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The Impact of COVID-19 on Urban Water Consumption in the United States

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Abstract: The COVID-19 pandemic has changed how we define "home", which is recast as the new coffee shop, restaurant, entertainment center, and office during the pandemic. The shift toward working from home led to substantial changes in how consumers behave, affecting the consumption of resources in some cases for years to come. Using data from six water utilities in various states in the U.S., we investigated how water consumption has changed attributable to the implementation of stay-at-home (SAH) orders. The results indicated an overall increase of between 3.08% and 13.65% in daily water consumption during the SAH orders compared to the same period in 2018 and 2019, with the gaps closing as lockdown restrictions eased. The findings also revealed that the changes in water consumption across sectors and user groups were heterogeneous. Specifically, the results showed that total daily residential water demand during SAH orders in 2020 increased significantly, between 11.80% and 13.65%, relative to the same period in 2018 and 2019, but the changes in water consumption for non-residential properties headed in opposite directions with reductions between −22.53% and −45.08%. In addition, we found that the low-income groups did not change their water consumption even with the lockdown.

Keywords: COVID-19; urban water; United States

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Citation: Nemati, M.; Tran, D. The Impact of COVID-19 on Urban Water Consumption in the United States. *Water* **2022**, *14*, 3096. https://doi.org/10.3390/w14193096

Academic Editor: Robert Sitzenfrei

Received: 20 July 2022
Accepted: 29 September 2022
Published: 1 October 2022

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1. Introduction and Background

A central strategy for responding to the COVID-19 pandemic is "locking down" parts of the economy to slow contagious transmission, thus allowing the medical system to cope with the influx of infected people. On 21 January 2020, the U.S. Centers for Disease Control and Prevention (CDC) confirmed the first COVID-19 case in the U.S. On 19 March 2020, California became the first U.S. state to issue a stay-at-home (SAH) order. Many other U.S. states quickly followed in issuing the orders. The country shifted to embrace working from home. This unprecedented situation led to significant changes in consumer behavior, affecting the consumption of resources (e.g., energy, water, and food, and materials) [1–3]. Water, sanitation, and hygiene (WASH) practices were essential during the early phase of the pandemic. People were urged to use WASH practices more frequently [4], and some even went as far as encouraging people to wash packages and groceries [5]. This followed the existing literature, highlighting the important role of WASH practices in controlling previous contagious diseases, such as Ebola and SARS [6,7]. The increased use of WASH practices likely led to increased water consumption during the pandemic relative to the same period before the pandemic. At the same time, many low-income U.S. households continued to live with tight budgets, which might have affected their consumption behavior, particularly in the face of increasing food prices due to supply chain issues. This study's first key research question is the extent to which the SAH orders affected water consumption. The second was whether there were asymmetric pandemic responses regarding water consumption across users and sectors.

Several studies investigating the impact of the COVID-19 pandemic restrictions have been carried out on portable water demand worldwide. Bich-Ngoc and Teller [8] and

Changklom et al. [9] used a cascade model by dividing predictors into four groups (i.e., trend, holiday, weather, and calendar) to study the impacts of the COVID-19 pandemic restrictions on water demand in tourist cities (i.e., Liège, Belgium and Phuket, Thailand), respectively. Balacco et al. [10] studied the effect of restriction measures due to the COVID-19 spread on water demand in Puglia, Italy. The authors concluded that lifestyle changes were the main factor that shifted the peak demand during the lockdown. Kalbusch et al. [11] studied the changes in water demand during the restrictions in Joinville, Brazil, and concluded that water consumption during the restrictive movement period was lower than that in the pre-pandemic period. Dzimińska et al. [12] used a k-means clustering approach to evaluate the impacts of the pandemic on daily water demand patterns. The authors concluded that water consumption during the day and night, between 2:00 and 4:00 a.m. during the pandemic, increased relative to the same period before the pandemic. Similarly, Di Mauro et al. [13] studied how the change in social and economic factors during the pandemic affected residential water consumption in the city of Naples, Italy, by calculating consumption statistics, hourly consumption patterns, and the frequency of daily and weekly use before and during the lockdown. The authors revealed that the COVID-19 sanitary emergency significantly changed the residential water consumption pattern. Lüdtke et al. [14] used a linear mixed model to study the residential water consumption in Wasserbeschaffungsverband WBV Harburg, Northern Germany, from 1 January 2006, until 28 June 2020. The authors concluded that the increase in residential daily water consumption during the COVID-19 pandemic was 14.3%, and the increases were higher during the morning and evening demand peaks. Shrestha et al. [15] reported an increase in residential water consumption and a decrease in commercial water consumption during the nationwide lockdown in Nepal from March through April 2020. Likewise, Abu-Bakar et al. [16] examined water consumption data from 11,528 households in England to study the changes in water consumption during the lockdown relative to the pre-lockdown period. The authors concluded that lockdown led to higher water consumption—average household consumption increased by some 46% compared with the pre-lockdown average. Rizvi et al. [17] analyzed the combined effects of Ramadan and the COVID-19 crisis in Dubai and showed that water consumption increased by 30% during Ramadan and the COVID-19 crisis. A study in Antalya City of Turkey found a considerable decrease (42%) in the total flow rates at public places because of the lockdown measures [18].

Several attempts have been made to better understand water consumption during the pandemic in the U.S. Nemati [19] is likely the first researcher to empirically analyze the changes in water consumption during the lockdown in California, U.S. The author used large-scale micro water consumption data from a water utility in Northern California, U.S., and concluded that residential water consumption increased. However, non-residential water consumption decreased during the lockdown. The study of the structural behavior of water consumption during the SAH orders in the U.S. was likely first carried out by Irwin, McCoy, and McDonough [2]. This study is likely the closest study to ours. Irwin, McCoy, and McDonough [2] used the daily water consumption data to analyze the changes in water consumption from the SAH order for a utility in Henderson, Nevada, U.S. The authors found an opposite trend in water consumption for residential and non-residential users. Their findings showed an initial and continuous decline in average daily water consumption for commercial and school users, but the water consumption for residential users rose in the same period. These changes led to an increase in total water consumption because residential water consumption accounted for a large proportion of total water usage in this water utility.

Overall, evidence indicates that water consumption patterns during the pandemic changed considerably. However, most previous studies only focused on the changes in a single location. Simply estimating the change in water consumption from a water utility potentially ignores important differences in the socioeconomic context and the characteristics of the SAH orders, depending on the state of the pandemic evolution and other factors. Water consumption varies from user to user, community to community, and utility to utility [20,21]. Thus, estimating the change in water consumption from a water utility only can mischaracterize the changes in the water consumption patterns after SAH orders. Therefore, this study set out to assess the changes in water consumption subsequent to SAH orders and the heterogeneity of the water consumption across six major water utilities in five U.S. states. Herein, we estimated changes in water consumption during the SAH orders relative to pre-pandemic periods for the six utilities. We are likely the first to consider the effect of SAH orders on water consumption across the U.S. Thus, compared to Irwin, McCoy, and McDonough [2], our study provides a more complete picture of the effect of SAH orders on water consumption. In addition, our study is the first to analyze the heterogeneity of water consumption not only across the utilities but also within the utilities. We expected that the consumption of resources such as water would change during the SAH orders. Still, previous studies have not provided important differences in the socioeconomic context and the characteristics of the SAH orders, depending on the state of the pandemic evolution and other factors that would affect water consumption.

We exploited the rich data set of micro-level daily water consumption for six water utilities before and after the SAH orders in 2020 to estimate the changes in water consumption during SAH orders relative to the same periods in previous years (i.e., 2018 and 2019). Our strategy for this study was to use a mixed methodology based on graphical and regression-based approaches. We first used graphical analyses to investigate the changes in daily and monthly water consumption (gallons per day) by sector from January to the end of May 2020. We compared it to the average in the same time frame in 2018 and 2019. We then used household-specific and fixed time (i.e., day, week, month, and year) effects models to control for household or temporal drivers of water consumption. We also controlled the weather variations (minimum and maximum temperature and precipitation).

Our results suggested that residential water consumption rose significantly. However, water consumption for commercial, industrial, and institutional (CII) and schools (SC) fell sharply after the SAH orders, then rebounded but was still lower than the pre-pandemic level. The total water consumption in these utilities rose because the increased total residential water consumption was much more than that of decreased total non-residential water consumption. Despite the findings showing substantial changes in daily water consumption for all sectors, our results showed that the daily water consumption for the low-income water group remained unchanged.

This work contributed to existing knowledge of the changes in water consumption following the implementation of the SAH orders in the U.S. during the COVID-19 pandemic. Our results provided further support for the hypothesis that consumer behavior changed during the pandemic. The results showed that water consumption patterns across all sectors changed dramatically after the SAH orders were enacted. Our second contribution to this study is related to the heterogeneity of water consumption across the water users and sectors during the pandemic. The water consumption for residential properties increased while the consumption for non-residential properties decreased during the SAH orders. Our results showed that despite the unprecedented time, water consumption for low-income users did not change. As remote work becomes increasingly common, policymakers might need to renew water management policies to protect and enhance the sustainability and resilience of water supply infrastructure. The results also have important implications for developing water conservation policies, especially among low-income water users, who are not as water price sensitive even during a crisis. This implies that most of the increase in water consumption in the six utilities considered is attributable to more affluent, middle- and high-income residential users.

2. Materials and Methods

The basic method used to attain the above objective involved fixed-effects models. Here, we provide a summary of the study areas and data used, followed by a description of the empirical implementation.

2.1. Study Area and Data

Water use and household characteristics data utilized in this analysis come from 2018–2020 at the customer level for water utilities across the United States serving Northern California (A), Southern California (B), Florida (C), Massachusetts (D), Montana (E), and Texas (F). Utilities A, B, C, and E are equipped with advanced metering infrastructure (AMI), also known as smart meters, which provide water usage data at the daily level. Our climate data came from the PRISM Climate Group [22].

Water-use data from utility A include water use from commercial, industrial, and institutional (CII), schools (SC), single-family residential (SFR), and multi-family residential (MFR) sectors. Utility B is in Southern California and serves mainly vacation homes; we only observed data for the SFR sector. Utility C is a Florida city known for its beaches and tourism. We also have daily water-use data from CII, SFR, and MFR sectors for this utility. Utility D is in a small town in Massachusetts, where we observed usage for the SFR sector at the monthly level. For this utility, we also have information on the low-income rate program for the households, which provided us with a unique opportunity to estimate how water use changed in low-income households. Utility E is in Southern Montana, and we observe daily water use for all three sectors (CII, SFR, and MFR). In addition, like with utility D, we noted whether a household was on a low-income rate assistance program. Finally, data from utility F came from a large agency in Texas and included monthly data from the SFR sector.

2.2. Empirical Strategy

This rich data set of micro-level daily water consumption also allowed us to include various fixed-effects models. Specifically, in our specification, we estimated the following equation:

$$\log\left(q_{\,iymd}\right) = \alpha_i + \beta D_{iymd} + \gamma_i + \mu_m + \theta_w + \delta_d + \vartheta W_{ymd} + \varepsilon_{iymd} \quad (1)$$

In Equation (1), the outcome of interest is the log of water consumption for consumer i in year y, month m, and day of the week d, $\log\left(q_{\,iymd}\right)$. α_i is the intercept. The variable of interest is D_{iymd} which is a vector containing dummies for the day of the week after the lockdown and seven weeks before the lockdown, and β is its parameters to be estimated; γ_i indicates consumer fixed effects; μ_m indicates the calendar month fixed effects; θ_w indicates the week of the year fixed effects; δ_d indicates day-of-the-week fixed effects, and ϑ is a vector of parameters and W_{ymd} is a vector of time-variant controlling for weather variations (minimum and maximum temperature and precipitation). The variable D_{iymd} measures how much water used in 2020 during a specific day of week differs from prior years (2018–2019) within the same week of the year, the month of the year, the day of the week, and the weather conditions. It takes 1 if the observation is after the SAH orders period, and 0 otherwise. Finally, ε_{iymd} captures all that remain unobservable, which affects the dependent variable. We applied the Halvorsen–Palmquist transformation to calculate the correct percentage changes [23].

Estimating Equation (1) generates consistent estimates of all parameters in the equation without the need to include all possible observed and unobserved time-invariant factors at the water consumer level and other time-invariant factors corresponding to the day of the week, week of the year, and calendar month. One drawback of fixed effects is that the influence of any time-invariant characteristics cannot be analyzed, even if the information is available. The main objective of this study is to estimate the extent to which the COVID-19 lockdown affects water consumption and how the effects differ across water use sectors and groups. To consistently estimate the effects, we include as many time-invariant factors as possible to remove the effect of those time-invariant characteristics so we can assess the net effect of the predictors on the outcome variable of interest, β. Herein, the time-invariant consisting of γ_i indicates consumer fixed effects; μ_m indicates the calendar month fixed effects; θ_w indicates the week of the year fixed effects; and δ_d indicates day-of-the-week fixed effects.

3. Results

3.1. Exploratory Analysis and Descriptive Statistics

Figure 1 compared the 2020 average monthly water consumption to those of 2018–2019 for two utilities by sector: Utility A in California and Utility C in Florida. Here, the months considered can be divided into two periods: prior-SAH orders from January to March and post-SAH orders from April to May. The results showed that household water consumption increased from April to May 2020, compared to the same period in 2018 and 2019, with the gap closing as lockdown restrictions eased. The average total monthly water consumption in Utility A over the post-SAH order period was higher than that of the prior one, mainly due to the rising residential water consumption. However, CII and SC sectors showed the opposite trends in water consumption after the SAH order was in effect. Water consumption for CII and SC properties fell sharply after the SAH order. The water consumption in Utility C (FL) showed a similar pattern in terms of total monthly water demand, but the magnitude of the changes was quite different. For example, water consumption for residential properties in Utility C increased steadily after the SAH order, while in Utility A, the water consumption rose in April but dropped in May. On the other hand, monthly water consumption for CII properties in Utility A showed an upward trend after the SAH order was enacted, but the increased water consumption for CII properties in Utility C during the post-SAH order seems to be at a slower pace in May compared with April.

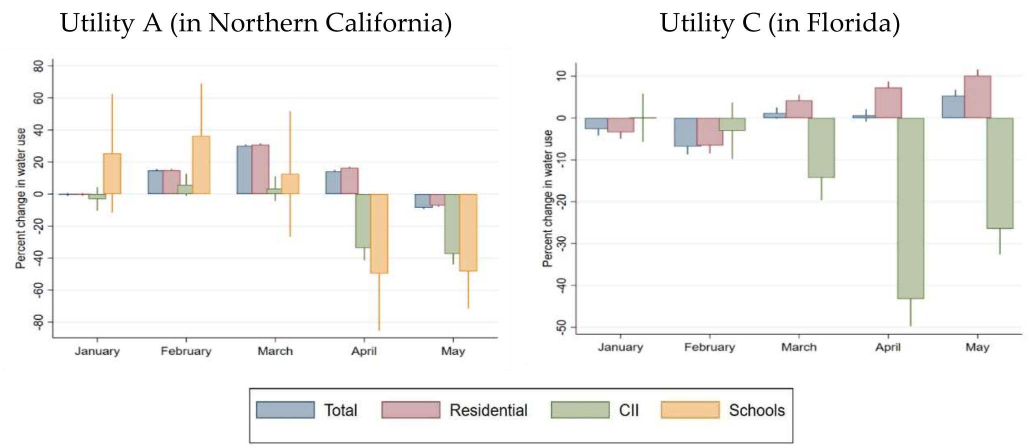

Figure 1. Percent change in monthly water use by category compared with average 2018 and 2019 levels.

Figure 2 shows the weekly percentage changes in water consumption before and after the SAH order in Utility A, located in Northern California, for the residential and CII properties. In general, total weekly water consumption after the SAH order rose considerably compared with before the SAH order. However, the trajectory of residential and CII water consumption was the opposite: residential water use increased at a decreasing trend while CII water consumption decreased at an increasing trend. After the SAH order was enacted, residential water consumption rose by some 30% in two weeks after the SAH order and started to come down to a close pre-pandemic level. In contrast, CII water consumption was on a rising trajectory before the SAH orders but fell drastically by some 30% over five weeks after the SAH order.

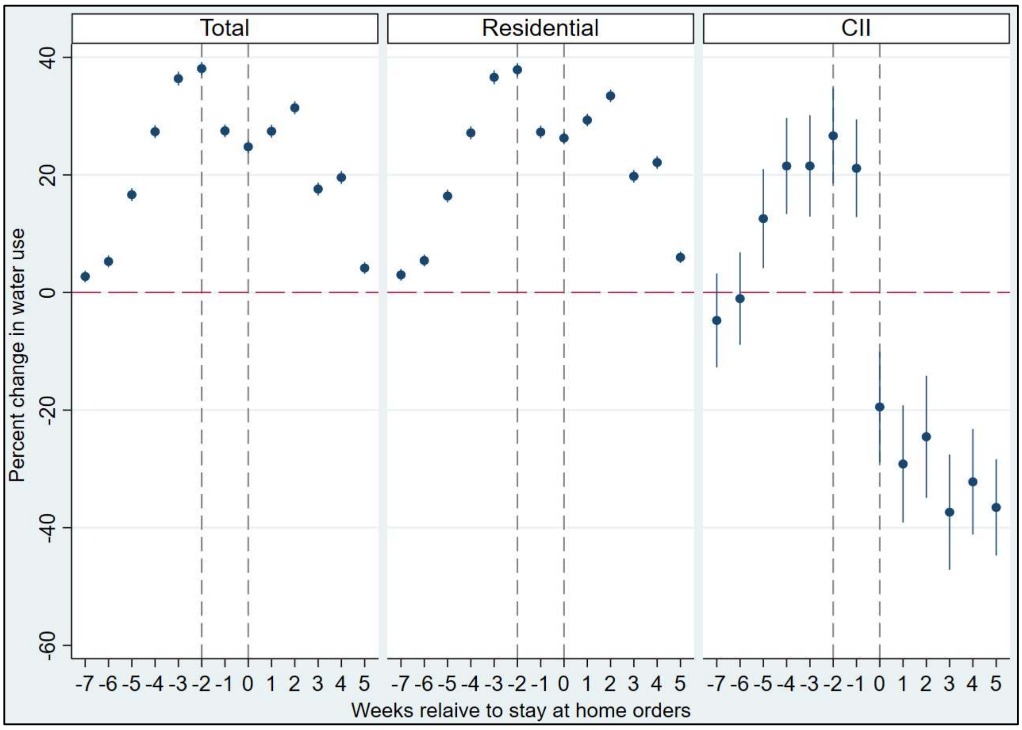

Figure 2. Weekly percent change in water use before and after the stay-at-home orders in Utility A (Northern California) for residential and CII sectors. Notes: First dashed line indicates the week of emergency orders, and the second dashed line indicates the week of stay-at-home orders. Week-7 is from 12 February to 18 February.

Figure 3 shows the weekly percentage changes in water consumption before and after the SAH in Utility E, located in Montana, for residential and CII properties. The weekly total water consumption rose moderately after the SAH orders, primarily due to increased water consumption for residential properties. The trajectory of water consumption for CII properties was downward sloping, which was similar to that of Utility A, but the residential sector showed a different trend of rising water demand after the SAH. Unlike the trend observed in Utility A, the residential water consumption for Utility E increased at a stable rate. It is worth noting that CII water consumption for this utility rebounded after a sharp reduction, but at a much lower level than that of the pre-pandemic period.

Figure 4 presents the dynamics pattern of water consumption for Utility C in Florida. The change in water consumption was similar to that of Utility E. After the SAH orders, residential water consumption rose while CII water consumption decreased sharply and then recovered, but still at a much lower level than that of the pre-pandemic period. It is worth noting the magnitude of the change in water consumption for CII properties is extremely large (84%) one week after SAH. Regarding changes in weekly total water consumption, consisting of the trends found in Utility A and E, the weekly total water consumption increased after the SAH.

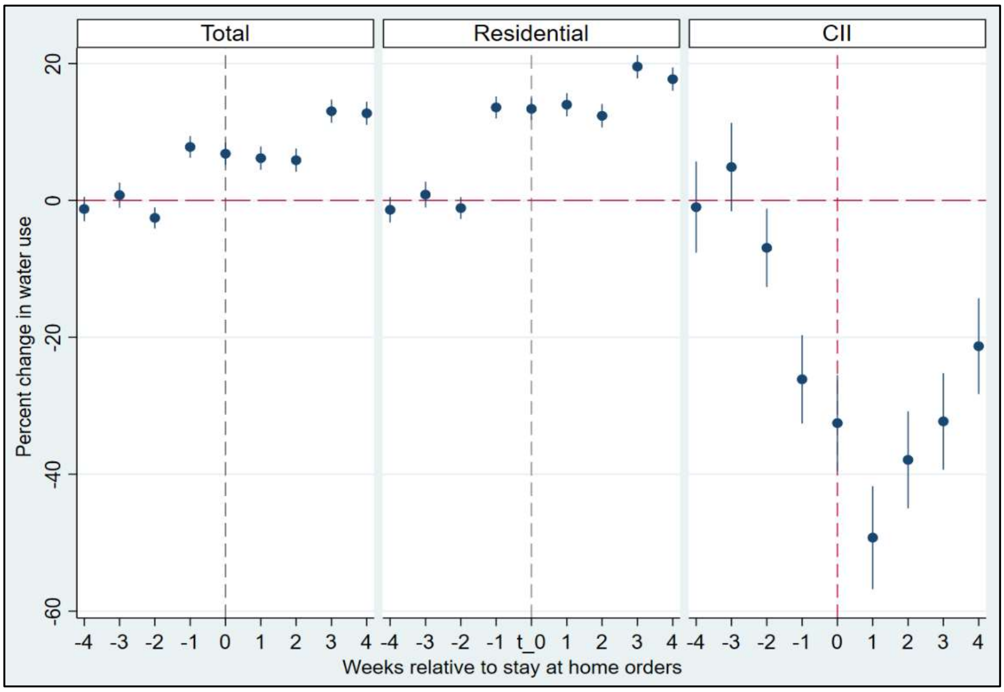

Figure 3. Weekly percent change in water use before and after the stay-at-home orders in Utility E (Montana) for total, residential, and CII sectors.

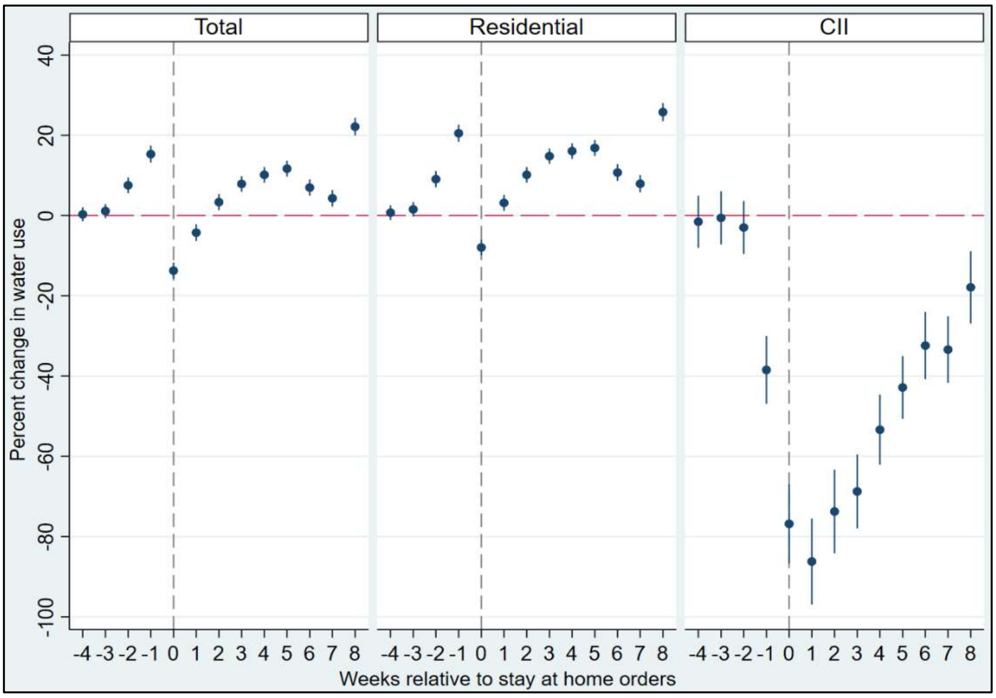

Figure 4. Weekly percent change in water use before and after the stay-at-home orders in Utility C (FL) for total, residential, and CII sectors. Notes: vertical dashed lines indicate the start of stay-at-home orders.

3.2. Fixed Effects Regression Models to Estimate the Changes in Water Demand

We reported estimates of Equation (1) in Table 1. As indicated in Table, we estimate the impact of COVID-19 on overall water use (Total). We also break down the changes in water consumption due to COVID-19 by sector, including single and multi-family residential water use (Residential), single-family water use (SFR), multi-family water use

(MFR), seniors living in a multi-family housing (MFR Senior 55+), low-income water users (Low-Income), commercial, industrial, and institutional sectors (CII), and schools (SC). We also use weather controls (min and max temperature as well as rainfall) and fixed effects, including the day of the week, week of the year, calendar month, and household, to control for time-invariant unobservable.

Table 1. Percent change average daily total and sectoral water use during the COVID-19 pandemic compared with average 2018 and 2019 levels.

	Utility A (NorCal)	Utility B (SoCal)	Utility C (FL)	Utility D (MA)	Utility E (MT)	Utility F (TX)
Total	11.80 ***	13.65 ***	3.08 ***	-	11.89 ***	-
	(0.003)	(0.006)	(0.007)		(0.007)	
Observations	15,053,899	3,914,586	12,889,743	-	6,227,916	-
Residential	13.23 ***	-	8.74 ***	5.82 ***	17.08 ***	9.28 ***
	(0.003)		(0.007)	(0.005)	(0.007)	(0.003)
Observations	14,120,911	-	10,721,209	308,099	5,631,080	5,557,488
SFR	13.82 ***	-	10.26 ***	-	17.76 ***	16.95 ***
	(0.004)		(0.007)		(0.008)	(0.005)
Observations	13,152,120	-	9,429,680	-	4,548,167	1,953,158
MFR	4.43 ***	-	−1.88	-	14.38 ***	4.89 ***
	(0.012)		(0.017)		(0.016)	(0.003)
Observations	873,278	-	1,291,529	-	1,082,913	3,604,330
MFR Senior 55+	19.14 ***	-	-	-	-	-
	(0.031)					
Observations	87,035	-	-	-	-	-
Low-Income	−1.08	-	-	6.99	−3.42	
	(0.263)			(0.068)	(0.055)	
Observations	8478	-	-	2199	74,948	
CII	−22.53 ***	-	−34.27 ***	-	−45.08 ***	-
	(0.031)		(0.030)		(0.035)	
Observations	560,920	-	1,176,272	-	521,888	-
SC	−31.61 ***	-	-	-	-	-
	(0.112)					
Observations	25,412	-	-	-	-	-
Weather Controls	Y	Y	Y	Y	Y	Y
Customer FEs	Y	Y	Y	Y	Y	Y
Month FEs	N	N	N	Y	N	Y
Week of Year FEs	Y	Y	Y	N	Y	N
Day of Week FEs	Y	Y	Y	N	Y	N

Notes: Numbers in parentheses indicate the clustered standard errors. Asterisks *** indicate significance at 10%, 5%, and 1% level, respectively.

The results indicated the opposite water consumption trends for residential vs. non-residential properties: residential properties showed an increase in water consumption. In contrast, non-residential properties (i.e., CII and SC) decreased water consumption after the SAH orders. All the results, except for the low-income water user group, were statistically significant. The regression results indicated that total daily water consumption increased significantly by 11.80% in Utility A, 13.56% in Utility B, 11.89% in Utility C, but only 3.08% in Utility C after SAH compared with the pre-SAH period.

Regarding the water consumption for CII and SC properties, the estimated effects were significantly negative, showing evidence of a large decline in water usage during SAH relative to the pre-SAH period. For CII properties, Utility E had the highest reduction in water usage (−45.08%), followed by Utility C (−34.27%) and Utility A (−22.53%). These reductions were expected because most of the retail, office buildings, hotels and motels, and manufacturing plants were closed during SAH periods.

Turning to the increases in water consumption for residential properties, among five utilities (A, E, C, F, and D), the results showed that Utility D (Montana), had the lowest level of increase in water consumption during the SAH relative to the pre-SAH period. The estimated increase in water consumption for residential properties in this utility was only 5.82%, compared with 8.74% in Utility C, 9.28% in Utility F, 13.23% in Utility A, and 17.08% in Utility E.

We had the most comprehensive data for Utility A, in which we could break down the changes in water consumption for residential and non-residential properties. We further divided residential properties into single-family, multiple-family, and multiple-family with seniors and low-income earners. The regression results presented in Table 1 show that after the SAH, total daily water consumption, on average, increased by 11.80%. As expected, the breakdown by customer type showed SFR and MFR properties had an increased water consumption by 13.82% and 4.43%, respectively. Interestingly, we found that MFR with seniors, 55 years of age or older, had the largest increase in water consumption (19.14%). Water consumption for CII and SC properties, on the other hand, the average daily water consumption decreased by −22.53% and −31.61%, respectively. The estimated change in water consumption for low-income users reveals that the SAH order did not change water consumption for this group of customers. The estimated parameter was negative but non-significant.

Turning to Utility E (Montana), we obtained a similar amount of data as that of Utility A, but data for estimating water consumption for MFR included seniors residing in the household. The estimated effects of SAH on daily total water usage were similar to that of Utility A. However, water consumption for the residential properties located in Utility E increased by a larger percentage (17.08%) compared with Utility A (13.23%). The estimated SAH effects for CII properties followed an opposite pattern for residential properties, with estimated declines in water consumption being large in relative terms. Similar to the findings from Utility A, water consumption for low-income earners remained flat during the SAH order. This was also true for the change in water consumption for low-income users residing within Utility D's service area.

Utility C (FL) had fewer data than Utilities A (NorCal) and E (MT). When compared with the estimated daily total water consumption with A (11.80) and E (11.89), the daily total water consumption in Utility C (3.08%) showed a much smaller increase in water consumption during the SAH relative to the pre-SAH period. However, the breakdowns of the changes in water usage for residential and CII properties in this utility showed somewhat similar levels of changes in water consumption relative to that in Utilities A and E.

For Utility F (TX), we obtained and analyzed only the changes in water consumption for residential properties. The results show no major significant differences compared to the results in the other three utilities. The estimated residential water use for Utility F indicated an increase of 9.28%, with a larger rise in water consumption for SFR (16.95%) and a smaller rise in MFR (4.89%).

4. Discussion

It is not surprising that the results showed a substantial change in water consumption across the utilities. The average total daily water consumption in all utilities over the post-SAH period was significantly higher than that of the prior-SAH period, mainly due to the rising residential water consumption. The estimated effects were significantly positive, indicating that there was a potential shift in water consumption behavior for users living in single and multiple household families. This finding has important implications for developing and maintaining water infrastructure to meet future demand, especially in the areas facing water shortages and having large numbers of people working from home. These areas require additional efforts to conserve water or find additional water sources to meet the rising water demand.

Our results showed that water consumption for CII and SC properties fell sharply as Americans, along with the rest of the world, were forced to change their lifestyles and restrict movement to curb the spread of COVID-19. Schools and commercial centers were shut down and working from home became widespread. The estimated effects were significantly negative, showing evidence of a large decline in water consumption for CII and SC properties during the SAH orders relative to the pre-SAH order periods. For CII properties, Utility E had the highest reduction in water usage with −45.08%, followed by Utility C with −34.27%, and Utility A with −22.53%. These reductions were expected because most of the retail, office buildings, hotels and motels, and manufacturing plants were closed during the SAH order periods. It is worth noting that the magnitude of the change in water consumption for CII properties in the utility located in Florida was extremely large (−87%) one week after the SAH order. This likely indicated that many CII properties within this utility belong to nonessential business groups. This finding is not surprising given this utility is located in a tourist city.

With regard to the increases in water consumption for residential properties, among five Utilities (A, E, C, F, and D) our results showed that Utility D (Montana) had the lowest level of increase in water consumption during the SAH order relative to the pre-SAH order period. The estimated increase in water consumption for residential properties in this utility was only 5.82%, compared with Utility C (8.74%), Utility F (9.28%), Utility A (13.23%), and Utility E (17.08%). These increases reflected changes in behavior during the pandemic when people were encouraged to frequently wash their hands and adopt other hygiene practices to manage viral and bacterial transmission [4], which are heavily associated with increases in water use [24]. During the pandemic, cooking and eating at home became much more frequent because a large number of restaurants were closed, and/or people were hesitant to eat outside of their home setting [25]. This behavior changes undoubtedly led to an increase in water consumption for all activities related to eating at home. During the pandemic, the role of the home has transformed [26]. Many more activities took place within homes, as everyday mobility was restricted [27]. This change led to an increase in residential water consumption [2,16,28,29]. We found, in relative terms, that after the SAH orders ended, the increases in residential water consumption were much smaller than the reductions in CII and SC relative to the pre-SAH orders period. However, residential water use accounted for a large proportion of total water consumption in the utilities studied. Thus, even a small per-residence increase outsized effects on the aggregated total. These results match those observed in earlier studies [2,20,29,30].

Our findings should not be extrapolated to all utilities and for the full SAH order period. The effect of the COVID-19 pandemic on total water demand varies from utility to utility and community to community [21], and the duration of the lockdown period was taken into consideration [21,31,32]. Key factors include the relative proportion of residential and non-residential water uses and the makeup of the non-residential sectors in a utility. Residential utilities likely experienced increases in total demand, while utilities located in large metropolitan areas would experience a reduction in total demand [21]. Most of the lockdown period in the U.S. spanned from March to April 2020, but the application, timing, and duration of lockdowns varied across the U.S. As a result, we expect these factors would affect the dynamics of water consumption. Li, Engel, Ma, Porse, Kaplan, Margulis, and Lettenmaier [31] compared the water demand for the state of California during the lockdown in April 2020 to the same period in 2014–2019 and concluded that in April 2020, California's urban water use decreased by 7.9% compared to the April of the previous years. Cooley et al. [21] found that large metropolitan systems in Boston, Pittsburgh, and Austin cities in the U.S. experienced a reduction in total water demand during the SAH orders due to large cutbacks in non-residential water consumption.

It is somewhat surprising that no significant differences in water consumption were found for low-income users in three utilities (A, C, and E) during the lockdown in March–April 2020 compared to the same period in 2018 and 2019. The possible explanation for this might come from the nature of the SAH orders. Even though the overwhelming majority of people were required to stay at home, large numbers of the "frontline" workers did not have the luxury to stay home or work from home—they were still working during the lockdown. These workers are a varied group but often receive lower wages on average. Previous studies showed that approximately one-third of workers in frontline industries live in low-income families [33]. Thus, it is likely that the low-income water users group in our study represented a large portion of the frontline workers who had to go to work during the lockdown. As a result, their water consumption is unlikely to change during the SAH orders for this group.

5. Conclusions

This work contributes to existing knowledge of the changes in water consumption following the implementation of the SAH order during the COVID-19 pandemic for six utilities located in five U.S. states (i.e., California, Florida, Texas, Montana, and Massachusetts). The estimated results showed that water consumption for CII and SC across all utilities decreased significantly after the SAH. However, the residential water consumption increased substantially after SAH orders were enacted. All the changes were expected from the nature of SAH orders. One of the most interesting findings was the total water consumption in these utilities rose because the increased total residential water consumption was much more than that of decreased total non-residential water consumption. The present study confirmed previous findings [2,29] and contributed additional evidence that suggested an increase in water consumption during the early pandemic. An implication of this is that as remote work becomes increasingly common, policymakers might need to renew water management policies to protect and enhance the sustainability and resilience of the water supply infrastructure. The key strengths of this study are its coverage and analyses of the heterogeneity of water consumption across the water users and sectors during the pandemic. The large coverage of this study allowed us to compare and contrast the changes in water consumption for multiple utilities in five states of the U.S. Given the rich amount of data, this study estimated the changes in water consumption during the SAH orders for different water users and sectors. The estimations highlighted the heterogeneity of water consumption during an unprecedented crisis, the COVID-19 pandemic.

The current research was not specifically designed to evaluate the factors related to the shifts in water consumption. The factors that led to changes in water consumption after the COVID-19 pandemic are intriguing and could be usefully explored in further research. In addition, this study focused only on the changes in water consumption a few weeks after the SAH, and thus has yet to conclude the extent to which SAH affects long-term water consumption and whether the increased total water consumption is a long-lived trend. Previous studies provided mixed results. Results from Nemati [19] suggested increases in residential use and reductions in non-residential use during the lockdown relative to the same period pre-lockdown. However, from June 2020, when the lockdown was eased considerably, daily water consumption rebounded to the pre-pandemic level. In contrast, Irwin, McCoy and McDonough [2] found the same water consumption patterns for residential and non-residential properties indicated in Nemati [19], but the authors suggested that the changes in water consumption patterns likely persisted due to the increased popularity of working from home. More information on water consumption after the SAH orders would help us to establish a greater degree of accuracy on this matter. Another key policy priority is related to the ability of water utilities to adjust financially during a crisis. It would be interesting to assess the pandemic's effects on the water utilities' revenue to better understand the extent to which the pandemic affects their financial resilience.

Author Contributions: Conceptualization, M.N.; methodology, M.N.; software, M.N. and D.T.; validation, M.N. and D.T.; formal analysis, M.N. and D.T.; investigation, M.N. and D.T.; resources, M.N.; data curation, M.N. and D.T.; writing—original draft preparation, M.N. and D.T.; writing—review and editing, M.N. and D.T.; visualization, M.N.; supervision, M.N.; project administration, M.N.; funding acquisition, M.N. All authors have read and agreed to the published version of the manuscript.

Funding: Partial support from the W4190 Multistate NIFA-USDA-funded project, Management and Policy Challenges in a Water-Scarce World, is greatly appreciated.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from this analysis are available upon reasonable request from the corresponding author.

Acknowledgments: We would like to thank Robb Barnitt and Dropcountr for sharing the anonymized dataset for this analysis. Partial support from the W4190 Multistate NIFA-USDA-funded project, Management and Policy Challenges in a Water-Scarce World, is greatly appreciated.

Conflicts of Interest: The authors declare no conflict of interest.

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