Connecting Pre-existing Characteristics of Water Utilities to Impacts during the COVID-19 Pandemic

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ABSTRACT

The COVID-19 pandemic changed the way societies operate. Consequentially, the public, businesses, and industry used water differently, leading to changes in overall demand, along with spatial shifts in use. These changes stressed US water utilities, as they had to implement social distancing policies, adjust to changing revenues, and create customer assistance programs. The capabilities and characteristics of water utilities vary throughout the US, which may impact their resilience. Here, we aim to understand which pre-existing characteristics of water utilities may have led to resilience during the pandemic using results from a qualitative analysis of interviews with 27 US utilities conducted during 2020. We searched for statistical associations between utility characteristics (e.g., population dynamics, geographic location) and the challenges or changes experienced during the pandemic. Results of this study reveal the possible operating environments that increase the resilience of pandemic-induced shocks and help utilities prepare for future pandemics or population dynamics.

INTRODUCTION

Water infrastructure systems are built based on assumptions about the operating context in which they exist. For instance, engineers assume certain human-infrastructure interactions—how people use their systems (e.g., peak demands). Although systems are managed based on assumed population changes (e.g., steady growth) and emergency response plans (ERPs) are often present and required to be updated every five years (US EPA 2021), disasters can impact physical systems and stress existing management protocols. Such disaster-induced challenges may impact water utilities' financial capacity, physical operations, and even cascade to impact society. For instance, disaster-induced displacement after the California Camp Fire created challenges as water utilities adapted to serve the existing and new populations (Spearing and Faust 2020). Further, physical damage from disasters can impact water infrastructure systems (e.g., hurricanes might impact the water supply; Bigger et al. 2009). More recently, the COVID-19 pandemic has caused unexpected water infrastructure challenges (Berglund et al. 2021; Cotterill et al. 2020; Spearing et al. 2020a).

The COVID-19 pandemic (SARS-CoV-2) led many countries to implement social distancing policies to reduce disease spread. These policies altered how society functions, leading schools and businesses to close, travel to diminish, and people to stay at home. In turn, people began using their water systems differently, drastically altering human-infrastructure interactions and thus placing stress on water utilities (Spearing et al. 2020a). Many utilities saw a reduction in citywide demand due to decreased commercial and industrial activity. Additionally, water utilities—often spurred by state policies—enacted moratoriums on water service shutoffs to support users during the COVID-19 financial crisis (Warner et al. 2020). These delinquent accounts, paired with decreased demand, led to reduced revenues at many utilities. This decrease in financial capacity had negative short-term, as well as long-term effects on capital projects, operations, and maintenance. For instance, some utilities postponed capital projects during the pandemic, reduced proactive monitoring, or suspended non-critical maintenance (Spearing et al. 2020a). Conversely, other utilities continued with little adaptations, indicating resilience to these financial and operational shocks (Spearing et al. 2020a).

We expect that resilience to the COVID-19 pandemic varied based on utility characteristics (e.g., rural versus urban; Cutter et al. 2016). For instance, revenue loss may have a greater impact on small utilities because they have a smaller customer base to counteract losses (Cooley et al. 2020). In fact, the Rural Community Assistance Partnership estimated that small, rural water utilities in the US have lost between $3.6 and $5.58 billion in revenues during the pandemic (RCAP 2020). Additionally, water system resilience may vary based on geographic location—water systems may be less resilient to system shocks in the Northeast and Midwest as these systems are older and aging (Casey 2020). Further, utilities in shrinking cities, which are common in the Midwest and Northeast, may be more likely to experience challenges due to their already reduced financial capacity (Faust et al. 2015, 2017).

Recognizing the potential impacts of disasters (or other crises) on water infrastructure, water utilities and researchers alike have studied the resilience of water systems (Faust and Kaminsky 2017; McDaniels et al. 2008; Morley 2019). For instance, researchers have studied how natural disasters (e.g., Hurricanes Katrina and Rita; Leavitt and Kiefer 2006; Matthews 2016) and population displacement have impacted water infrastructure systems (Faust and Kaminsky 2017). Much of this existing work focuses on discrete events in a specific geographic location or context (e.g., Butte County, Spearing and Faust 2020; New Orleans/Lake Charles, Matthews 2016). On the other hand, little research has explored the provision of water infrastructure during protracted crises (e.g., refugee crisis in Germany; Kaminsky and Faust 2017). The COVID-19 pandemic is a unique protracted event as its impacts were experienced globally, allowing for comparison between water utilities with varying characteristics, located across geographies.

Here, we aim to identify the pre-existing characteristics of water utilities that are associated with financial resilience during the COVID-19 pandemic when there is a temporary spatial redistribution of populations. We specifically focus on financial resilience because of the largescale financial losses experienced in the water sector during COVID-19 (AWWA and AMWA, 2020). To do so, we use results from a qualitative analysis of 29 semi-structured interviews with over 50 practitioners, spanning 27 US utilities. Here, we view resilience as "the resistive and adaptive capacities that support infrastructure functionality in times of crisis or stress, such as natural hazards" (Opdyke et al. 2017 p. 774). Using this definition, we used four utility challenges or changes to understand resilience: 1) no increase in delinquent accounts, 2) increase or no change in revenue, 3) increase or no change in demand, and 4) no deferrals of capital projects. These factors allow us to understand utilities' financial (also called economic) resilience, as well as overlaps with other resilience dimensions (e.g., social, infrastructure; Opdyke et al. 2017). Inferential statistics were used to assess relationships between these resilience factors and three utility characteristics: 1) US region, 2) number of customers served, and 3) population dynamics that indicate if the city is shrinking, stabilizing, or growing. This study fills a gap in literature about which types of utilities were resilient to COVID-19 impacts, informing policy and practical recommendations. For instance, if utilities located in the Northeast were less resilient to COVID-19, policies may provide extra support to help these utilities prepare for future pandemics (e.g., increased tools for financial capacity development).

METHODS

Data Sources

Here, we frame resilience as whether utilities experienced challenges or changes during the COVID-19 protracted crisis. To understand these challenges, we use results from a qualitative analysis of semi-structured interviews and focus groups with 28 US utilities (see Spearing et al. 2020a). In the current paper, we use 27 utilities as one utility was a university which has different governance structures. These interviews were conducted from June 8th, 2020 to August 3rd, 2020, capturing resilience to shocks experienced early in the pandemic. More information about the data collection and participating utilities is available in Spearing et al. (2020a).

In the current study, we use four challenges or system changes, called resilience factors: 1) overall demand changes, 2) overall revenue changes, 3) increase in delinquent accounts, and 4) delays in capital projects. Based on Opdyke et al.'s (2017) work on disaster resilience of infrastructure systems, we conceptualize these as forms of financial (also known as economic), social, or infrastructure system resilience (see Figure 1). Here, we focus on financial resilience, but many aspects of financial resilience overlap with social and technical systems. For instance, utilities' financial state is dependent on if customers are able to pay their bills so delinquent accounts can be conceptualized as financial and social resilience. On the other hand, demand changes are related to all three dimensions of resilience as customers drive the demand change (i.e., social) which may cause operational changes (e.g., pressure changes; i.e., infrastructure) and revenue changes (i.e., financial). Lastly, capital project deferral is related to both financial and technical resilience because financial limitations lead to delayed projects which contributes to infrastructure challenges, such as aging infrastructure.

Utility characteristics were collected from publicly available sources, such as the US Census Bureau and utilities' websites. Geographic locations were based on the US Census Bureau's definition (U.S. Census Bureau 2010) and the utility sizes were determined using EPA's classification (U.S. EPA 2006). Lastly, population dynamics—whether a city is shrinking, growing, or stabilizing—was calculated using population data from 1930 to 2019 and the classification method presented in Spearing et al. (2020b). Tables 1-2 show the descriptive statistics of the utility characteristics and COVID-19 related challenges.

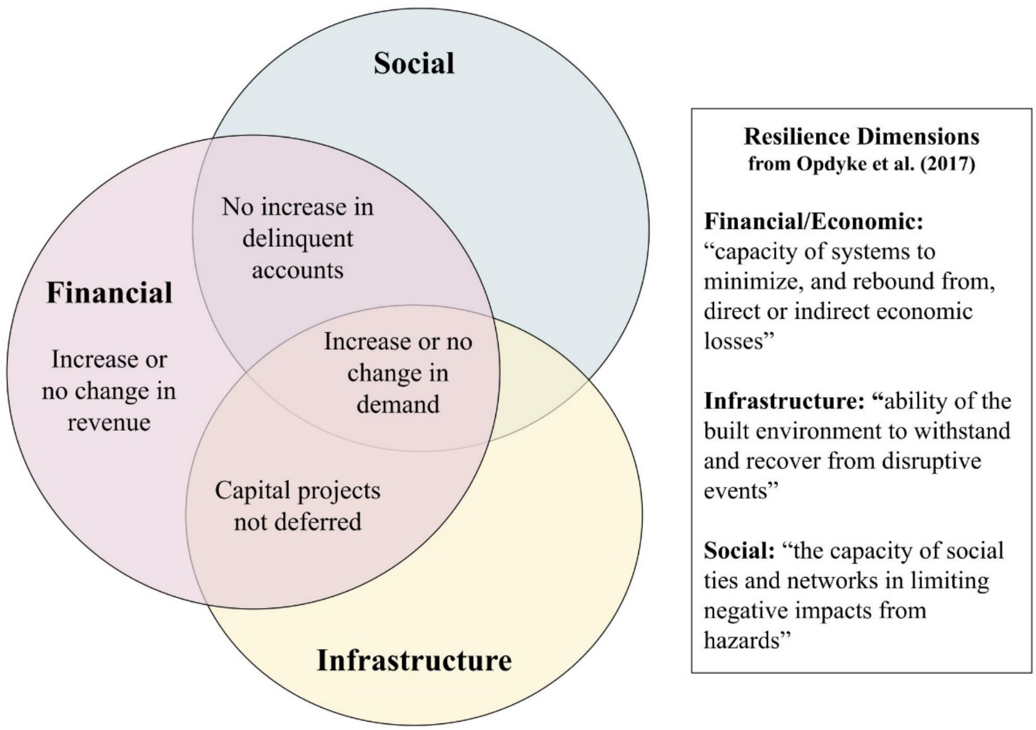

Figure 1. Resilience conceptualization of COVID-19 impacts on water utilities (based on dimensions defined in Opdyke et al. 2017). Text shown in the Venn diagram are system challenges/changes of interest and what type of resilience they represent. Definitions of resilience dimensions are shown on the right.

Statistical Tests and Thematic Mapping

To understand the association between utility characteristics and utilities' self-reported financial and operational challenges during the COVID-19 pandemic, we performed Fischer exact tests (Washington et al. 2010). Fischer exact tests were used instead of chi-squared tests because over 20% of cells had expected frequencies of less than five, limiting the reliability of chi-squared results (Washington et al. 2010). Some categories were combined to perform statistical tests (e.g., shrinking and stabilizing were combined), indicated with an asterisk in Tables 1-2. Using the statistical test results, we created thematic maps to visualize trends in resilience.

Table 1. Descriptive Statistics of Resilience Factors

Resilience Factors		Number of Utilities	Percent of Utilities
Revenue Change	Increase*	2	7%
	No Change*	5	19%
	Decrease	12	44%
	Unknown/Unsure	8	30%
Demand Change	Increase*	3	11%
	No Change*	9	33%
	Decrease	9	33%
	Unknown/No Data	6	22%
Increase in Delinquent Accounts	Yes	13	48%
	No	3	11%
	Unknown/Unsure	11	41%
Delays in Capital Projects	Yes	11	41%
	No	8	30%
	Unknown/Unsure	8	30%

*Variables were combined during statistical tests
Note: Some percentages may not add to 100% due to rounding

Table 2. Descriptive Statistics of Utility Characteristics

Utility Characteristics		Number of Utilities	Percent of Utilities
US Region	West	17	63%
	South*	5	19%
	Northeast*	3	11%
	Midwest*	2	7%
Number of Customers	10,001 – 100,000*	6	22%
	100,000 – 1 million	15	56%
	> 1 million*	6	22%
Population Dynamics	Growing	18	67%
	Stabilizing*	6	22%
	Shrinking*	3	11%

*Variables were combined during statistical tests
Note: Some percentages may not add to 100% due to rounding

RESULTS AND DISCUSSION

Table 3 shows the results of the Fischer exact tests. Interestingly, only one relationship was found significant. We see that there is a statistical association between geographic location and demand change. To visualize this relationship, a thematic map is shown as Figure 2. Due to the expected relationship between demand and revenue, we also include a thematic map of revenue change (Figure 3).

Table 3. Results of Fischer Exact Tests

	US Region	Number of Customers Served	Population Dynamics
Revenue Change	1.00	0.350	1.00
Demand Change	**0.0318***	0.387	0.331
Increase in Delinquent Accounts	0.489	1.00	0.489
Delays in Capital Projects	1.00	1.00	0.633

*Statistically significant at 0.05

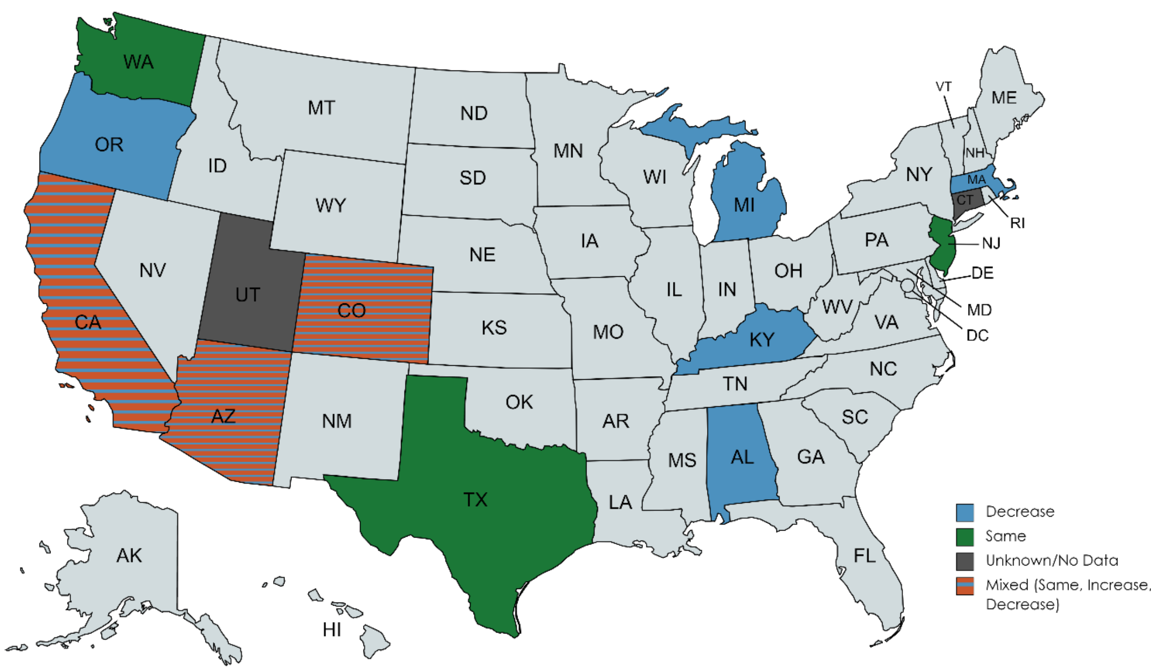

Figure 2. Demand Change ("MapChart" 2021)

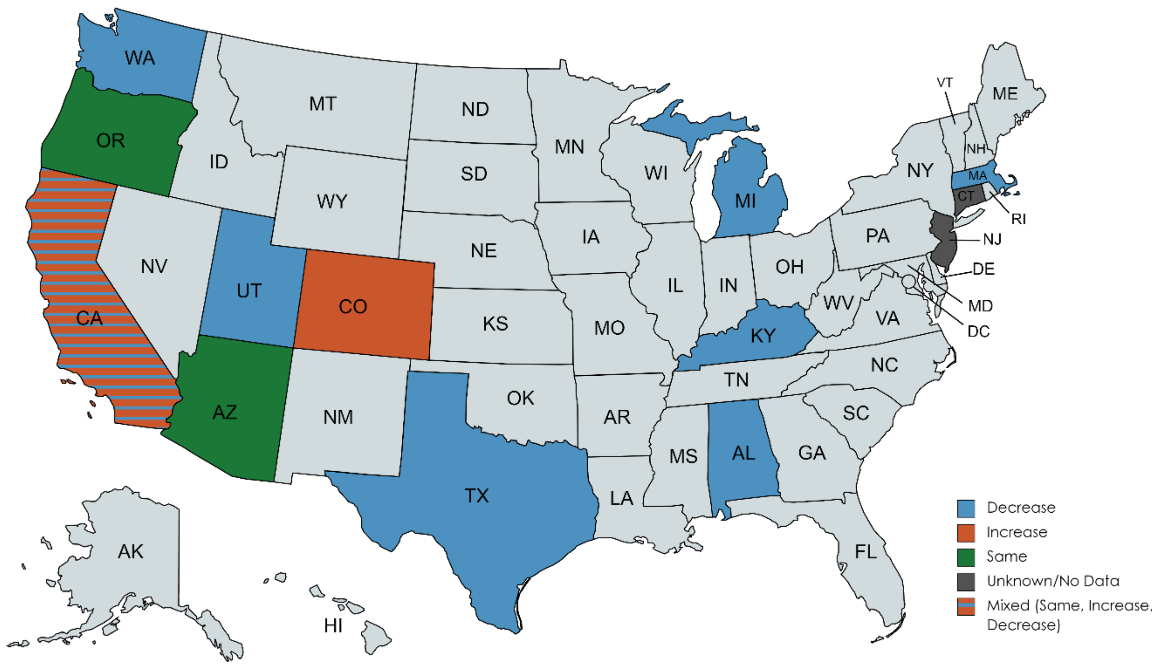

Figure 3. Revenue Change ("MapChart" 2021)

Here, we see that utilities in the West tended to see an increase or no change in overall demand as compared to utilities in other geographic regions (see the thematic map shown in Figure 2). Utilities in the West may have experienced little demand changes due to the rapidly growing nature of the region (US Census Bureau 2020). Here, we see that context matters when studying the resilience of water infrastructure systems, a trend present in other disasters (Faust and Kaminsky 2017). Oftentimes, planning recommendations and requirements (e.g., ERPs) are based on the federal level; yet we see that there are notable differences in resilience based on locality. In turn, we recommend that policies be put in place at a state or local level to adjust for geographical variations. For instance, states may provide extra instructions and resources as utilities create their federally required ERPs (per America's Water Infrastructure Act of 2018 Section 2013b; US EPA 2021).

Although revenue change was not found significant in any of the statistical tests, we can still use overall trends to gain insight into possible factors that influence resilience. Interestingly, all utilities that saw an increase or no change in revenue were located in the western half of the country (e.g., Colorado, California, Oregon), while utilities in the Northeast and Midwest tended to experience decreased revenue (see Figure 3). This revenue change is in part due to the demand changes previously discussed (shown in Figure 2), but delinquent accounts may impact overall revenue. Although no utility characteristics were found to be significantly associated with a change in delinquent accounts, late payments may be creating a revenue deficit at utilities. This is especially likely for utilities in states that mandated water moratoriums. All the states represented in our sample that did not implement a moratorium were located in the South or West. In turn, utilities in these states may not have had a moratorium in place, contributing to the trends in revenue seen in Figure 3. Future work should investigate the financial impact of moratoriums (or similar policies) on water utilities.

It is surprising that utility size was not found significant for any resilience factor because we would expect utilities with a smaller customer base to experience financial challenges because they may not be able to absorb financial shocks (Cooley et al. 2020). Notably, the majority of utilities interviewed (78%) were medium to large utilities (over 100,000 customers), and none of the utilities were characterized as a small water system (US EPA 2020). In turn, our analysis may not have captured variances between large and small utilities, explaining the lack of significance in the results. Future studies should analyze small water system's resilience to the COVID-19 pandemic to capture any challenges specific to those utilities. Based on previous literature, we would expect that shrinking or stabilizing cities would experience more challenges because population decline might reduce the tax base, and consequentially utility revenues (Cutter et al. 2016; Faust et al. 2015, 2017). This trend of population dynamics may be captured in the geographic region variable. Many shrinking cities are located in the Midwest and few are located in the West. In fact, of the top 15 fastest-declining large cities between 2010 and 2019, nine are located in the Midwest and zero are located in the West.

LIMITATIONS

As with any research study, limitations are present. First, we used self-reported data to understand resilience, which could lead to bias. When conducting the interviews, we noted that utilities were eager to share the challenges experienced in order to help utilities respond to future pandemics. Additionally, this bias was reduced by following a rigorous qualitative protocol (Saldana 2013) when analyzing interview data for the resilience factors. Another limitation is that the independence tests used are only identifying the presence or lack of statistical association and no information is provided about the type of associations. Moreover, we have a relatively small sample size for statistical tests (Washington et al. 2010); however, our results are useful to reduce the uncertainty surrounding the understanding of the COVID-19 pandemic, due to limited literature about water infrastructure and pandemics.

It is important to note that at the time of data collection, many utilities were unsure of COVID-19 impacts because it was early in the pandemic (June-August 2020; see Table 1). This uncertainty limited the statistical tests performed in the current study. Despite this, we are able to make a first step to understand how different types of utilities were impacted by the COVID-19 pandemic, reducing the epistemic uncertainty discussed in literature (Berglund et al. 2021). Future research could expand on this work to include a larger sample size and allow the time needed for utilities to assess the COVID-19 impacts.

CONCLUSION

The current study explored the association between US water utilities' resilience during the COVID-19 pandemic and the utilities' pre-existing characteristics (geographic location, number of customers, and population dynamics). To understand resilience, we used financial, social, and infrastructure system resilience dimensions. We used results from a qualitative analysis of semi-structured interviews with 27 utilities throughout the US to identify four resilience factors—demand change, revenue change, increase in delinquent accounts, and deferring capital projects. Results revealed that demand change was significantly associated with geographic region, while all other statistical tests were not found significant. The trends identified and discussed in the current study will help policymakers understand which utilities may need increased support to develop financial capacity and improve disaster resilience. For instance, water utilities located in the eastern side of the US may need additional financial management tools to understand how to continuously update aging infrastructure. During a financial crisis, additional financial support to ensure these utilities have the capacity to continue the provision of services may be warranted.

In this study, we took a first step to understand how water utilities' resilience towards prolonged disasters varies based on utility characteristics. The COVID-19 pandemic provided a unique opportunity to understand which types of utilities may struggle in future disasters because the pandemic impacted utilities throughout the US. The trends revealed in this analysis can be used by authorities when preparing for future financial shocks, such as economic depressions, or disaster scenarios, such as hurricanes. Future work should investigate other aspects of resilience and explore these trends found here further using regression models to isolate the impacts of each utility characteristic on disaster resilience. Moreover, future avenues of work might expand on the variables used to assess the different dimensions of resilience among water utilities.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 2032434/2032429 and the National Science Foundation Graduate Research Fellowship Program under Grant No. DGE-1610403.

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