Journal of Water & Health

Journal of Water and Health Vol 20 No 1, 139 doi: 10.2166/wh.2021.184

Water use behaviors and water access in intermittent and continuous water supply areas during the COVID-19 pandemic

Emily Kumpel[a,*], Nayaran Billava[b], Nayanatara Nayak[b] and Ayse Ercumen[c]

[a] Department of Civil and Environmental Engineering, University of Massachusetts Amherst, 130 Natural Resources Road, Amherst, MA 01003, USA
[b] Centre for Multi-Disciplinary Development Research, Dr B.R. Ambedkarnagar, Near Yalakki Shettar Colony, Dharwad- 580 004 Karnataka, India
[c] Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695, USA
*Corresponding author. E-mail: ekumpel@umass.edu

EK, 0000-0003-0138-8441; NN, 0000-0002-3580-9614; AE, 0000-0001-6002-1514

ABSTRACT

More than one billion people worldwide receive intermittent water supply (IWS), in which water is delivered through a pipe network for fewer than 24 h/day, limiting the quantity and accessibility of water. During the COVID-19 pandemic, stay-at-home orders and efforts to limit contact with others can affect water access for those with unreliable home water supplies. We explored whether water service delivery and household water-use behaviors changed during the COVID-19 pandemic in Hubballi–Dharwad, India, and whether they differed if households had IWS or continuous (24×7) water supply through a longitudinal household survey in 2020–2021. We found few perceived differences in water service delivery or water access, although one-quarter of all households reported insufficient water for handwashing, suggesting an increased demand for water that was not satisfied. Many households with 24×7 supply reported water outages, necessitating the use of alternative water sources. These findings suggest that water demand at home increased and households with IWS and 24×7 both lacked access to sufficient water. Our findings indicate that water insecurity negatively affected households' ability to adhere to protective public health measures during the COVID-19 pandemic and highlight the importance of access to uninterrupted, on-premise water during public health emergencies.

Key words: COVID-19 pandemic, drinking water, handwashing, intermittent water supply, piped water, water access

HIGHLIGHTS

- Water access in households with intermittent and continuous piped water supply was compared during the COVID-19 pandemic.
- Households reported using more water during the pandemic and having insufficient water for handwashing.
- Social distancing while using public water points and toilets was often infeasible.
- Access to uninterrupted on-premise water should be ensured during public health emergencies.

INTRODUCTION

Insufficient or unreliable water supply, which can exacerbate poor sanitation and inadequate hygiene practices, can fuel the spread of disease in densely populated areas. In settings with access to piped water, available water can be restricted by intermittent water supply (IWS), in which water is delivered through a piped network for a limited number of hours per day or per week. IWS can compromise the safety of delivered water, lead to increased risk of waterborne infections, and result in high household expenditures on coping costs (Andey & Kelkar 2009; Fan *et al.* 2014; Ercumen *et al.* 2015; Guragai *et al.* 2017; Gurung *et al.* 2017; Kumpel *et al.* 2017). Previous studies have also found that households with IWS often have very restricted volumes of water available (Kumpel *et al.* 2017). Furthermore, households in low-income urban communities often access water from off-premise locations, requiring that they leave home to collect water (Elliott *et al.* 2019; WHO/UNICEF 2021).

During the COVID-19 pandemic, governments around the world required residents to stay at home to reduce transmission and promoted hygiene measures such as handwashing. Therefore, households experiencing water insecurity from IWS during the COVID-19 pandemic faced increased demand for water for handwashing and hygiene and from increased time spent at home due to stay-at-home restrictions, while they were at the same time often restricted from leaving their homes to collect additional water. Handwashing, requiring water, is a key mechanism for reducing transmission of SARS-CoV-2; however, 2 billion people in the world lack access to adequate handwashing facilities, a challenge further compounded by the inadequate or unreliable water access provided by IWS (Brauer *et al.* 2020; Freeman & Caruso 2020; Ray 2020; Rohilla 2020; Sayeed *et al.* 2021). While governments around the world extended free water supply to citizens, deferred payments of water bills, or issued moratoria on water disconnections during the public health emergency (Lakhani 2020; NDTV 2020), in many of these places, unpaid bills entered into arrears and households faced large bills when collection resumed (Walton 2020; Rajwi 2021).

While more than one billion people in the world are served by IWS systems, there is little understanding of the impact of IWS on households during public health emergencies as compared to continuous water supply, including the impact of stay-at-home orders on household water access and the effects of IWS on COVID-19 mitigation behaviors such as handwashing and social distancing (e.g., while queuing to collect water). Given the widespread use of IWS worldwide, it is important to know whether households with IWS may have experienced differential changes in water access and water-use behaviors during public health emergencies such as the COVID-19 pandemic and whether IWS affected their ability to adhere to mitigation measures. This information can inform future policies or interventions to improve water access during public health emergencies, such as whether additional measures are needed to ensure water access, and help prioritize efforts to upgrade IWS systems to provide continuous supply.

In this study, we seek to understand water access and use during the COVID-19 pandemic among households with intermittent and continuous water supply. Specifically, the objective was to compare household water access, water usage, and adherence to disease transmission mitigation behaviors during and after the stay-at-home orders in Hubballi–Dharwad, India, in households with IWS and those with continuous ('24×7') water service.

MATERIALS AND METHODS

Study area

Hubballi–Dharwad are twin cities in northern Karnataka, India, with a population of more than one million. In 2006 and 2007, approximately 10% of the population were changed to 24×7 water supply on a pilot scale, while the rest of the city received IWS. Details about Hubballi–Dharwad, the water system, the conversion from IWS to 24×7 supply, and the impact of the conversion on child health, household economics, and water quality are documented elsewhere (Kumpel & Nelson 2013, 2014; Burt & Ray 2014; Ercumen *et al.* 2015; Kumpel *et al.* 2017; Burt *et al.* 2018; Ray *et al.* 2018). The wards that were upgraded to 24×7 in this initial pilot conversion are referred to as '24×7 demonstration wards' hereinafter. Since the initial conversion, 24×7 water supply has been introduced to additional areas of Hubballi–Dharwad; as of 2018, 19 of the cities' 67 wards were reported to be served fully by 24×7 supply, 20 wards were partially served by 24×7 supply, and 28 wards remained on IWS. However, notably, our household survey in 2018 found that, even in wards classified by the water authority as 'fully covered' by 24×7 service, some households continued to have IWS. We focused the current study on the 16 wards where at least 50% of households had 24×7 supply.

COVID-19 in Hubballi–Dharwad

In India, country-wide stay-at-home orders were implemented from March 22–June 1, 2020, with the gradual lifting of restrictions through June and July 2020. In the state of Karnataka, lockdown was ended on July 22, 2020 (ET Bureau 2020). Hubballi–Dharwad reported its first confirmed positive case of COVID-19 on March 22, 2020 (Menasinakai 2020). As of July 14, 2021, Dharwad District reported 60,275 positive cases of COVID-19 and 1,264 deaths related to COVID-19, out of 2,876,587 total cases in the state of Karnataka (GoK 2021).

Study design

We used a genetic matching algorithm (Diamond & Sekhon 2012) to select 16 IWS wards as matched controls for the 16 wards with >50% 24×7 service. Wards were matched on socioeconomic indicators, sanitation conditions, and pre-upgrade water service using a representative dataset collected before the conversion. As described in Ercumen *et al.* (2015), the matching variables included percentages of pukka structures (concrete or reinforced cement concrete), low-income, one-room, and self-identified slum households; illiterate females; households with own tap, receiving water less often than every 5 days, with own latrine, and with a designated garbage disposal location provided by the municipality and garbage collection service; and monthly household health expenses. During field inspection, one of the selected wards was observed to primarily contain commercial units and was dropped.

We enrolled households from the remaining 31 wards in Hubballi–Dharwad, India, with a target of approximately 20 households per ward. The 31 wards had a total of 86,627 households with 432,676 residents in 2011 (the last available census data), with 18.7% of the population designated as residing in a slum area. For each selected ward, participants were identified through snowball sampling, with the initial list generated through personal contacts at the Center for Multidisciplinary Development Research (CMDR) in Dharwad, India. Further participants were identified by asking these contacts to provide phone numbers of their personal contacts from different wards and from different socioeconomic segments of each ward until the sample size was reached. The sample size was selected based on feasibility with the snowball sampling method, which the study team estimated as 500–1,000 households total. Due to lockdown and public health protection, participants were recruited and surveyed via phone.

We enrolled 606 households from 31 wards (326 with IWS and 280 with 24×7) with a mean of 19.5 households per ward (range: 17–23). Round 1 (R1) data were collected from July 9–August 30, 2020 (after the national lockdown had lifted), Round 2 (R2) data were collected from November 15–December 30, 2020, and Round 3 (R3) data were collected from May 1–June 10, 2021 (Figure 1). Out of 606 households enrolled originally in R1, 580 households (301 with IWS and 279 with 24×7) remained in the study at the time of R2 and 560 remained in R3 (286 in IWS and 274 in 24×7). Reasons for loss to follow up included participants being out of service/unreachable and moving.

Data collection

Trained enumerators from CMDR used a structured questionnaire to assess whether the household had IWS or 24×7 service and collect data on the reported frequency of water delivery, frequency and duration of any water outages, user-perceived water pressure and water quantities, water bills, and reported hygiene behaviors including handwashing, during the early stages of the pandemic. They also asked how these compared to their experience during lockdown. The survey included very limited questions on socioeconomic indicators because of the personal relationships between participants due to the snowball sampling method and potential participant discomfort disclosing socioeconomic information on a telephone survey. Each enrolled household was surveyed a total of three times over the course of approximately 1 year. The study protocol was reviewed and approved by the Institutional Review Board of the University of Massachusetts, Amherst. We also collected information on revenue collection and water service delivery from water service providers (Karnataka Urban Water Supply & Drainage Board and the Hubballi–Dharwad Municipal Corporation) in Hubballi–Dharwad.

Data analysis

Descriptive statistics, including tabulated percentages (for binary variables) and means, medians, and standard deviations (for continuous variables), were generated using R (R Core Team 2020). We compared self-reported household perceptions on water service and water use between the three rounds of data collection and between households with IWS vs. 24×7 service. Significance testing for quantitative data on water delivery durations and days between supplies was performed using the non-parametric Kruskal–Wallis (KW) test. Significance testing for binary values comparing IWS and 24×7 groups was performed using χ^2 tests. The p-values were considered significant at the $p \leq 0.05$ level.

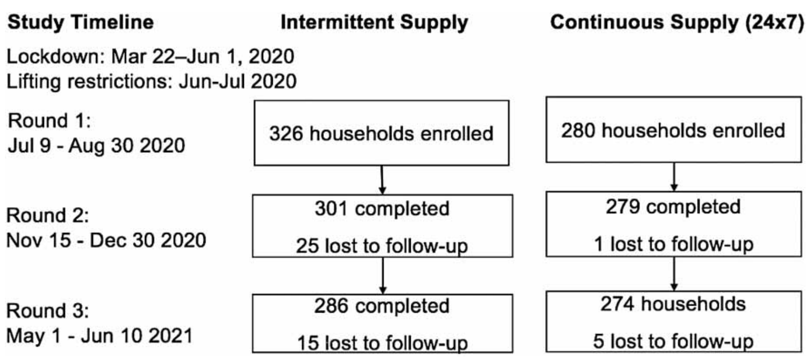

Figure 1 | Number of households enrolled and lost to follow-up across study arms and data collection rounds.

RESULTS

Respondent characteristics

Respondents with IWS and 24×7 water service were 44 and 43% female and mean of 42 vs. 41 years old, respectively. The primary occupation of respondents' head of household was also similarly distributed between both groups: in IWS and 24×7, respectively, 41 vs. 37% held private, government, or NGO jobs, 23 and 26% were business owners, 13 and 19% were day laborers or street vendors, 7 and 5% were retired, and 6 and 5% worked in agriculture.

Water service

Households with IWS received water every 5 days for a mean of 4 h (Table 1). In R1, most households perceived that this was the same number of days between delivery (94%, $n = 326$) and duration of delivery (91%, $n = 326$) as compared to before the COVID-19 pandemic or the lockdown period. The differences in days between deliveries from R1 to R2 was 2.4 h, and from R1 and R3 was 18.8 h. The difference in supply duration from R1 to R2 was 18 min, and from R1 to R3 was 24 min. Differences in the days between deliveries were significant between the rounds (KW: $p < 0.05$), and differences in delivery duration were only significant between R1 and R3 (KW: $p < 0.05$) (Table 1). In R1, the majority of households self-reported that they perceived the same water pressure during the reporting period as prior to lockdown (79% same, 11% lower, 10% higher, $n = 325$). Delivery frequency and duration varied between wards; some households in the 24×7-demonstration wards and 24×7-fully covered wards still had IWS (Figure 2), consistent with our previous household survey in these wards in 2018 (unpublished).

During R1, households with 24×7 reported a mean of 0.5 outages in the last 2 weeks, with 60% of households reporting no outages, 31% experiencing one outage, and 8% experiencing two ($n = 262$) (Table 1). Of the households reporting an outage, households reported that, during their last outage, water was off for a mean of 2.1 h. All of the 24×7 households (100%, $n = 262$) said their experience with the number of outages was the same as before pandemic and most (94%, $n = 272$) said it was the same during lockdown, and most households (93%, $n = 274$) perceived a similar outage duration as before the pandemic. During R2, households reported more outages in 24×7 and with longer durations: 91% of households reported an outage in the prior 2 weeks, with an overall mean of 2.3 outages among the 24×7 households ($n = 274$) lasting a mean of 11.8 h ($n = 173$). During R3, outages reduced from R2 but were higher than R1, with 75% of households reporting an outage in the prior 2 weeks ($n = 271$) for a mean of 5.8 h ($n = 168$). Differences in outage frequency and duration were significant between all of the rounds (KW: $p < 0.001$) (Figure 2). More than half of the 24×7 households (56%, $n = 248$ in R2; 60%, $n = 253$ in R3) reported that the utility gave advance notice of the outages.

Water use

During R1, approximately one-third of both 24×7 and IWS households perceived using more water than before the pandemic (35 and 31%, respectively) (Table 2). Of 24×7 households, 31% perceived higher water bills in R1 than prior to the pandemic,

Table 1 | Reported service delivery among respondents with IWS and 24×7 in R1 (July–August 2020), R2 (November–December 2020), and R3 (May–June 2021)

		Unit	R1	R2	R3	R1 compared to pre-pandemic (%)		
			Mean			Less	Same	More
IWS	Delivery frequency	days	4.6 ($n = 326$)	4.7 ($n = 300$)	5.3 ($n = 286$)	4	94	2
	Duration of supply	h	4.1 ($n = 323$)	4.4 ($n = 300$)	4.5 ($n = 286$)	5	91	4
	Perception of water pressure ($n = 325$)					11	79	10
24×7	Outages in the last 2 weeks	% of hh	40 ($n = 262$)	91 ($n = 274$)	75 ($n = 271$)	0	100	0
		times	0.5	2.3	1.5			
	Duration of outages	h	2.1 ($n = 116$)	11.8 ($n = 173$)	5.8 ($n = 168$)	5	93	2
						R1 compared to lockdown (%)		
IWS	Delivery frequency ($n = 353$)					2	94	4
24×7	Outage frequency ($n = 272$)					3	94	3

Lockdown period refers to March 22–May 31, 2020.

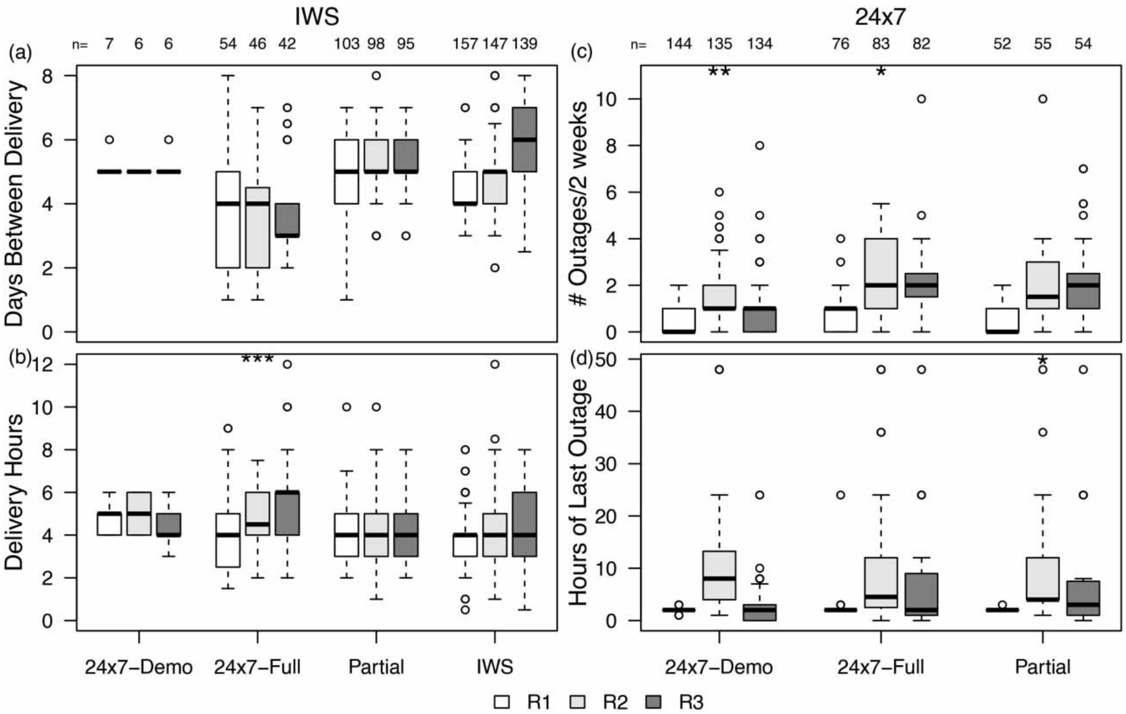

Figure 2 | Boxplots showing household-reported IWS and 24×7 service delivery. (a) Days between water deliveries in IWS. (b) Duration of water delivery in IWS; *** three outliers at 30 h not shown. (c) Number of outages in 24×7; * one outlier at 14 outages not shown; ** two outliers at 24 outages not shown. (d) Duration of the last outage in 24×7; * one outlier at 72 h not shown. Colors represent data collection rounds. 24×7-Demo refers to the eight wards that were converted to 24×7 supply in the pilot conversion in 2007. 24×7-Full refers to additional wards where the water authority reports having extended 24×7 service to all households in the ward since the pilot conversion (however, we note that many households in these wards lacked 24×7 service). Partial refers to wards where the water authority reports having extended 24×7 service to some households. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.10.2166/wh.2021.184.

Table 2 | Water quantity and water bill perceptions

				Frequency compared to pre-pandemic (%)		
Variables	**Round**	**Supply type**	***n***	**Less**	**Same**	**More**
Quantity of water used	R1	IWS	326	1	68	31
		24×7	279	3	62	35
Water bill	R1	IWS	310	1	82	17
		24×7	275	1	68	31
	R2[a]	IWS	241	–	–	40
		24×7	244	–	–	41
	R3	IWS	301	0	72	29
		24×7	279	<1	69	30

[a]Question was phrased as a Yes/No in R2.

while only 17% of IWS households perceived an increase in water bills. However, during R2 and R3, similar percentages between IWS and 24×7 perceived higher water bills, although this may be an artifact of the change in the question from less/same/more to a yes/no.

Use of alternative water sources

In R1, 26% ($n = 326$) of IWS households used a non-municipal water source compared to only 4% ($n = 280$) of 24×7 households (Table 3). Of those IWS households using another source, the most common was borewell water (groundwater) from a piped system (34%), a public non-piped water point (33%), or trucked water (e.g., a vehicle equipped with a water tanker)

Table 3 | Alternative water sources, handwashing, and sanitation access

Variables	Supply type	R1				R2				R3			
		n	Yes (%)	No (%)	p^a	*n*	Yes (%)	No (%)	p^a	*n*	Yes (%)	No (%)	p^a
Rooftop storage tank	IWS	326	71	29	<0.01*	–	–	–	–	–	–	–	–
	24×7	280	55	45		–	–	–		–	–	–	
Roof unable to support a tank[b]	IWS	95	8	92	0.40	–	–	–	–	–	–	–	–
	24×7	124	13	87		–	–	–		–	–	–	
Use any other water[c]	IWS	326	26	74	<0.01*	–	–	–	–	–	–	–	–
	24×7	280	4	96		254	85	15		206	96	4	
Borewell – private	IWS	86	5	95	<0.01*	–	–	–	–	–	–	–	–
	24×7	10	40	60		216	2	98		198	1	99	
Borewell – piped	IWS	86	34	66	0.08	–	–	–	–	–	–	–	–
	24×7	10	0	100		216	2	98		198	1	99	
Borewell – shared tank	IWS	86	1	99	1.00	–	–	–	–	–	–	–	–
	24×7	10	0	100		216	1	99		198	1	99	
Borewell – neighbor	IWS	86	7	93	0.86	–	–	–	–	–	–	–	–
	24×7	10	0	100		216	4	96		198	2	98	
Public water point	IWS	86	33	67	0.45	–	–	–	–	–	–	–	–
	24×7	10	50	50		216	2	98		198	4	96	
Trucked	IWS	86	27	73	0.44	–	–	–	–	–	–	–	–
	24×7	10	10	90		216	91	9		198	89	11	
Bottled	IWS	86	1	99	1.00	–	–	–	–	–	–	–	–
	24×7	10	0	100		216	0	100		198	3	97	
Open well	IWS	86	1	99	1.00	–	–	–	–	–	–	–	–
	24×7	10	0	100		216	0	100		198	0	100	
Use off-premise water sources	IWS	326	12	88	<0.01*	301	7	93	<0.01*	286	4	96	0.9
	24×7	280	5	95		279	1	99		274	3	97	
Social distance at water points[c]	IWS	39	54	46	0.87	–	–	–		–	–	–	
	24×7	13	46	54		3	0	100		9	33	67	
Sufficient water for handwashing	IWS	326	75	25	0.58	301	75	25	0.11	286	80	20	0.06
	24×7	280	77	23		279	69	31		274	73	27	
Use of hand sanitizer	IWS	326	95	5	0.65	301	89	11	0.75	286	80	20	0.20
	24×7	280	94	6		279	88	12		274	76	24	
Use of public toilets	IWS	326	3	97	1.00	301	3	97	0.94	286	0	100	0.23
	24×7	280	3	97		279	3	97		274	1	99	
Social distance at public toilets	IWS	10	10	90	0.04*	12	8	92	0.45	–	–	–	
	24×7	9	67	33		10	30	70		3	67	33	

[a]χ^2 test for difference between IWS and 24×7.
[b]Roof unable to support a tank' refers to whether the respondents lived in a house or an apartment that could not structurally support the weight and/or size of a roof tank.
[c]In R2 and R3, the questions were asked only of 24×7 households and referred to during water outages.
*Significant at $p < 0.01$.

(27%) ($n = 86$). In R1, few households used off-premise water in either IWS or 24×7 (12 and 5%, respectively), and fewer still during R2 (7 and 1%) and R3 (4 and 3%); these were likely a mix of alternative sources and public piped water points. Of those that used off-premise water during R1, approximately half in both water supply schemes said they were able to maintain 2 m (social distance) at the water point. In R2 and R3, only CWS households were asked about their ability to maintain social distance; of the few households that used off-premise water, less than a third reported challenges in doing so (Table 3). In open-ended questions, 17 IWS households and one 24×7 household said they wore a mask and tried to maintain social distancing when collecting other sources, and 10 IWS households and no 24×7 households reported that they stopped using another source or lacked access to another source due to the pandemic.

When 24×7 households were asked whether they accessed other water sources when they had an outage during R2 and R3, many households (85% in R2 and 96% in R3) reported using another water source, primarily trucked water (91 and 89%) (Table 3). A few used borewell water from neighbors (4 and 2% in R2 and R3) or public water points (2 and 4% in R2 and R3). Few households in either IWS or 24×7 reported that the water utility had provided for water during piped water shortages (3 and 4% of IWS households in R2 and R3, and <1 and 3% of 24×7 households in R2 and R3). Seventy-one (71%, $n = 326$) of IWS households in R1 had a rooftop storage tank, while only 55% of households with 24×7 had a rooftop storage tank; accepting large volumes of water, such as from a truck delivering to a home, would require households to have a large amount of household storage.

All households were asked an open-ended question during R1 of how the COVID-19 pandemic lockdown and stay-at-home orders affected their water and sanitation access. When asked during R1 whether the COVID-19 pandemic affected any of their other water and sanitation-related practices, many households in IWS and 24×7 perceived no effect (37 and 41%), one-third perceived cleaning more (27 and 34%,), and one-fifth reported drinking treated water (20 and 18%) ($n = 326$ and $n = 280$). Compared to 24×7 households, IWS households reported storing more water (13 vs. 5%), using more water (7 vs. 1%), and using water more carefully (5 vs. 1%). Other responses from households included obtaining a private water source to use (e.g., neighbor's borewell), storing more treated water, drinking hot water, and washing clothes and vegetables more often. Several houses requested more frequent delivery of water or reported problems with the 24×7 delivery or water pressure.

Hand hygiene and sanitation

Approximately three-quarters of both IWS and 24×7 households perceived having sufficient water for handwashing in R1 (75 and 77%, respectively), with no significant difference between IWS and 24×7 households (Table 3). During R2 and R3, the numbers were similar for IWS households. In R2, the percent reporting sufficient water for handwashing among 24×7 households dropped somewhat, potentially related to the more frequent outages experienced during R2. Most households in both IWS and 24×7 groups reported using hand sanitizers in R1 (95 and 94%, respectively), with a slight drop during R2 (89 and 88%) and a further drop in R3 (80 and 76%); there were no significant differences between IWS and 24×7 households. In an open-ended question of how the COVID-19 pandemic affected handwashing practices in R1, almost all households (91% in IWS and 97% in 24×7) reported washing their hands more frequently, while few households reported no change (7 and 4% in 24×7 and IWS). Few of the households used public toilets (3% in both IWS and 24×7 during both R1 and R2 and <1% in R3); during R1, two-thirds of those using public toilets in 24×7 areas were able to maintain social distance at public toilets, while most of those in IWS (90%) were not ($n = 10$). During R2, only one-third of 24×7 households using public toilets were able to maintain social distancing, while the percentage remained similar for IWS households; however, few households reported using public toilets.

Water utility impacts

The Water Board in Hubballi–Dharwad reported initial challenges in ensuring that workers were outfitted with proper personal protective equipment and identification. They provided alternative water sources to increase water availability at COVID-19 quarantine centers and public facilities (e.g., schools, hostels, community halls, and public places), including tanker trucks and drinking water barrels and bottles to low-income populations during lockdown. They did not report changes in supplying water nor unusual problems with the 24×7 area supplies but did report pipe leak issues in IWS areas. They worked at half staffing capacity in Water Board offices through lockdown.

Water billing and revenue collection were reported to be challenging during the COVID-19 pandemic. This included delays in issuing water bills and, when finally issued, that the bills then reflected 6 months of consumption. Households frequently prohibited meter readers from accessing the household to read meters. Only 10% of revenue was collected during the lockdown period (March 22–May 31, 2020), and only 40% of revenue was collected in the 2020–2021 financial year (April 2020–March 2021). This was attributed to lack of online bill payment options in 24×7 areas, while online bill payment was available in IWS areas.

DISCUSSION

Households with IWS perceived few differences in water delivery during the early months of the pandemic or during lockdown in Hubballi–Dharwad, India. The Water Board and other government offices reported no changes to their water production or delivery. Among households with IWS, days between subsequent water deliveries varied by 2–19 h and the duration of delivery varied by 18–24 min across three rounds of data collection over the course of 1 year. Since households, particularly low-income households, often wait at home to collect and store water, varying water timings can make a substantial difference for households with members working outside of the home (Burt *et al.* 2018; Kumar *et al.* 2018). Similarly, available water volumes in an IWS system can be proportional to the total amount of time the supply is on; a difference in minutes in the duration of supply can directly and substantially affect water volumes available to households (Kumpel *et al.* 2017). Notably, in areas with 24×7 supply, there were increases in outages during the pandemic. While we do not know the reason for this, it did pose potential challenges for households with expected 24×7 water access, especially since only half of 24×7 households had an overhead storage tank (larger in-home storage would be needed to accept larger water deliveries from trucked water). Previous studies in Hubballi–Dharwad have noted that public borewells were removed from 24×7 areas as part of the conversion to 24×7 supply, potentially threatening household water security during water outages (Burt *et al.* 2018). The variations in IWS service delivery and in water outages in 24×7 supply areas are consistent with seasonal changes in piped water availability observed during earlier studies of water access in Hubballi–Dharwad (Kumpel & Nelson 2013). Our first round of data collection was during the monsoon season where water supplies at the source (and electricity supplies for consistently operating the water system) tend to be higher, while the second and third rounds, collected during dryer seasons, showed more outages and potential shortages of supply. At the height of supply scarcity during the second data collection round, households with 24×7 supply reported a mean of 2.3 outages in the past 2 weeks for 11.8 h in duration (309 h of supply/336 total hours in a week, or supply on 92% of the time). During the same period, IWS households received water for 4.4 h every 4.7 days (13 h of supply/336 total hours in a week, or supply on 4% of the time).

Approximately one-quarter of households in both 24×7 and IWS areas perceived insufficient water for adequate handwashing. This finding is of notable concern due to the importance of handwashing to mitigate the spread of the COVID-19 pandemic. Households with IWS and 24×7 both reported increasing their frequency of handwashing in response to the pandemic, suggesting that changes in human behavior in response to perceived risks led to an increase in demand for water that was not satisfied by either supply scheme. These findings support previous calls for the provision of handwashing stations to interrupt SARS-CoV2 transmission in low-income communities (Freeman & Caruso 2020; Ray 2020). Notably, households in this study did adjust their reported handwashing behavior and reported dedicating scarce water resources towards handwashing.

Households also largely perceived using more water overall during the pandemic. Both IWS and 24×7 households perceived higher water bills starting during the second round of data collection. 24×7 households are metered based on consumption. Some IWS households are metered based on consumption, but many are not and are charged a flat rate no matter the consumption; perceived higher water bills may have been due to higher metered consumption or due to utility-reported delays in billing.

Of note, many residents with 24×7 and IWS collect piped water in their yard and alternative sources, such as their own or a neighbor's borewell, were available on premise or close to home. However, those households that did need to venture out for alternative water sources did report issues with social distancing at public water sources, particularly later in 2020, a finding consistent with a study of water access in a town with IWS in Zimbabwe (Zvobgo & Do 2020). These findings indicate that water insecurity negatively impacted individuals' ability to adhere to protective public health measures (Stoler *et al.* 2020) and highlight the importance of on-premise, uninterrupted water access in reducing the need for collection, and therefore potential exposure, from off-premise public water points during the COVID-19 pandemic. Notably, many households at our study site reported using sources that did not require queuing, such as trucked water delivered to home or neighbors' private sources. While water sharing has been noted as a widespread and important mechanism of ensuring household water security (Stoler *et al.* 2019), it has also been suggested as a mechanism for SARS-CoV2 transmission through close interaction between neighbors (Stoler *et al.* 2020). In particular, households with IWS frequently relied on multiple types of alternative water sources; while they appeared to have continued practices existing prior to the pandemic, it was likely further strained as water use increased and households needed to more actively manage their water supplies and use. Additionally, some households did report having to abandon the use of some water sources due to the pandemic. A notably large portion of household with 24×7 supply reported relying on trucked water due to the numerous outages in water supply experienced in rounds 2 and 3.

This study had several limitations. First, the study population was drawn from a non-random sample; due to restrictions imposed by the COVID-19 pandemic, it was not possible to travel to recruit a random sample of households from the study areas. Therefore, we relied on snowball sampling to recruit participants. We were also unable to collect detailed socioeconomic information from participants via the phone survey approach necessitated by the pandemic, and we therefore report analyses that are not adjusted for socioeconomic covariates. However, our study design relied on multivariate matching to generate well-balanced study groups (Arnold *et al.* 2010) and, in our prior work in Hubballi–Dharwad, matching balanced socioeconomic covariates between households with IWS and 24×7 supply (Ercumen *et al.* 2015). All information was self-reported, and the information about water delivery details during lockdown relied on respondents' memories, subject to the risk of inaccurate recall.

CONCLUSION

Safe water, sanitation, and hygienic conditions are essential to protecting human health during all infectious disease outbreaks, including the COVID-19 pandemic (Stoler *et al.* 2020; Tortajada & Biswas 2020; Desye 2021). Our study represents the only assessment, to our knowledge, comparing water access during the COVID-19 pandemic under intermittent and continuous water supply schemes. We did not find large differences in key metrics of water service delivery and water-related behaviors between households with IWS and 24×7 supply during the COVID-19 pandemic in Hubballi–Dharwad, India. Many households had systems for accessing water, including alternative sources, that persisted during lockdown. While few households reported relying on off-premise sources, among the few households that did, maintaining social distancing while collecting water was often not feasible. Most households reported using more water overall during the pandemic, likely straining households' water management capacities and leading to higher bills. Households with IWS and 24×7 both struggled to access sufficient quantities of water for handwashing, suggesting that water insecurity can limit their ability to adhere to COVID-19 mitigation measures. In particular, households expecting 24×7 water service but facing outages may not have been prepared to cope with the outages. Our findings highlight the role of ensuring adequate supplies of uninterrupted, reliable water during public health emergencies; and ensuring alternative supplies and sufficient household storage for households not otherwise prepared for outages.

ACKNOWLEDGEMENTS

We are thankful to households in Hubballi–Dharwad for their participation and the enumerator team for collecting the data.

FUNDING

Funding was provided by the UMass Amherst Department of Civil and Environmental Engineering.

DATA AVAILABILITY STATEMENT

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

REFERENCES

Andey, S. P. & Kelkar, P. S. 2009 Influence of intermittent and continuous modes of water supply on domestic water consumption. *Water Resources Management* **23**, 2555–2566.

Arnold, B. F., Khush, R. S., Ramaswamy, P., London, A. G., Rajkumar, P., Ramaprabha, P., Durairaj, N., Hubbard, A. E., Balakrishnan, K. & Colford, J. M. 2010 Causal inference methods to study nonrandomized, preexisting development interventions. *Proceedings of the National Academy of Sciences* **107**, 22605–22610. https://doi.org/10.1073/pnas.1008944107.

Brauer, M., Zhao, J. T., Bennitt, F. B. & Stanaway, J. D. 2020 Global access to handwashing: implications for COVID-19 control in low-income countries. *Environmental Health Perspectives* **128**, 057005. https://doi.org/10.1289/EHP7200.

Burt, Z. & Ray, I. 2014 Storage and non-payment: persistent informalities within the formal water supply of Hubli-Dharwad, India. *Water Alternatives* **7**, 106–120.

Burt, Z., Ercümen, A., Billava, N. & Ray, I. 2018 From intermittent to continuous service: costs, benefits, equity and sustainability of water system reforms in Hubli-Dharwad, India. *World Development* **109**, 121–133. https://doi.org/10.1016/j.worlddev.2018.04.011.

Desye, B. 2021 COVID-19 pandemic and water, sanitation, and hygiene: impacts, challenges, and mitigation strategies. *Environmental Health Insights* **15**. https://doi.org/10.1177/11786302211029447.

Diamond, A. & Sekhon, J. S. 2012 Genetic matching for estimating causal effects: a general multivariate matching method for achieving balance in observational studies. *The Review of Economics and Statistics* **95**, 932–945. https://doi.org/10.1162/REST_a_00318.

Elliott, M., Foster, T., MacDonald, M. C., Harris, A. R., Schwab, K. J. & Hadwen, W. L. 2019 Addressing how multiple household water sources and uses build water resilience and support sustainable development. *npj Clean Water* **2**, 6. https://doi.org/10.1038/s41545-019-0031-4.

Ercumen, A., Arnold, B. F., Kumpel, E., Burt, Z., Ray, I., Nelson, K. & Colford Jr., J. M. 2015 Upgrading a piped water supply from intermittent to continuous delivery and association with waterborne illness: a matched cohort study in urban India. *PLoS Medicine* **12**, e1001892. https://doi.org/10.1371/journal.pmed.1001892.

ET Bureau 2020 *Karnataka Lockdown News: No More Lockdown Anywhere in Karnataka from Wednesday, Says CM BS Yediyurappa*. *The Economic Times*.

Fan, L., Liu, G., Wang, F., Ritsema, C. J. & Geissen, V. 2014 Domestic water consumption under intermittent and continuous modes of water supply. *Water Resources Management* **28**, 853–865. https://doi.org/10.1007/s11269-014-0520-7.

Freeman, M. C. & Caruso, B. A. 2020 Comment on 'Global access to handwashing: implications for COVID-19 control in low-income countries'. *Environmental Health Perspectives* **128**, 098001. https://doi.org/10.1289/EHP7852.

GoK 2021 *Government of Karnataka Department of Health & Family Welfare*. Available from: https://karunadu.karnataka.gov.in/hfw/pages/home.aspx.

Guragai, B., Takizawa, S., Hashimoto, T. & Oguma, K. 2017 Effects of inequality of supply hours on consumers' coping strategies and perceptions of intermittent water supply in Kathmandu Valley, Nepal. *Science of the Total Environment* **599–600**, 431–441. https://doi.org/10.1016/j.scitotenv.2017.04.182.

Gurung, Y., Zhao, J., Kumar KC, B., Wu, X., Suwal, B. & Whittington, D. 2017 The costs of delay in infrastructure investments: a comparison of 2001 and 2014 household water supply coping costs in the Kathmandu Valley, Nepal. *Water Resources Research* **53**, 7078–7102. https://doi.org/10.1002/2016WR019529.

Kumar, T., Post, A. E. & Ray, I. 2018 Flows, leaks and blockages in informational interventions: a field experimental study of Bangalore's water sector. *World Development* **106**, 149–160. https://doi.org/10.1016/j.worlddev.2018.01.022.

Kumpel, E. & Nelson, K. L. 2013 Comparing microbial water quality in an intermittent and continuous piped water supply. *Water Research* **47**, 5176–5188.

Kumpel, E. & Nelson, K. L. 2014 Mechanisms affecting water quality in an intermittent piped water supply. *Environmental Science & Technology* **48**, 2766–2775. https://doi.org/10.1021/es405054u.

Kumpel, E., Woelfle-Erskine, C., Ray, I. & Nelson, K. L. 2017 Measuring household consumption and waste in unmetered, intermittent piped water systems: water use in intermittent piped systems. *Water Resources Research* **53**. https://doi.org/10.1002/2016WR019702.

Lakhani, N. 2020 *Detroit Suspends Water Shutoffs over Covid-19 Fears*. The Guardian. Available from: http://www.theguardian.com/us-news/2020/mar/12/detroit-water-shutoffs-unpaid-bills-coronavirus (accessed 7 December 2021).

Menasinakai, S. 2020 One tests positive for Covid-19 in Karnataka's Dharwad | Hubballi News - Times of India. The Times of India.

NDTV 2020 *Delhi Extends Water Bill Waiver Scheme Till September 30 Amid Coronavirus Pandemic*. *NDTV.com*. Available from: https://www.ndtv.com/delhi-news/delhi-extends-water-bill-waiver-scheme-till-september-30-amid-coronavirus-pandemic-2254722 (accessed 7 December 2021).

Rajwi, T., 2021 *In Kerala, Electricity and Water Bill Arrears Pile Up During COVID-19 Pandemic*. The Hindu.

Ray, I. 2020 Viewpoint – handwashing and COVID-19: simple, right there…? *World Development* **135**, 105086. https://doi.org/10.1016/j.worlddev.2020.105086.

Ray, I., Billava, N., Burt, A., Colford Jr, J. M., Ercümen, A., Jayaramu, K. P., Kumpel, E., Nayak, N., Nelson, K. L. & Woelfle-Erskine, C. 2018 From intermittent to continuous water supply: A household-level evaluation of water system reforms in Hubli-Dharwad, Karnataka. *Economic and Political Weekly* **53** (49), 39–48.

Rohilla, S. K. 2020 *COVID-19 Outbreak: More Hand Washing Can Increase India's Water Woes*. *Down to Earth*. Available from: https://www.downtoearth.org.in/blog/water/covid-19-outbreak-more-hand-washing-canincrease-india-s-water-woes-69900 (accessed 7 December 2021).

Sayeed, A., Rahman, M. H., Bundschuh, J., Herath, I., Ahmed, F., Bhattacharya, P., Tariq, M. R., Rahman, F., Joy, M. T. I., Abid, M. T., Saha, N. & Hasan, M. T. 2021 Handwashing with soap: a concern for overuse of water amidst the COVID-19 pandemic in Bangladesh. *Groundwater for Sustainable Development* **13**, 100561. https://doi.org/10.1016/j.gsd.2021.100561.

Stoler, J., Brewis, A., Harris, L. M., Wutich, A., Pearson, A. L., Rosinger, A. Y., Schuster, R. C. & Young, S. L. 2019 Household water sharing: a missing link in international health. *International Health* **11**, 163–165. https://doi.org/10.1093/inthealth/ihy094.

Stoler, J., Jepson, W. E. & Wutich, A. 2020 Beyond handwashing: water insecurity undermines COVID-19 response in developing areas. *Journal of Global Health* **10**, 010355. https://doi.org/10.7189/jogh.10.010355.

Tortajada, C. & Biswas, A. K. 2020 COVID-19 heightens water problems around the world. *Water International* **45**, 441–442. https://doi.org/10.1080/02508060.2020.1790133.

Walton, B. 2020 Water Shutoffs Are Suspended, But the Bills Will Still Be Due. Circle of Blue. Available from: https://www.circleofblue.org/2020/world/water-shutoffs-are-suspended-but-the-bills-will-still-be-due/ (accessed 7 December 2021).

WHO/UNICEF 2021 *Progress on Household Drinking Water, Sanitation, and Hygiene 2015–2020: Five Years into the SDGs*. Joint Monitoring Programme, Geneva, Switzerland and New York, NY, USA.

Zvobgo, L. & Do, P. 2020 COVID-19 and the call for 'Safe hands': challenges facing the under-resourced municipalities that lack potable water access – a case study of Chitungwiza municipality, Zimbabwe. *Water Research X* **9**, 100074. https://doi.org/10.1016/j.wroa.2020.100074.

First received 30 July 2021; accepted in revised form 12 November 2021. Available online 24 November 2021