

Water Utilities and the COVID-19 Pandemic: A Review of Pandemic-Related Research

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ABSTRACT

To reduce the spread of the COVID-19 disease, government mandated social distancing policies (SDPs) halted the operations of non-essential businesses and changed operations at essential businesses, including water utilities. This change was difficult for some utilities to adapt to as the SDPs impacted supply chain and altered workforce management, among other operational aspects. Here, we posit that SDPs have implications for water infrastructure resiliency and technical performance, and may impact the future design, construction, and operation of water infrastructure. However, there is a dearth of literature on this topic. Therefore, we complete a literature review of sources from grey and scholarly literature to understand the impact of pandemics on water infrastructure. We found that the literature focuses on contextualizing COVID-19 within water infrastructure, direct impacts to utilities, and recommendations for immediate and future mitigation. Our research points out a gap in the literature that examines pandemic impacts on specific types of water utilities (e.g., small, rural) and identifies future research opportunities (e.g., relating water utility pandemic impacts to population dynamics). Here, we point out potential water infrastructure resiliency problems that, without intervention, could negatively impact technical system operations and public health.

INTRODUCTION

Following the World Health Organization's (WHO's) declaration of the COVID-19 (SARS-CoV-2) pandemic on March 11th, 2020 (Cucinotta and Vanelli 2020; Liu et al. 2020; Mahase 2020; Warner et al. 2020), countries began enacting social distancing policies (SDPs) to curb the spread of the virus (Sun and Zhai 2020). Businesses that were considered essential (e.g., utilities, hospitals, and grocery stores) were required to adhere to these SDPs, influencing daily operations. In the United States (U.S.), drinking water utilities were tasked with altering their status-quo operations while ensuring that their customers had access to clean water (Poch et al. 2020; Sowby 2020; Spearing et al. 2021; States 2020; Zechman Berglund et al. 2021). Similar to other industries (Cai and Luo 2020; Hobbs 2020), water utilities faced issues regarding supply chain, finances, and workforce management (Gude and Muire 2021; Spearing et al. 2021; Switzer et al. 2020). These challenges may have affected water utilities differently depending on their size, resources, or pandemic preparedness (Cooley et al. 2020; Howard et al. 2020; Rural Community

Assistantship Program 2020). For instance, smaller systems may be more susceptible to revenue losses due to their smaller customer bases (Cooley et al. 2020). Such changes caused by COVID-19 could have implications on future capital projects, affecting how utilities plan and enact capital improvements, such as the replacement of aging infrastructure (Spearing et al. 2021). Notably, one study completed a review of literature to understand COVID-19's influence on the water sector (Langone et al. 2021). This review summarizes knowledge regarding the virus's presence in wastewater and its implications to public health. Additionally, earlier works added to pandemic literature by examining emergency response plan adoption and preparation (van Atta and Newsad 2009; Hoffbuhr et al. 2006). However, these works do not examine the responsibilities and responses of water utilities during a the COVID-19 pandemic or previous pandemics/epidemics. This information would be critical in identifying resiliency issues within water infrastructure that may affect continued water service.

Here, we review existing literature to address the current gap in research regarding the impacts of the COVID-19 pandemic on U.S. drinking water utilities. To do so, we performed a systematic search of both scholarly and grey literature (i.e., sources not in scholarly journals) and qualitatively coded articles to determine the emerging trends. Based on the completed analysis, we discuss knowledge gaps and suggest future research. By recognizing areas in which studies can be expanded, this research can assist in identifying water infrastructure resiliency problems (e.g., water quality) that could have negative implications on technical system operations and public health in future pandemics.

METHODS

To understand the current trends within COVID-19 research focused on the U.S. drinking water infrastructure, we completed a literature review. Grey literature was reviewed in conjunction with scholarly literature to better account for the current availability of COVID-19 related research, given the recency of the pandemic. The search for scholarly articles was completed utilizing two databases: Web of Science and Engineering Village. These databases were chosen given their breadth of information spanning a variety of journals (Aksnes and Sivertsen 2019; Clarivate Analytics 2021; Elsevier 2021). As this study aims to review articles regarding COVID-19 in the U.S. drinking water infrastructure, the phrases "COVID-19 AND water utilities" and "pandemic AND water utilities" were used. Additionally, the singular version of the phrase (e.g., water utility) was included in the search to ensure an accurate representation of the available data. Given the expected small sample of articles, all articles were considered regardless of their source journal. The given search criteria resulted in 33 articles from Web of Science and 61 articles from Engineering Village. These articles were then filtered based on their publishing date; articles published before December 2019 (i.e., before the COVID-19 pandemic began) were not considered. Articles that focused on water utilities in countries other than the U.S. and wastewater systems were excluded, resulting in 13 articles.

A similar search was performed for grey literature. Researchers chose relevant sources from the American Water Works Association (AWWA), the Pacific Institute, and the Rural Community Assistantship Partnership (RCAP); these sources were chosen based on their known work in the water sector (e.g., resources and reports involving water infrastructure, water efficiency, and operations). Lastly, additional grey and scholarly literature sources were gathered from Google Scholar using the same search terms (e.g., "COVID-19 AND water utility/utilities" and "pandemic AND water utility/utilities") as the initial search, and a total of 100 results per search phrase were examined. After removing articles out of scope and disregarding duplicates,

13 scholarly articles and 14 grey literature pieces were included in the final sample. The process for the selection of the 13 scholarly articles is described in Figure 1.

The final 27 articles were imported into a qualitative analysis software (NVivo) for coding. An inductive analysis approach was taken to allow for emergent themes in the data (Saldaña 2016). The coding was completed by two researchers and was confirmed by an intercoder reliability check [$\kappa=0.78$]. The κ value, which is considered moderate for qualitative research (McHugh 2012), was determined based on approximately 11% of the excerpts coded.

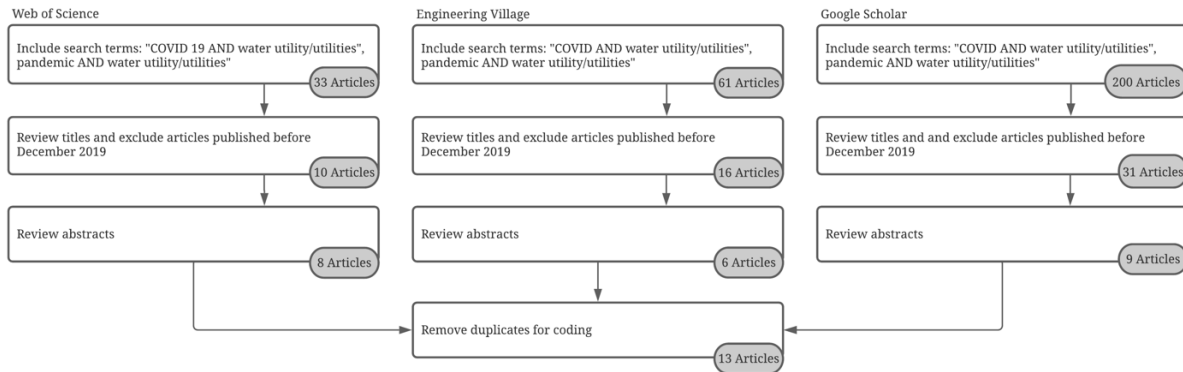


Figure 1: Selection of scholarly articles for qualitative coding

LIMITATIONS

While the analysis allows us to examine existing literature, it faces some limitations. For example, the use of Web of Science and Engineering Village may have limited the total amount of sources as not all relevant journals are on the databases. To combat this, we used Google Scholar to collect additional publications. Additionally, the sources used for this analysis were collected before the end of February 2021; this search does not take into consideration more recent articles that reflect the ongoing nature of the COVID-19 pandemic. Although articles published since February may supplement the dataset, a boundary allowed us to analyze and disseminate results quickly. Lastly, given the methodology for grey literature (e.g., a review of the first 100 search results for each search phrase, using known sources), this analysis does not represent a comprehensive sample of grey literature. Other information regarding water utilities and COVID-19 may be in other forms of literature (e.g., webinars, posters) that were not included in this analysis. Despite these limitations, the current study presents an avenue to better understand the current state of literature focused on pandemics and water infrastructure.

RESULTS AND DISCUSSION

During qualitative coding, 741 excerpts were categorized into thematic categories (i.e., contextualizing COVID-19, relating to water utilities, and future planning) as described in Tables 1-3. These categories represent the emergent topics found in the data (Saldaña 2016). A single source is only counted once in the aggregation of a parent code's file count (i.e., a single source may involve multiple child codes but will be counted once in the final total). The following sections broadly review these categories; "Relating to Water Utilities" and "Future Planning" were reviewed in the context of their common sub-categories (e.g., technical system, planning and management).

Table 1. Frequency Table of Excerpts Contextualizing COVID-19

<i>Code</i>	<i>File Count</i>	<i>Frequency</i>
Contextualizing COVID-19	24	89%
COVID-19 descriptors (origin, make-up, etc.)	6	22%
COVID-19 in water supply (concerns or evidence)	6	22%
Effects on economy	3	11%
General response to COVID-19	7	26%
Importance of water (WASH)	9	33%
Reference to other pandemics	6	22%
SDPs enacted or cleaning protocol	9	33%
Spread or transmission of COVID-19	4	15%

Table 2. Frequency Table of Excerpts Relating to Water Utilities

<i>Code</i>	<i>File Count</i>	<i>Frequency</i>
Relating to water utilities	27	100%
Digitalization of utilities	2	74%
Finances	20	71%
Additional expenses	4	15%
Cash flows, funding, and budget cutbacks	4	15%
Customer assistance programs	1	4%
Federal funding	3	11%
General	8	30%
Late payments and delinquencies	7	26%
Moratorium or shut-off	14	52%
Rate change or tariffs	5	19%
Revenue change	10	37%
General	15	56%
Mentions discrepancy between utilities of different sizes	2	7%
Utility or city case study	9	33%
Planning and management	13	48%
Capital projects	4	15%
Collaboration	5	19%
Between other entities	3	11%
Between utilities (mutual aid)	4	15%
Emergency response, continuity, or pandemic plans	4	15%
General	3	11%
Internal communication	2	7%
Maintenance	1	4%
Related to workforce (e.g., staggered shifts)	10	37%
Supply chain	8	30%
Related to the public	18	67%
Public-centered	10	37%

Equity or inequality concerns	7	26%
Public employment	4	15%
Relationship between water utilities and the public	12	44%
Moratorium (public, city, or state perspective)	4	13%
Community outreach	4	15%
Pre-existing conditions	6	22%
General relationship with water utilities	4	15%
Utility disconnections	2	7%
Technical system	15	56%
Demand changes	13	48%
By customer type	6	22%
General	12	44%
Flushing and stagnation (pre-existing or COVID-19 concerns)	4	15%
Monitoring the system or operations	3	11%
Pipe breaks	1	4%
Regulatory testing	2	7%
Risks of exposure	2	7%
Water quality (chlorination, legionella, etc.)	5	19%
Water source	1	4%

Table 3. Frequency Table of Excerpts about Future Planning

<i>Code</i>	<i>File Count</i>	<i>Frequency</i>
<i>Future planning</i>	21	78%
Future prospects of digitalization	2	7%
Recommendations	20	74%
Regarding future research or work	5	19%
Regarding public or non-utility	7	26%
Regarding water infrastructure	17	63%
Collaboration (mutual aid, federal guidance, etc.)	4	15%
Communicating to public or stakeholders	9	33%
Finances (federal funding, moratorium, etc.)	7	26%
Operations and technical system	5	19%
Policies and pandemic planning	8	30%
Tips for internal communication	1	4%
Water quality and stagnation	5	19%
Workforce management and SDPs	2	7%

Contextualizing COVID-19

In general, most articles (24 articles; 89%) made efforts to describe the origin of COVID-19 and the disease's relevance to water infrastructure. More than one-third (9 articles; 33%) of articles mentioned SDPs and cleaning protocols enacted either at the state level or within water utilities, such as handwashing and other hygiene-related protocols. Six articles (22%) drew

comparison between the COVID-19 pandemic and previous pandemics and epidemics such as the H1N1 flu (swine flu epidemic). Notably, 22% of articles discussed the possibility of the virus in the water supply, although this fear was often discussed to be unfounded. This reference was often used to describe the response of water utilities and the public. For example, one article mentioned that “misconceptions about COVID-19 and drinking water safety may at least in part explain why March 2020 sales of bottled water in the United States rose by more than half” (Heath 2020 p. 22). This viewpoint may represent the general uncertainty surrounding COVID-19 and its impacts on water infrastructure at the start of the pandemic.

Finances

The financial impact of the COVID-19 pandemic was the most frequently discussed topic, comprising 74% of the total sources. These articles primarily focused on revenue change, often citing the U.S. drinking water sector’s expected loss of \$13.9 (AWWA and AMWA 2020). Studies described this revenue change as being caused by a variety of sources, including increased spending on personal protective equipment (PPE) and delinquent payments. More than half of the studies (14 articles) referenced the financial ramifications of moratoriums on water disconnections. Although the moratoriums provide relief to customers, it is important to note that they contribute to water utilities’ revenue decreases. Four articles (15%) discussed additional expenses associated with hazard pay and new equipment. To accommodate work-from-home arrangements, utilities procured items such as computers and monitors for employees, increasing costs. Several articles mentioned the relevance of federal funding (11%) and rate changes (19%). According to one article, several utilities had planned for rate increases before the pandemic (Retzlaff 2020); however, some utilities may refrain from implementing these changes due to political influences.

Despite the detailed discussion regarding financial impacts, recommendations for finances were limited (7 articles: 26% of the sample). One article explicitly encouraged the use of customer assistantship programs to better assist customers in paying for their bills, but this recommendation was not paired with a discussion of the financial capacity needed for these programs. Some articles focused on government intervention and encouraged advocating for “federal funding for clean, safe, and affordable water access” (Rivas 2020 p. 306). By reviewing literature, we see that having a safety net of federal and state funding may be critical in ensuring that water utilities can continue providing safe and equitable services during pandemics. There are existing policy avenues for households to receive financial support to pay for water utility bills (e.g., Low-Income Household Water Assistance Program, Homeowner Assistance Fund through the American Rescue Plan Act of 2021), but few programs provide relief directly to utilities (e.g., Drinking Water State Revolving Loan Funds; Environmental Protection Agency 2021). Our review of literature emphasizes the importance of expanding relief funding for water utilities to deal with pandemic induced financial challenges.

Technical System

More than half (56%) of the analyzed articles referenced impacts to water utilities’ technical systems. 13 articles (48% of the entire sample) mentioned demand changes either through observations at the utility level (e.g., meter reading) or estimations based on the shutdown of many commercial businesses. 22% of the sample went on to discern demand changes by customer type (e.g., residential, commercial). Overall, the literature shows that a decrease in demand was seen for utilities with a mixed customer type. Other topics were primarily related to water utility operations. Multiple articles discussed monitoring and controlling the water system;

two articles referenced digitalization of water infrastructure, while three articles discussed the importance of measurement and documentation of water quality and quantity. These articles highlighted the pandemic's potential of increasing modernization in water utilities. Funding efforts for this digitalization could assist in technologically advancing the water sector's management capabilities. Additionally, 19% of the articles mentioned water quality concerns associated with the shutdown of non-essential businesses. In response to this phenomenon, four articles (15%) discussed the necessity of flushing to reduce risks affiliated with increased water age. Lesser discussed topics included risk of exposure for operators (7%) and regulatory testing (7%).

Technical system-related recommendations focused primarily on water quality and operations, each representing 19% of the sample. Recommendations included retrofitting of office space to include heating, ventilation, and air-conditioning (HVAC) system checks, increasing digitalization of the system, and monitoring potential leaks to safeguard against recontamination of water. On the water quality side, recommendations focused on the need for water professionals to inspect cases of stagnant water. These suggestions demonstrate that there may be a shift in the equipment used by water utilities in the future. If followed, these changes would have direct implications on utility performance and operation, possibly accelerating technological innovation.

Planning and Management

Topics involving planning and management comprised just 48% of the articles. The majority of this group broadly referred to workforce management (10 articles: 37% of the total sample). These articles mainly discussed work-from-home arrangements, staggered shifts for in-person work, or a potential workforce shortage. Concerning workforce management, two articles (7%) mentioned how internal communication was used to relay information to the affected workforce. Additionally, 30% of articles discussed supply chain management often citing the need to stockpile PPE. One article went further, mentioning that "keeping up with the major vendors was necessary to ensure that they could [acquire] chemicals the utility needs to maintain water treatment and water systems upgrades and repairs" (Gude and Muire 2021 p. 7). The topic of collaboration (19% of the articles) also emerged as authors referenced utilities working with each other and other entities to combat challenges posed by the COVID-19 pandemic. In the realm of planning, 15% of the articles referred to capital projects and how they would be impacted by COVID-19. For example, these articles discussed how some capital projects were accelerated due to reduced water demand while others were deferred due to financial uncertainty. Notably, only 15% of the sample discussed emergency or contingency planning.

A majority of the recommendations in this category were related to policies and pandemic planning; these articles provided advice on creating effective resilience plans for future pandemic scenarios. Only two articles in the sample discussed recommendations for workforce management and enacting SDPs at the workplace (Gude and Muire 2021; States 2020). In addition, one article provided insight on improving internal communication to ensure the reduction of misinformation (Retzlaff 2020). Although suggestions on this subject matter were minimal, utilities may have received this information from internal webinars and sources outside of the scope of this literature review. Lastly, 15% of the sample advised water utilities to consider mutual aid and partnerships with organizations as a part of their resiliency planning initiatives. Strengthening pandemic plans and communication networks could improve utility resiliency not only in pandemic scenarios but also during status quo operations and other disasters.

Relating to the Public

Many articles focused on the public (37%) or observing the relationship between water utilities and the public (44%). Public-centered articles discussed equity or inequality concerns (26% of articles), either in direct relation to COVID-19 or describing potential implications of existing problems (e.g., low-income customers facing disconnections due to non-payment before the pandemic). Half of the articles that looked at the relationship between utilities and the public (22% of the total sample) were concerned with pre-existing conditions. For example, two articles (7%) pointed out previous histories of enacting or banning disconnections. Moratoriums on disconnections that focused on the public, city, or state perspective were also discussed, comprising 15% of the total sample. Contrary to utilities' viewpoints, these articles discussed the relationship between moratoriums and public affordability. Lastly, several articles (15%) mentioned communicating with the public; two of these articles were from the perspective of a single utility. Recommendations related to the public either focused on improving communication efforts to customers (33%) or a general call to action for local, state, and federal agencies for additional funding or policy change (26%). This literature shows that strengthening the relationship between utilities and the public would be beneficial in reducing panic and misinformation.

FUTURE RESEARCH OPPORTUNITIES

The analyzed studies focus on preliminary COVID-19 concerns in water infrastructure. This is evident through the nature of the three thematic categories (i.e., contextualizing COVID-19, relating to water utilities, and future planning). For example, several articles referenced the later unfounded suspicion of COVID-19 exposure risk in the water supply and recommendations for immediate action for water utility operations. Additionally, 33% of the articles were either entirely from the perspective of a single utility or provided data from specific utilities. Despite providing useful information regarding immediate impacts on water utilities, the literature exemplifies more of an observational account of the pandemic's relationship with U.S. water utilities rather than an analytical view that observes impacts in terms of other metrics (e.g., population dynamics, water quality).

This gap presents several avenues for future research that examine 1) customer size, 2) geographic location, and 3) implementation of moratoriums in the context of water utilities and the COVID-19 pandemic. For example, only two of the reviewed articles mentioned potential discrepancies between utilities with different customer sizes. The observational data may suggest differential impacts, but the literature does not describe the potential causes (e.g., contrast in available resources, financial capacity). Therefore, future work should expand on this through a review of COVID-19 impacts on water utilities of different sizes and access to resources. Furthermore, these impacts can be observed within different geographical contexts to determine if certain COVID-19 challenges are more common in select regions. Additionally, our literature review revealed a need in examining how to effectively implement water moratoriums, especially policies about funding support (i.e., state and federal governments should also create a funding mechanism to aid utilities during moratoriums). Without providing funding to water utilities, their financial capacity may decrease, leading to a lack of investments and compounding existing issues. Research on water moratoriums may be relevant to future economic crises as well as pandemics.

CONCLUSION

Understanding how water utilities were impacted during the COVID-19 pandemic will help utilities prepare for future pandemics and understand possible repercussions of the COVID-19 pandemic. Here, we completed a review of the grey and scholarly literature related to COVID-19 and the U.S. drinking water infrastructure. Through qualitative coding of 27 articles, we observed that the existing research focuses on contextualizing COVID-19's impacts on water infrastructure, direct impacts on drinking water utilities, and recommendations for immediate action. Given the recency of the COVID-19 pandemic, there are gaps in the literature that we have noted, such as the need to study a pandemic's differing impact on rural and urban water systems. Additionally, studies should examine the difference between challenges faced by water utilities of different sizes and in various geographies. Such work may reveal insights into which water systems need support during crises, creating more resilient systems.

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