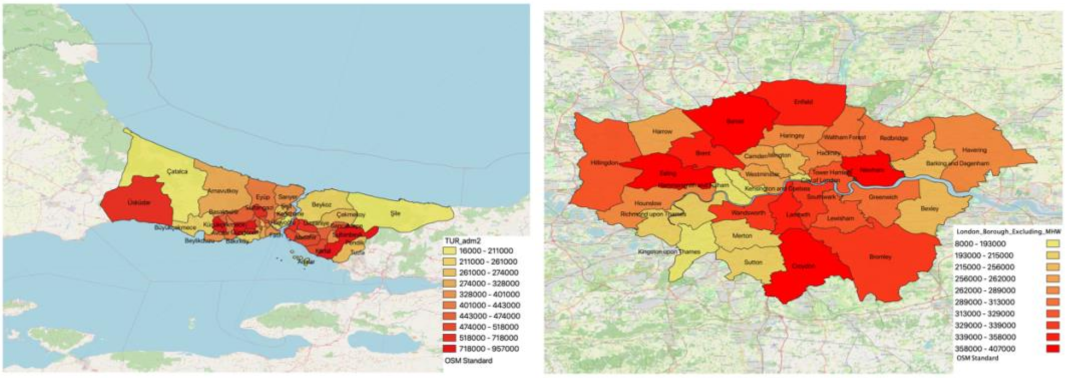

Figure 1. Istanbul and London Area with 2020 districts' and boroughs' population (Greater London Authority, 2022; TURKSTAT, 2022)

Assessing the impact of the pandemic on water resources needs to include consideration of the prevailing environmental conditions relevant to the hydrological cycle. **Figure 2** shows how monthly temperature and precipitation changed during 2020, in Istanbul. In 2020, the first quarter was the wettest month and there was almost no rainfall in the summer months (June July, August, and September), which are also the hottest time of the year.

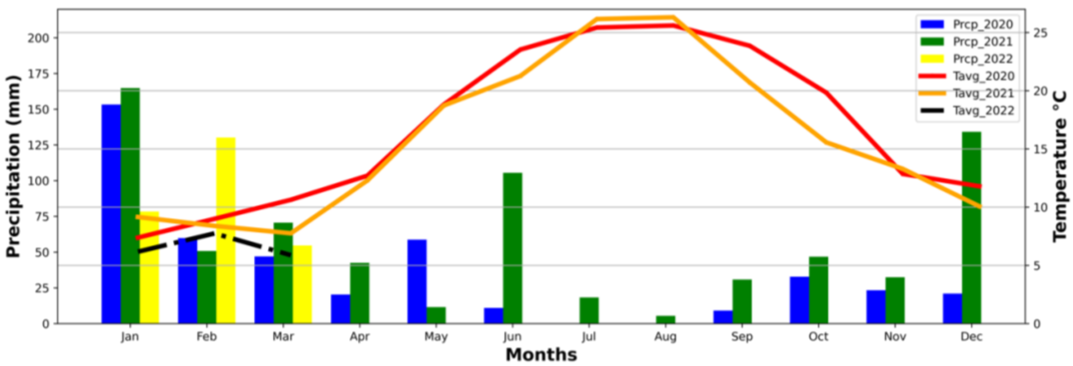

Figure 2. Monthly temperature (°C) and total precipitation (mm) in Istanbul

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. February had been the wettest on record in some parts of the UK

(NRFA CEH, 2020). **Figure 3** shows average temperatures and precipitation for London during 2020/21. In general, the weather in the summer months of 2020 for London and the South-east of England allowed people to use outside spaces such as parks and gardens extensively for exercise and leisure during periods when lockdowns and other Covid-related restrictions were in place provided that rules on social distancing were adhered to.

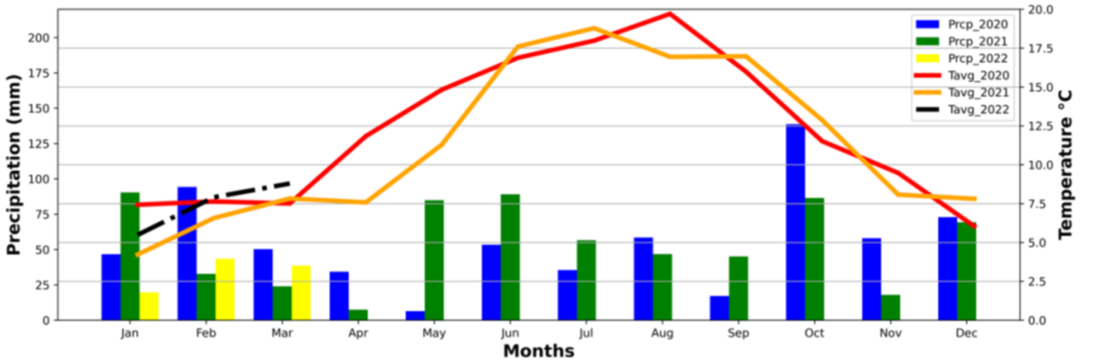

Figure 3. Monthly temperature (°C) and total precipitation (mm) in London

2.2. Initial DPSIR Framework

In this study, a DPSIR framework was set out in two ways (an initial view and an expanded version based on findings from this study). Smeets and Weterings (1999) detail the origins of the DPSIR approach introduced by the European Environment Agency. The initial framework for Istanbul (Figure 2) includes the factors thought most likely to be involved in changing water consumption in pandemic circumstances together with the equivalent climate change factors that might be important in the longer term or in the event of an extreme event that coincided with a pandemic.

Pandemic and climate factors co-located in the sectors of the model (**Figure 4**) might amount to interacting factors or compound risks in their own right. We assume that governmental bodies and others would want to respond to issues by developing an adaptive management plan to deal with at least the climate change aspects of the hazards and risks and adjust emergency planning to account for impacts on pandemic preparedness and response.

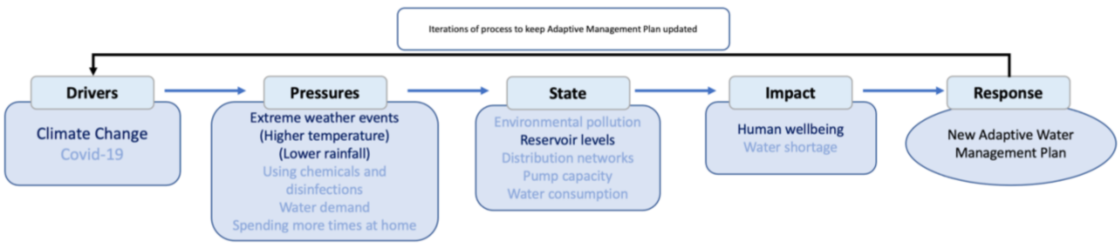

Figure 4. DPSIR Framework: *Overview of factors likely to be involved in changing water consumption in pandemic circumstances that might lead to supply challenges (light text) with the equivalent climate change factors (dark text).*

2.3. Data Sources

In this study, Istanbul data on water consumption, water reservoir levels, weather, climate change and population have been used to develop a water management framework that might be resilient to both climate change and other extremes such as future public health emergencies. So, we have taken a mixed methods approach using both quantitative as well as qualitative data.

Additional analysis of air quality and traffic movements was used to support the contention that the Covid-19 pandemic changes human behaviour in Istanbul. All data sources/sets can be freely accessed from the link provided in the references (Yilmaz et al., 2022) at https://doi.org/10.5522/04/19122179.

Weather data (temperature and rainfall) were retrieved from National Oceanic and Atmospheric Administration and Turkish Met Office (NOAA, 2021; TSMS, 2021a). Istanbul water consumption, reservoir level, and air quality and transport (traffic monitoring at Kadikoy) data were obtained from Istanbul Municipality (IBB, 2020b, 2020c, 2021). Population data in Turkey is published by the Turkish Statistical Institute each year (TURKSTAT, 2022). The National Hydrological Monitoring Programme publish Monthly Hydrological Summaries, including water reservoir levels across the UK. The UK water reservoir levels data has been obtained from monthly summaries in the Covid period (NRFA CEH, 2020).

Climate projection data (temperature, rainfall, and warm spell duration index) is presented on the World Bank's Climate Change Knowledge Portal (CCKP), including the Coupled Model Intercomparison Project (CMIP) Phase 5 and Phase 6 collections (which serve as a repository of model runs with consistent emission scenarios to standardise some of the output generated by diverse modelling groups. As the spatial scale of a global climate model's output is too large to characterise climate over small and specific areas, downscaling to a finer resolution is necessary. Thus, statistically downscaled climate variables over the studied region were downloaded from the World Bank's CCKP (CCKP, 2021).

2.4. Data Visualization and Analyses

Visual representation of data or information might make it easier to understand and identify any time-related changes in large data sets, so water consumption and reservoir data have been visualised as in **Figure 5**, **Figure 10** and **Figure 14**. For visualisation, we used Matplotlib, a Python plotting library generating and customising various types of plots, and Seaborn, a plotting package that builds on top of a Matplotlib library (Waskom, 2021).

3. Results

3.1. Main Case Study: Water Use and Resources in Istanbul

Water Use

Figure 5 shows that water use in Istanbul has varied month by month from 2000 to 2022. Water consumption in Istanbul has nearly doubled. It gradually increased since the 2000s (as shown by the shift from green to blue and darker blue) from an average of 1.6 million m^3/day to 3.1 million m^3/day. Water use was consistently higher in the summer. The overall increase in water use may be attributed to population increase, industrialisation, and rising standards of living and/or lifestyle choices (such as leisure uses) that go alongside increasing consumption levels in general. Additionally, **Figure 6** shows that over the 21 years of interest the population increased by about 40%, while water consumption rose by 70%.

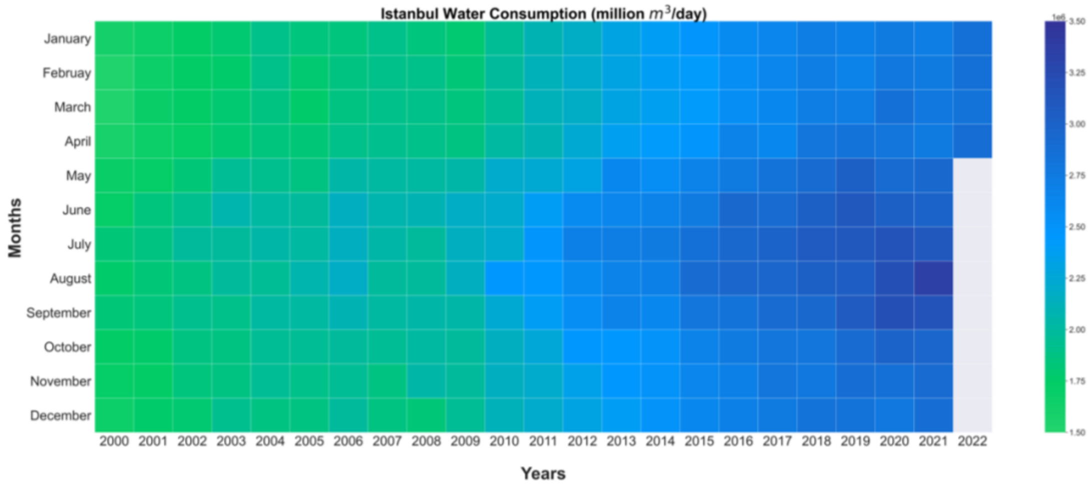

Figure 5. Monthly water consumption (million m^3/day) in Istanbul from January 2000 to April 2022.

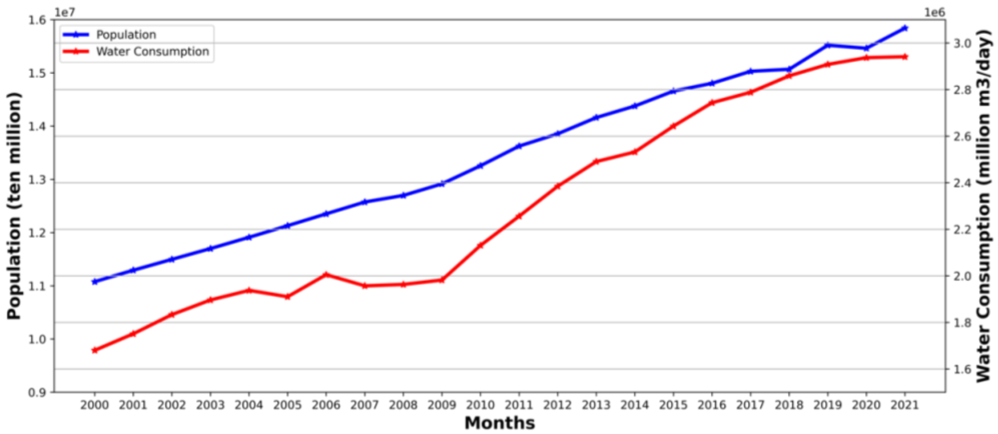

Figure 6. The comparison of population and water consumption in Istanbul from 2000 to 2021.

Although population and water consumption (**Figure 7**) 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 can be linked to low rainfall and drought periods in 2005 and 2007 (Unalan, 2011), with people and businesses adjusting their behaviour to reduce consumption following communications from governmental bodies and the media about water shortages.

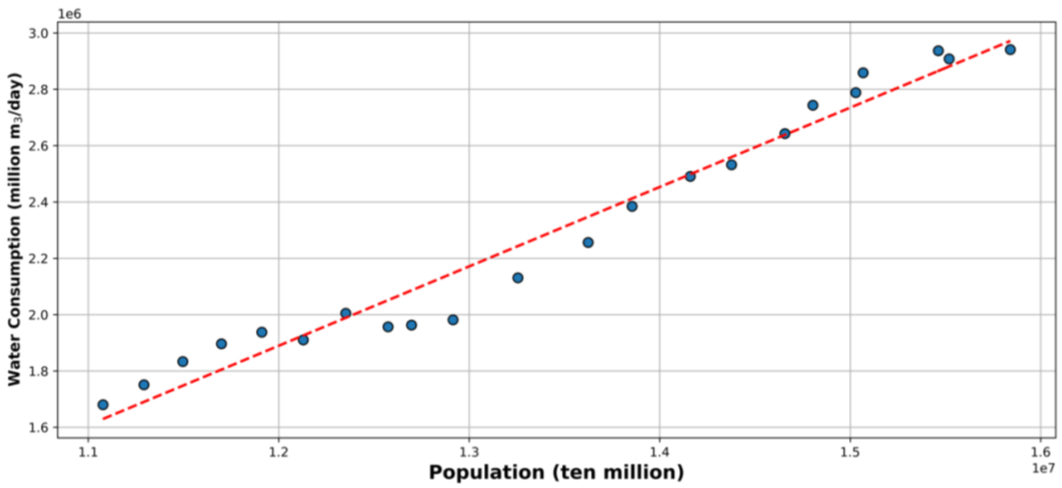

Figure 7. The relationship between population and water consumption (m^3/day) from 2000 to 2021 in Istanbul. *Overall, in this period, water consumption per head of population moved from about 150 litres/day to 190 litres/day, increasing by over 25%.*

Human Activities in the Istanbul Area During the Early Stages of the Covid 19 Pandemic

As has been recorded for many major cities (see Discussion), there were marked impacts on human activity in the early stages of the pandemic due to lockdown restrictions. Atmospheric chemistry (Annex) and transport data (Annex) for Istanbul indicate that there was less pollution and traffic movements in Istanbul in April and May 2020 and that altered levels of human activity were affecting these records due to temporary (Spring) migration out of and a return to Istanbul occurred during the Summer and later months of 2020. We might expect that these movements would affect water consumption in the Istanbul area and perhaps complicate the interpretation of changes in water consumption due to public health measures linked to Covid-19.

Data underpinning the visualisation in **Figure 5** show that in March 2020, when Covid-19 started to spread in Turkey, water consumption was higher than in March 2019 (from 2.73 million to 2.85 million m^3/day). This increase of about 120,000 cubic metres per day (or about 3%) could reflect additional water use due to the increased emphasis on hygiene measures such as hand washing or street disinfection (although it is uncertain if this later increase is included within the figures). This might appear to be a slight increase. However, in March and April, when the Turkish government decided to move to lockdown in big cities, including Istanbul, substantial numbers of people decided not to stay in a highly populated city and went to their hometowns or summer house. The movement of people seemed substantial for the Mayor of Bodrum, a coastal town in the Muğla area, stated '*Please do not come to Bodrum; Bodrum is full*'. Many vehicles 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 among the big cities in Turkey (NTV, 2020). These temporary internal migrations probably explain why consumption in Istanbul fell back in April by an average of 42,210 m^3/day.

From June, when Covid-19 cases started to decrease in Turkey as a whole, some people began returning to Istanbul, and water consumption gradually increased by 141,609 m^3/day to the end of the summer in August. Public health measures such as an increased emphasis on hand washing and the sanitisation of public spaces with water-based disinfectants (**Figure 8**) could all be expected to lead to increased water consumption.

Figure 8. Street disinfection photos from Turkey (Usak (left) and Istanbul (middle)), and Ethiopia (right) during the Covid-19 Pandemic (IBB, 2020a; 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 exceptional and extremely dry according to the Standardized Precipitation Index (SPI) from October to December 2020 (TSMS, 2021b), the municipality used lots of water and chemicals to clean its main streets.*

Monthly Water Use Per Head

Expressing the water use data in terms of consumption per head per day, as in **Figure 9** creates further insights, especially when the first Covid pandemic year of 2020 is compared to the same data for the three years preceding the pandemic (data from earlier years was not used to avoid complications linked to the rising water use rates in Istanbul).

Water use in 2020 (blue line) was higher than the average of 2017-2019 (black dashed line) for several months between March and October (an extra 2.56 litres per person per day was consumed across the year as a whole, assuming a constant population for Istanbul but we know this was not the case due to the scale of temporary migrations). A similar effect was found in other countries as well (see Discussion). In contrast, during the period people left Istanbul temporarily, water use was lower than the 2017-2019 average – for instance, in April, it was 2.73 litres per person per day lower than in March. 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 generally cause additional water usage, water consumption continued to climb above the three-year average right through until September, when, usually, consumption would have fallen back. This suggests that the Covid-19 pandemic placed an additional call on Istanbul's water resources (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 had 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, equivalent to approximately 150,000,000 litres per day or 150,000 cubic metres per day. An additional complexity of interpretation is that in the last three years, religious holidays (Islam) were in August and September). This might have an impact on water consumption as some people went to their hometown during the religious holiday.

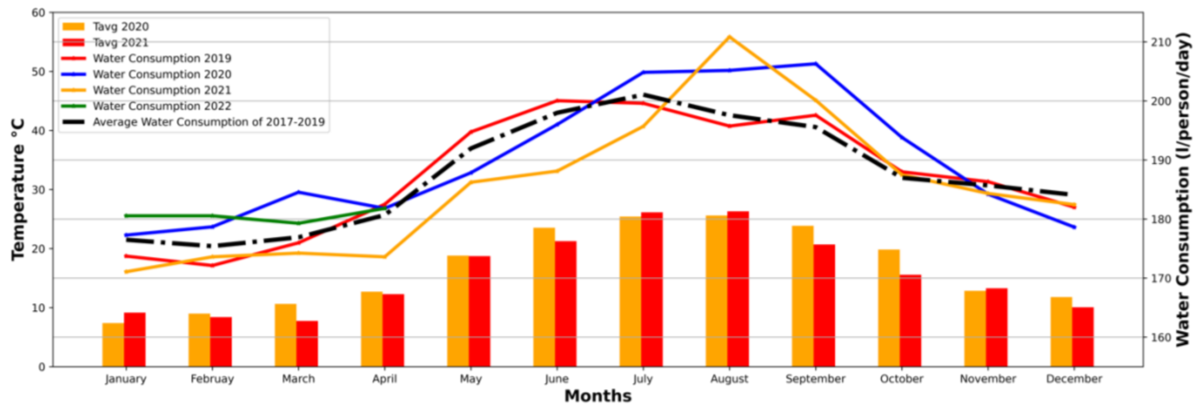

Figure 9. Water consumption (litres/person/day) and 2020/21 monthly temperature average in Istanbul. *During the pandemic period, daily water consumption per head was above both the average and range of consumption in the previous three years and did not fall back as temperatures fell as it had done 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

Yilmaz et al. (2020) provide information on the water resources of Istanbul, which are largely reservoir-based. Periodically, reservoir levels are low, suggesting that Istanbul is close to experiencing drought conditions should rainfall levels be lower than usual. Monthly water reservoir levels (as % of live capacity) from 2005 are given in **Figure 10**. 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 are shown clearly in the visualisation of **Figure 10**. 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, 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 12** and **Figure 13**). Within the data for our limited time period: a severe drought occurred in 2007/8, and no dissimilar conditions in 2014/15, and late 2019 and 2020 into perhaps 2021. **Figure 12** suggests that there may be a similar periodicity in periods where temperatures are anomalously high. This is also true for the rainfall patterns in Istanbul, and it is indicated that low reservoir levels occur when there is a lower rainfall.

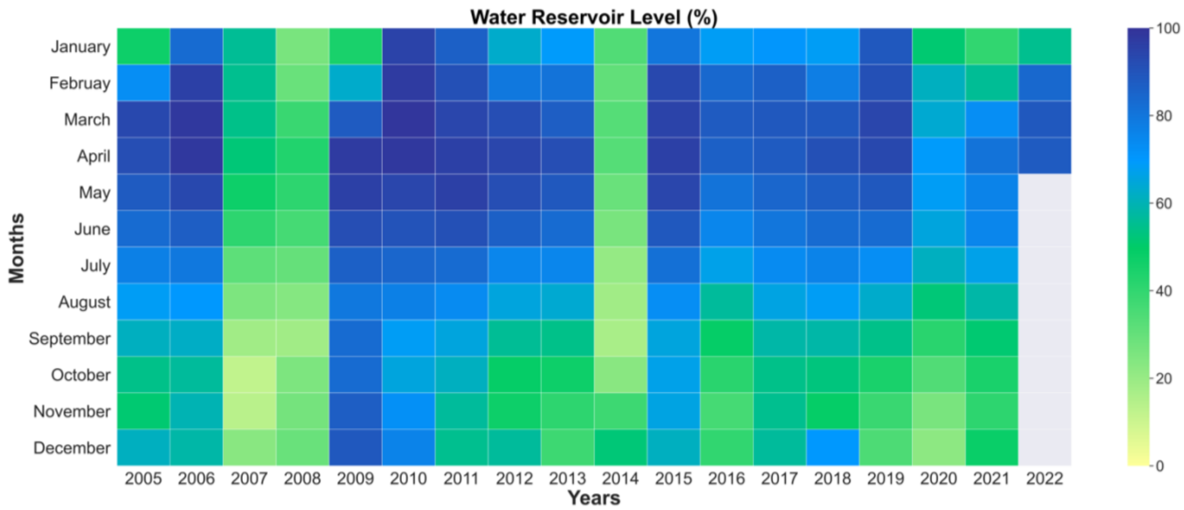

Figure 10. Monthly water reservoir levels (as % of capacity) in Istanbul

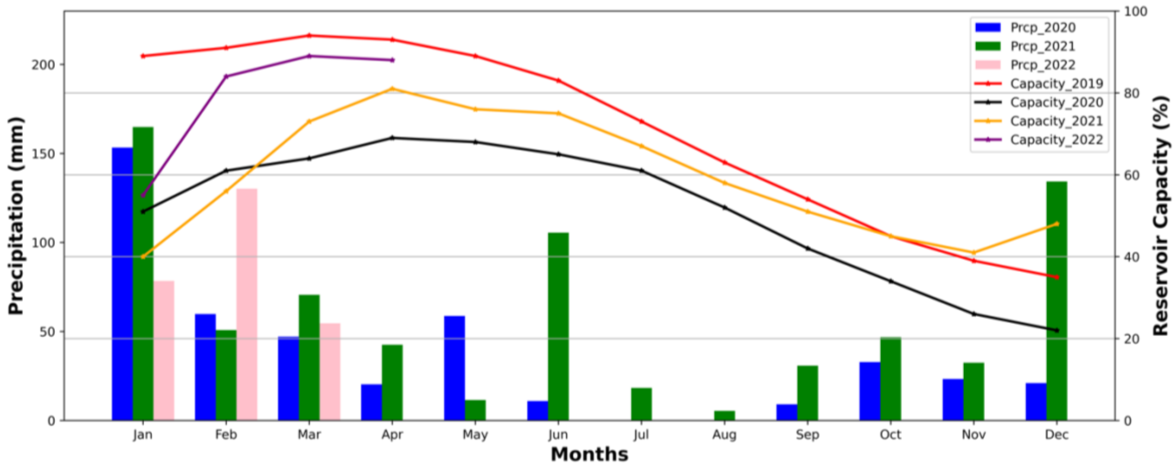

Figure 11. Comparison of water reservoirs' live capacity (%) and total monthly precipitation (mm) in Istanbul. *Live capacity in 2020 did not reach 2019 levels and was already close to the minimum level for 2019 (December) in August. Water resources were not replenished to 2019 levels in 2020 despite higher rainfall in early 2020 than in 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.*

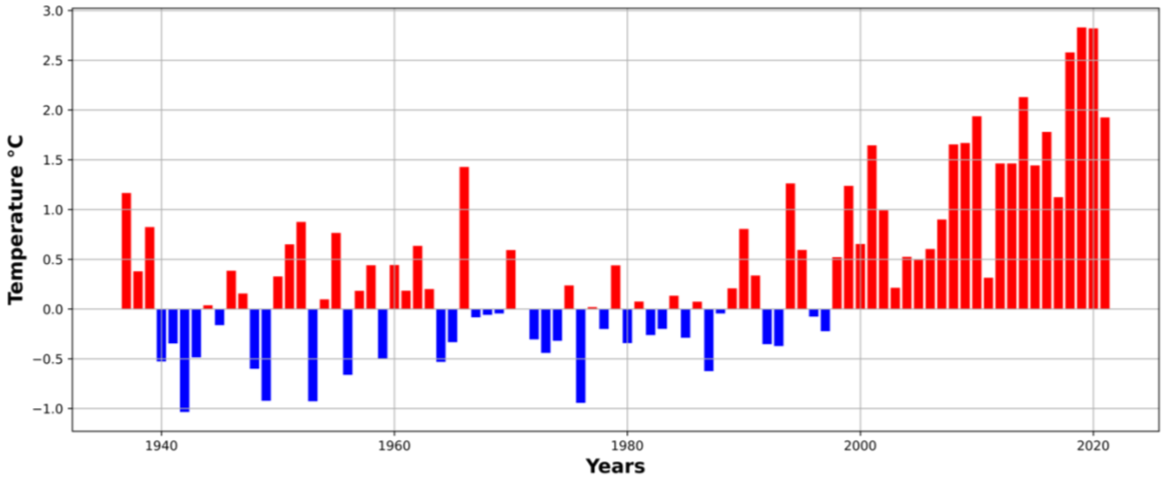

Figure 12. Istanbul temperature °C anomaly. *This figure plots the average temperature anomaly data from 1937 to 2021 relative to 1961 to 1990 values at the Florya Met Station, Istanbul. There is an increasing trend in the anomaly in Istanbul, especially after the 1990s. Since then, some of the relatively larger positive anomalies 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.*

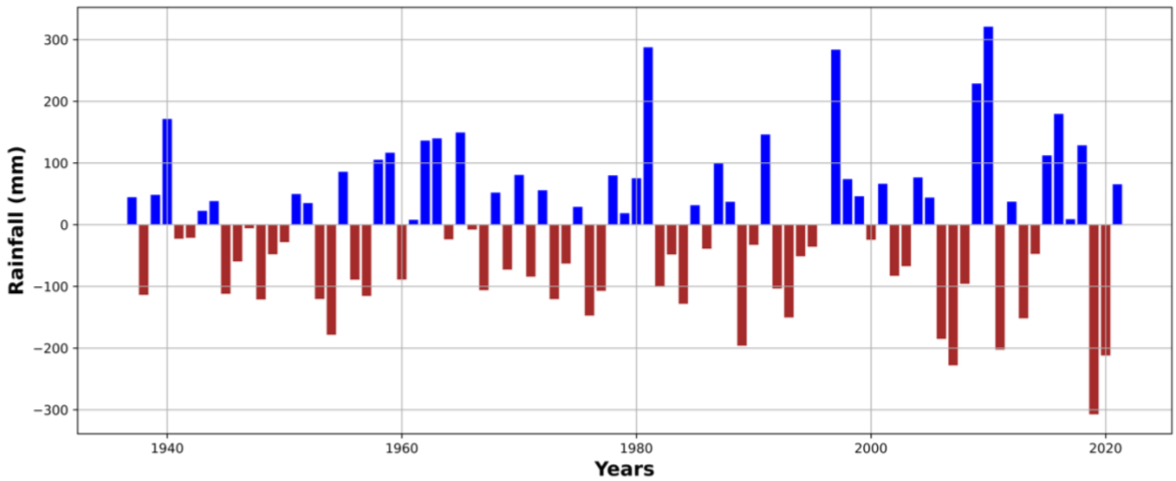

Figure 13. Istanbul rainfall (mm) anomaly. *This figure plots the total rainfall anomaly data from 1937 to 2021 relative to 1961 to 1990 values at the Florya Met Station, Istanbul. Since the 1970s, the rainfall anomaly has changed sign often. There may be some evidence of a cycle in rainfall anomalies as well (1990/1, 1994/5, 2001/2, 2007/8, 2014/5, 2019/20). This suggests that low reservoir levels occur when there is a lower rainfall.*

3.2. International Context to Observations from the Case Study in Istanbul

We wanted to establish whether the Istanbul situation was unique or rather similar to that found in other major cities or regions of countries, so we searched for comparative information in both academic publications and reports from companies and in the media.

Water use

Limited comparisons are possible between Istanbul and other countries at present due to a lack of data availability caused by the different ways water supply and resources are governed, managed, and monitored in different countries (for example, several different water companies deal with London and the south-east's water supply whereas in Turkey these matters are more centralised). These limited comparisons might be the result of culturally determined preferences, the initially adopted control paradigms and the associated strategies, and a high level of power distance and uncertainty avoidance (van der Voorn and de Jong, 2021).

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 particularly for factors that needed to be included in the DPSIR framework that was initially omitted and for confirmation that factors included in **Figure 4** were indeed of some importance. **Table 1** summarises the main findings of how countries have been affected by different phases of the pandemic with sources and main comments related to the final DPSIR framework in particular.

Table 1. Findings from International Context on water use and factors leading to or contributing to more challenging water management circumstances and factors linked to a revised DPSIR Framework.

Country	Reported changes in water use during the Covid-19 pandemic in 2020	Main Sources of information (academic, trade and media sources all used) and main comments relating to revision of DPSIR Framework taking both Covid-related and climate/weather influences into account
UK	• Decrease demand in central London • Increase in suburban areas • Overall raw water use was 25% higher across 10 water companies (effect due to pandemic perhaps 5% to 10% of total increase; rest due to high summer temperatures) • The highest level of demand for 31 years in Thames Valley area; 30-year peak in Severn Trent. • Thames Water: Recoded peak demand levels exceeding 1,000 million litres/day (over 150 million litres/day above norm) • The driest and hottest May 2020 on record in England • Northumbria Water: 29 litres extra/person/day • United Utilities 4.6bn extra litres water pumped in early part of pandemic • Some supply interruptions may have been partly due to increased domestic water demand in south-east England • At peak demand, South-East Water pumped about 150 million litres more than the daily norm.	• (Alda-Vidal *et al.*, 2020; BBC News, 2020a, 2020b; Goddard, 2020; Lee, 2020; Met Office, 2020; Rice, 2020; Smart Water Magazine, 2020; Smith, 2020; Thames Water, 2021; WWT, 2021; Water Resources South East, 2022; South East Water, 2022) • Changes in work pattern • Increase in water usage with a strong impact of high temperature compounded with Covid-related effects • Low/Lowest reservoir levels in some places could have been challenging if demand had been any higher. • Partnership working important in managing very high demand • Bowsers and bottled water to deal with interruptions in supply • More resilient infrastructure factoring in crises management as well as meeting demand from demographic trends, • Good public response to appeals to use less water (e.g.demand fell by 30 million litres/day in South-East Water area immediately after appeal).
USA	• Water use increased by up to 21% in some places • Delayed morning peak water consumption from 0700 to 0900 • Local water crisis driven by extreme weather	• (Poch *et al.*, 2020; TechRepublic, 2020; Merritt, 2021) • Increased in domestic water usage • Reduced commercial water use • Behavioural changes • Possible greater use of digital technologies needed
Brazil	• Shifted morning water consumption peaks from 0800 to 1000 • Decrease in commercial water use by over 30% • Increase in residual water use by 11%	• (Kalbusch *et al.*, 2020) • Behavioural/social factors • Changes in domestic and commercial water usage • Changes in morning routines

		• (ABB, 2020; EPDK, 2021)
Turkey	• Unbilled water consumption permitted to help manage pandemic • Higher and lower water demand likely linked to pandemic and associated temporary migrations	• Economic disruption for municipalities from falling revenue • Changes in water usage (both domestic and commercial) linked to pandemic and higher summer temperatures • Low reservoir levels could have been challenging if demand had been any higher.
Italy	• Complex shifts in water demand • Morning peak shifted from 0800 to 1000	• (Balacco *et al.*, 2020)
		• Behavioural and social factors important elements in both stochastic and deterministic aspects of complex shifts in demand
Germany	• 14.3% higher water consumption • Shift in water demand (i.e. later morning peak and higher evening peak)	• (Lüdtke *et al.*, 2021)
		• Increase water usage Behaviour changes

Reservoir 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 and a comparator for Istanbul.

Despite different weather patterns, there is evidence for a decline in reservoir-based water resources in both the UK (**Figure 14**) and Turkey (**Figure 5**) during 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.

In addition to the lowest reservoir levels in May 2020, **Figure 14** shows how Thames Water Reservoir Levels (%) in London changed 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 difference between the Istanbul and London areas is that London reservoir capacities rarely reach the low levels seen in those that serve Istanbul perhaps because London has the Thames catchment to call on as a freshwater resource.

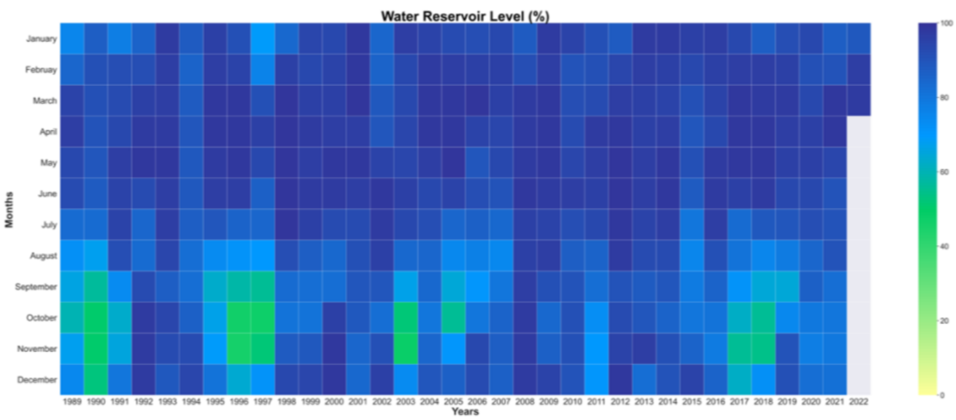

Figure 14. Monthly water reservoir levels (%) in Thames, London (Thames Water via Environment Agency, 2022)

3.3. Implications for future water consumption and resources under climate change

Projected temperature and rainfall

Given the evidence above in (**Figure 12** and **Figure 13**) that Istanbul may be subject to drought-like conditions relatively frequently, we examined four climate change emission scenarios to scope for the DPSIR Framework, whether such events might become more frequent or more intense in future. We chose RCP 2.6 as a low emission scenario (one where the Paris Agreement was met), RCP 4.5 as an intermediate emission scenario, RCP6.0 as a stabilising emission scenario, and the higher RCP 8.5 scenario if Paris were not successful at reducing global emissions. We define four different periods (2020-2039, 2040-2059, 2060-2079, and 2080-2099). In order to look at the specific location of Istanbul, the outcomes of CIMP5/6 ensemble model for RCP 2.6, RCP 4.5, RCP6.0, 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 policymakers and government agencies can get ready access to and might use for planning adaptations to climate change. The reference period here is 1986 – 2005. Shaded areas show the 10-90th percentile range of ensemble model outputs. Compared to the reference period (1986-2005), projected temperature and rainfall patterns have been shown in UCL Research Data Respiratory (Yilmaz et al, 2022).

Temperature

Under the low emission scenario (RCP2.6), 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, For the period 2040-2059; between 1 and 2.5°C per month increase is expected for all the months, with potential increase up to 3.5°C, in August. For the period 2060-2079; between 1 and 2.5°C per month increase is expected for all the months, with potential increase up to 3.7°C, in August. For the period 2080-2099; between 1 and 2.5°C per month increase is expected for all the months, with potential increase up to 3.6°C, in August.

Under the intermediate emission scenario (RCP4.5), for the period 2020-2039; between 1 and 2°C per month increase is expected for all the months, with potential increase up to 3.5°C, in July, For the period 2040-2059; between 1 and 3°C per month increase is expected for all the months, with potential increase up to 4.2°C, in July. For the period 2060-2079; between 1.5 and 3.5°C per month increase is expected for all the months, with potential increase up to 5.1°C, in July. For the period 2080-2099; between 2 and 4°C per month increase is expected for all the months, with potential increase up to 5.5°C, in July.

Under the stabilising emission scenario (RCP6.0), for the period 2020-2039; between 0.5 and 1.5°C per month increase is expected for all the months, with potential increase up to 2.7°C, in August, For the period 2040-2059; between 1 and 2°C per month increase is expected for all the months, with potential increase up to 3.5°C, in August. For the period 2060-2079; between 1.8 and 3.8°C per month increase is expected for all the months, with potential increase up to 4.8°C, in August. For the period 2080-2099; between 2.5 and 4.2°C per month increase is expected for all the months, with potential increase up to 5.3°C, in August.

Under the high emission scenario (RCP8.5), for the period 2020-2039; between 1 and 2°C per month increase is expected for all the months, with potential increase up to 4.2°C, in July, For the period 2040-2059; between 2 and 3.5°C per month increase is expected for all the months, with potential increase up to 5.4°C, in July. For the period 2060-2079; between 3 and 4.5°C per month increase is expected for all the months, with potential increase up to 7°C, in July. For the period 2080-2099; between 4 and 6°C per month increase is expected for all the months, with potential increase up to 9.2°C, in July.

Rainfall

Under the low emission scenario (RCP2.6), and the intermediate emission scenario (RCP4.5), and the stabilising emission scenario (RCP6.0), rainfall seems to be same as the baseline values in all months with potential changes up to ± 30 mm (2020-2039), ± 40 mm (2040-2059), ± 40 mm (2060-2079), and ± 35 mm (2080-2099) per month during winter months.

Under the high emission scenario (RCP8.5), rainfall is lower than the baseline values (-10mm) in all months with significant changes up to - 35 mm (2020-2039), - 35 mm (2040-2059), - 40 mm (2060-2079), and - 45 mm (2080-2099) per month especially during winter months.

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

The Warm Spell Duration Index (WSDI) is defined as the count of days with at least six consecutive days when daily Tmax > 90th percentile of the reference period (1986-2005) (CCKP, 2018). **Figure 15** shows historical Turkey WSDI for 1986-2005 and projected WSDI by 2060 under four emission scenarios. Even in a low emission scenario (RCP2.6), warmer periods seem likely to last about nine 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.

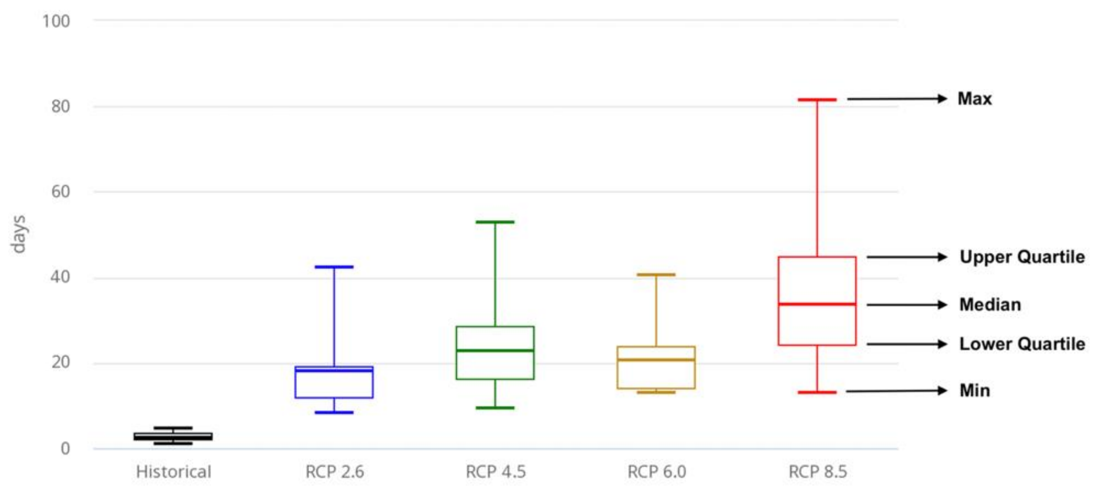

Figure 15. Warm Spell Duration Index in Turkey for the period 2040-2059, the only time period available in (CCKP, 2021), for the reference period 1986-2005.

4. Discussion

With the findings from case studies (Istanbul and London Area), it is worth discussing and looking at how other countries are affected by the Covid-19 Pandemic in terms of water demand and consumption. Combinations of pressures from climate change and pandemics from different examples (see further sections) will also help us to expand our initial DPSIR model.

Strategic and emergent issues

Although only limited comparison can be made between regions, countries and local areas as the Covid-19 pandemic is still playing out in many places, some strategic and emergent issues can be identified that might be relevant to improving the future resilience and adaptability of water systems facing hazards like pandemics and climate change. In trying to gain insights into the strategic and emergent a range of socio-ecological, socio-economic, socio-technical, and governance issues needing to be borne in mind account needs to be taken of differences between countries and local areas in terms of their characteristic approaches to hazards, risks and emergencies and that they may vary in their capacities and approaches to adaptation in different but related environmental and epidemiological situations (see van der Voorn and de Jong, 2021 for insightful discussion of these matters). By the way of example, if Turkey and the UK are compared then it can be argued that similar impacts occurred on water systems despite differences in strategic approaches (say, with respect to governance of water supply). As more information emerges about water use and water resources in the pandemic period a more complete set of strategic and emergent issues will emerge.

Strategic issues

Thus, in the UK, by May 2020, the pandemic was already impacting many areas of life because of public health restrictions. As impacts on the water system were already being recognised at a high level, Water UK (representing the UK water companies) and Ofwat (the water regulator) decided to work collaboratively and an early report (Frontier Economics, 2020) found many actual and potential impacts on water companies, including: unpaid bills and other consequences of raised unemployment rates, lower company income due to tariffs reductions for those many customers with reduced levels of activity, more household consumption, and less -non-household consumption. Similar issues arose in Turkey even though, below the national level, responses were less strategic in some senses with individual municipalities taking different approaches to, for example, whether or not to bill customers for using utility services for a three-month period from March 2020 when employment and thus earnings were affected by public health restrictions. (e.g. ABB, 2020; EPDK, 2021). This led to unbilled consumption and lower revenue for the municipalities. It also inadvertently complicated understanding of patterns of water consumption in some places in Turkey in a way that has yet to be fully resolved (see also **Table 1** for key information in relation to several countries).

Despite the importance of water in all aspects of life and its additional importance during almost all serious disease outbreaks it is noteworthy that 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 ones and water had only limited interventions. Those that did exist in some countries predominately consisted of short-term measures to ensure uninterrupted water supply and to cushion the impact of the loss of income. The findings in this study suggest a more complete view of the water system in managing emergencies with public health and environmental elements is needed.

Concerns about the impact of Covid-19 on water consumption in many other parts of the world are emerging. For instance, Sivakumar (2021) argues that efforts to control the spread of COVID-19 will likely increase the water demand and worsen water quality, leading to additional water planning and management challenges and an urgent need for issues to be addressed. For Sub-Saharan Africa (SSA), Anim and Ofori-Asenso, (2020) suggest that a wide range of different approaches were thought necessary. These were made more important by rapid population growth and the impact of climate change which would increase drought risk. Solutions might include: (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. An approach based around ecosystem services and community engagement has worked in the case of New York, USA (Salzman, Thompson and Daily, 2001; Appleton, 2002; Barbier and Heal, 2006; Poch *et al.*, 2020).

Emergent Water Issues

In the course of the study a number of emergent issues were uncovered ranging across of social, economic, and environmental fields.

<u>Disinfecting public buildings and spaces:</u> Issues are also emerging in terms of water use in the public domain of urban areas. For example, as evidenced in **Figure 8**, a lot of water has been used for disinfecting public spaces. Many kinds of cleaning, disinfecting and bleaching agents were probably used 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 the soil, water, and air to form a range of compounds some of which might be chlorinated. Other

materials, such as detergents, can have toxic effects on aquatic systems if they enter these systems at high enough concentrations. So, 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, accumulate in the food chain and eventually impact humans. Not all water used for disinfection 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 impact 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 significantly impact treatment plants. More evidence is needed on these emergent issues linked to public health measures taken in the public realm of many urban areas.

Increased sewage system blockages: As people stayed home more, increased flushing of inappropriate articles through the domestic toilet systems has 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 was thought linked to lockdown restrictions (Mann, 2020). Media messages to only allow permitted materials into the sewage system accompanied such images.

Economic impacts on water companies: Increased costs of sewer blockages (costing about £3M) were only one of the economic impacts of the pandemic on Thames Water. As people lost their jobs and experienced financial difficulties, they were advised to contact their water companies for help with deferring their water and sewerage payments. This led to bills going unpaid. There were also increased costs of running water infrastructure as a result of changes in the pattern and size of the demand. Thames Water 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, were 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 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.

A wider view of water and water efficiency: 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).

There are some global issues as well as local and regional emergent issues. For example, by disrupting economies and causing thousands of deaths globally, the Covid-19 pandemic has likely had a serious impact on progress toward the Sustainable Development Goals (SDGs) and further compromised the

2030 targets. Some argue it is important to introduce further cost-effective and innovative policies for achieving those SDGs (Barbier and 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 may be high in areas where sewage is untreated (Bhowmick *et al.*, 2020). Interestingly, water systems can also be part of the early warning systems for Covid-19 (or other types of pandemics or diseases). 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, 2022), can compound the pressure on water usage and availability that are already under pressure from climate change in some parts of the world.

<u>Local climate:</u> A similarity between Istanbul and the London South-East England area is that both regions are likely to experience higher temperatures and more periods of dry weather under climate change scenarios (UKCCRA, 2017, 2021a; Lowe *et al.*, 2019). 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 for the UK – that is, supply equivalent to that for between 8.3 and 19.7 million people (UKCCRA, 2021b). Actions is in hand to address the climate issues (South East Water, 2022; Water Resources South East, 2022) but issues linked to the pandemic may need to feature more explicitly than they do at present. Economic growth in south-east England together with rapid demographic changes driven in part by housing-led regeneration are adding to water quantity and quality issues with a pause on development in place during 2022 that will have long term impacts on a range of social issues.

<u>Water resources - reservoirs:</u> For a range of reasons reservoir levels in various countries were at low levels during the pandemic; this was certainly so in parts of Turkey and parts of the UK as this study indicates. We have not examined aquifer data as that is not a major factor relevant to the main case study area of Istanbul. Additional consideration of the operational margin needed to maintain a viable live capacity may be necessary given pandemic experiences and upcoming climate change impacts on precipitation patterns. New reservoirs are proposed for south-east England (South East Water, 2022; Water Resources South East, 2022) which allow for climate change but perhaps not a future pandemic whose control measures extend into hot weather periods when demand for water increases, especially if this occurred in a period of drought.

<u>Reducing risks with better data flows and analysis:</u> The substantial changes in raw water use during the pandemic and the pressure on such compound risks to water systems presented by climate change and other socio-economic events such as the current pandemic suggest that much greater use of digital technologies may be necessary for use in a reimagined water infrastructure system (Poch *et al.*, 2020).

With all these discoveries and examples, we have improved our initial DPSIR framework by adding more specific elements and renamed it the "Enhanced DPSIR Framework" (**Figure 16**). Our final DPSIR framework contains significant behavioural changes (shifts in water consumption peaks), numerous economic disruptions (due to not reading metres or loss of money), and the need for additional research on environmental degradation, particularly near water resources (in case of polluting the resources).

5. 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 southeast England). Table 2 summarises from this evidence how the pandemic had impacts on the water system of Istanbul, the wider London area and other countries and localities. 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 and perhaps also in gardens and other leisure uses (e.g. children's paddling pools) 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 tentatively identified that with a period of about 6/7 years reservoir levels in both the London and Istanbul areas are relatively low suggesting perhaps that the resilience of water systems may be at some risk from climate change given the possible association between increased water use and hot weather, especially if near-drought conditions occurred at the same time as a pandemic.

Table 2. Different factors related to the pandemic and weather/climate change and their possible impacts on water dynamics and the 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 4** has been modified to set out 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 London and the southeast. The modified diagram is **Figure 16**, 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 take 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 managing water resources and supply in future. This study suggests that the factors involved may be the same for different localities but need to be given different weights to account for differing environmental, social, and economic circumstances.

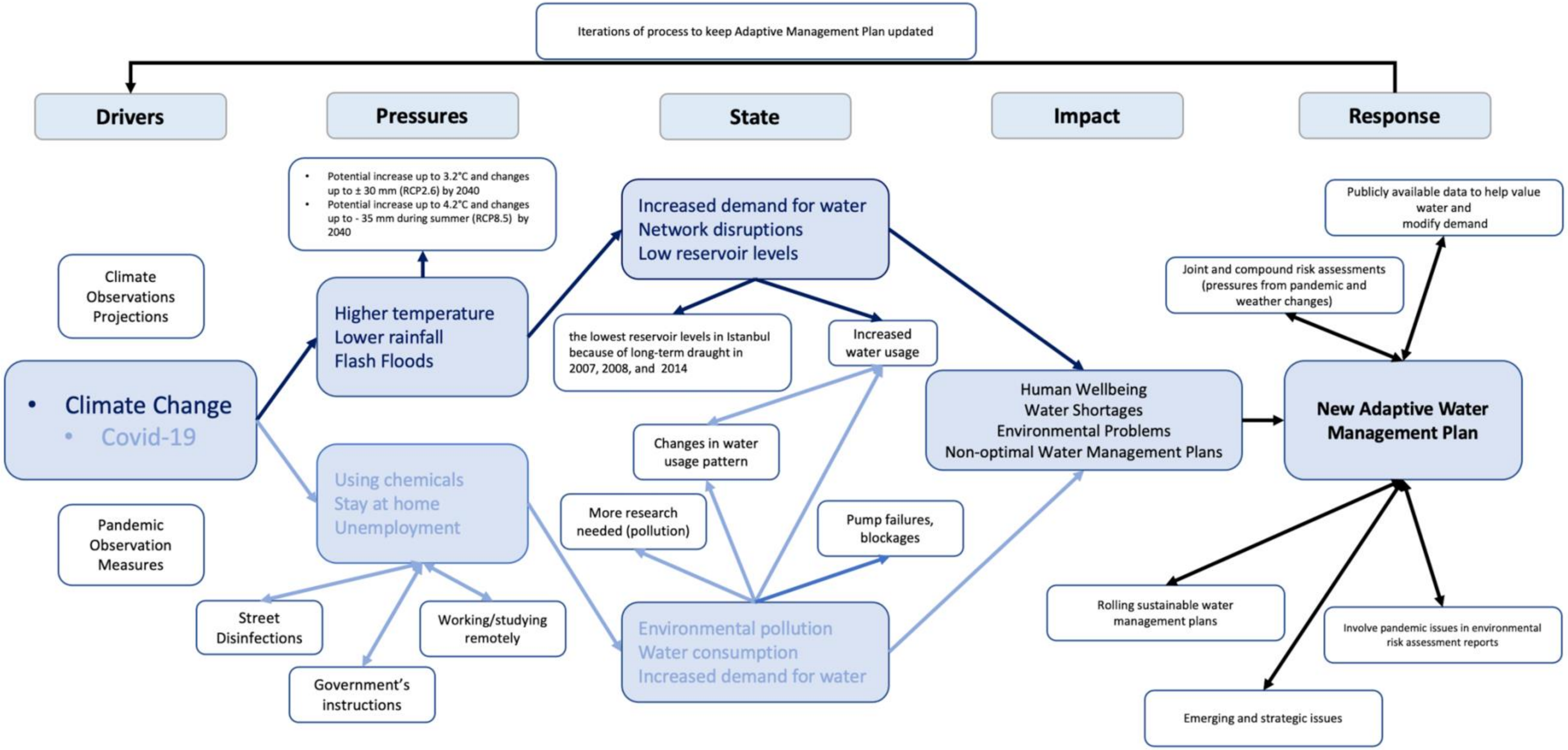

Figure 16. Enhanced DPSIR Framework

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Declarations and conflict of interest

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

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Annex

Human activity in the Istanbul area during the early stages of the Covid 19 pandemic

In order to get some separate evidence (other than that on water resources and consumption) 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 PM10, SO2, and CO are good evidence of these changes (IBB, 2020c). Annex – I (Yilmaz, Osborn and Tsamados, 2022) 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 in late March when national restrictions (working remotely, closing restaurants, and full lockdowns) were announced and applied. This indicates less commercial activity overall.

In addition to air quality parameters, **Figure 17** shows how monthly sensor-based numbers of vehicles at Kadikoy, Istanbul Station, have changed since 2016. The station (near Optimum Shopping Centre) is located on the main road, one of the connections from Asia to Europe through the Eurasia Tunnel. As the road is actively and intensively used during the day, it could be the indicator of how Covid-19 restrictions affected transportation in Istanbul. It is evident that there is a sharp decrease in April and May 2020, when the national restrictions (working remotely, closing restaurants, and full lockdowns) were announced.

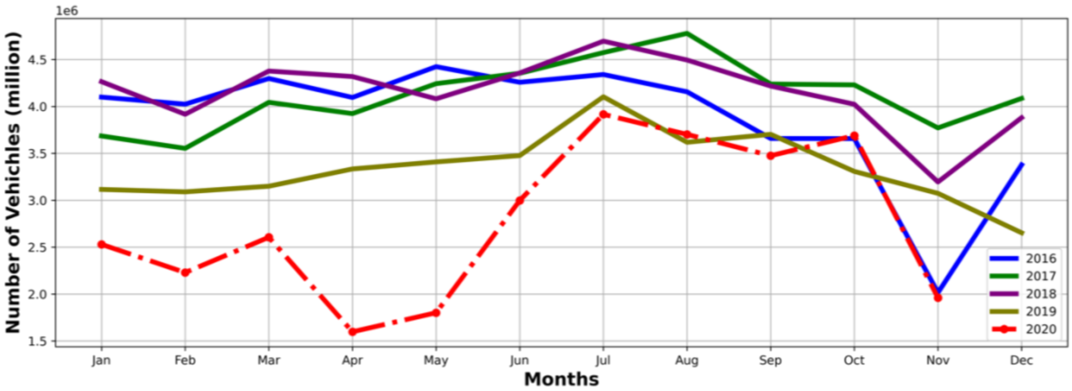

Figure 17. Monthly total number of vehicles at Kadikoy, Istanbul station (IBB, 2021). *It is clear that the total number of vehicles measured on one of the main roads in Istanbul decreased after many governmental restrictions (e.g., fully lockdowns) were applied from early April 2020. This suggests that traffic was less during the pandemic even if people may be ordering products and services online, delivery movements increased. It does affect the total number of vehicles in an increasing way during the first pandemic period. The effect persists throughout the pandemic period matching only the lower values for previous years in Autumn 2020.*

Data from English reservoirs

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 eight shown in **Figure 18** that recorded record low values. In the area of Thames, Southern, Wessex, and South West, most 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). With the general increased demand for water during the Covid-19 pandemic, most reservoirs in the UK, especially eight, faced their lowest levels on record in May 2020 (**Figure 18**). Most reservoirs in the UK also showed a remarkable decrease in reservoir levels (NRFA CEH, 2020).

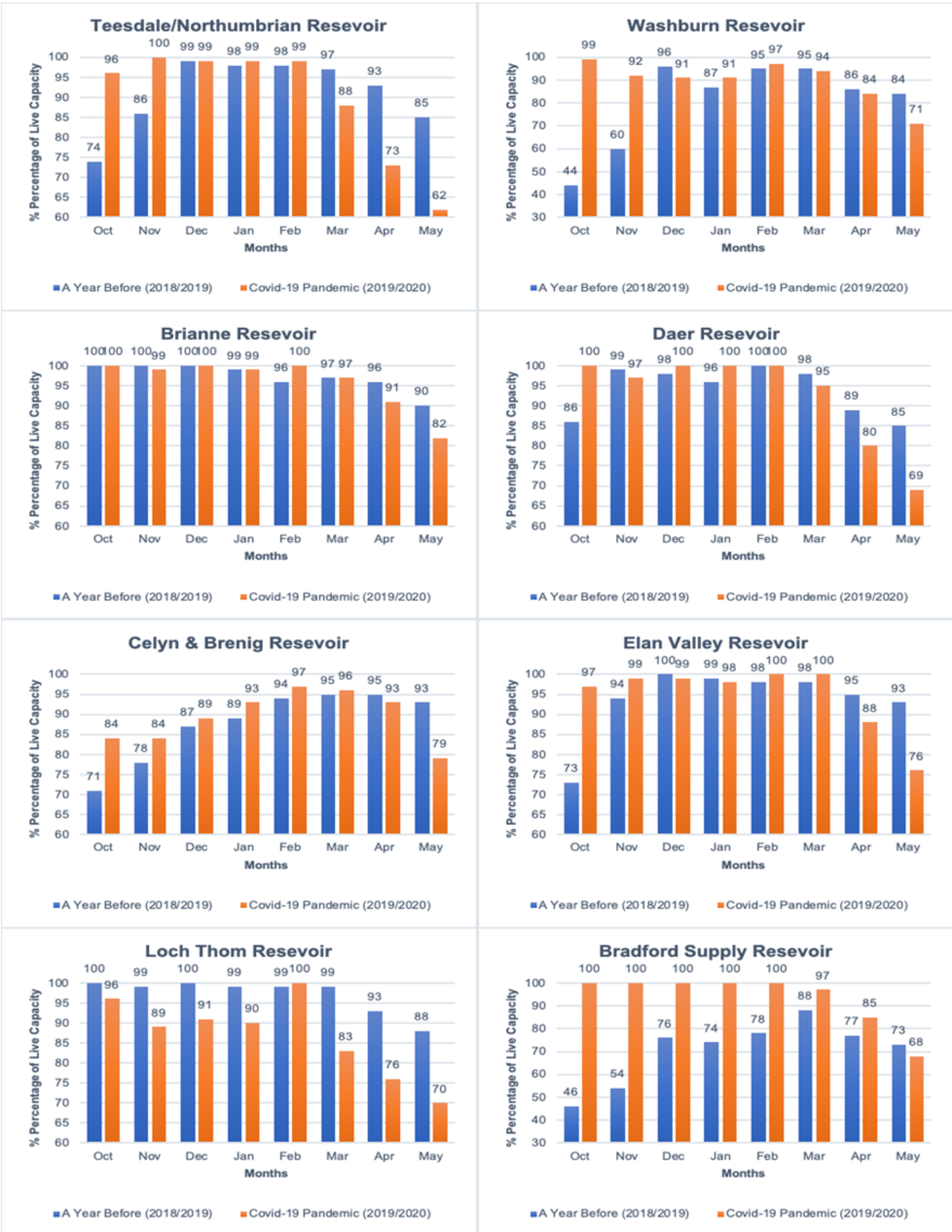

Figure 18. Capacity of the UK reservoirs where the min of May value has been observed in May 2020 (NRFA CEH, 2020)