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How does Water System Ownership Relate to Monitoring and Reporting Violations in the United States?

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ABSTRACT: The Safe Drinking Water Act (SDWA) regulates public water systems (PWSs) in the United States (US), serving as a safeguard for public health. Management and resource challenges at utilities can lead to violations of the SDWA, evidenced by the fact that 27 percent of active PWSs were reported to have violated at least one drinking water standard in 2022. SDWA violations can be either health-based violations (HBVs) or non-health-based violations (NHBVs). NHBVs indicate failure to report, monitor, and communicate water quality, helping to ensure that communities are adequately informed of the risks in their water systems and enabling the protection of public health. Notably, most research has focused on HBVs alone, not considering the necessity of robust monitoring and reporting. Filling this gap, we investigate monitoring and reporting violations (a subset of NHBVs) across the US using exploratory analysis of publicly available data and Mood's Median tests. Specifically, we focus on ownership type (e.g., private, public, public-private), examining how socioeconomic and demographic characteristics differ between communities served by utilities experiencing monitoring and reporting violations versus those who are not. This work provides insight about the communities that might be disproportionately impacted by inadequate monitoring and reporting. Results show that monitoring and reporting violations tend to occur in communities with higher social vulnerability, with this trend more evident in publicly owned systems. These findings shed light on which communities face increased risk, helping to guide the provision of funding and support for drinking water management.

1. INTRODUCTION

In the United States (US), it is estimated that 9 out of every 10 people, about 300 million total, receive their tap water from publicly regulated water systems, making their monitoring and regulation crucial for public health (CDC, 2024). The Safe Drinking Water Act (SDWA) was enacted in 1974 to further these efforts and ensure safe and clean drinking water. Through this legislation, the Environmental Protection Agency (EPA), regulates all US public water systems (PWSs), setting legal limits and enforcing protective standards for over 90 contaminants, from chemical contaminants like lead and arsenic to harmful microbial pathogens. These regulations are critical to maintaining drinking water standards and minimizing risks to public health.

While the SDWA provides important standards, utilities can sometimes fall short of meeting these regulations. For example, in 2022, 27 percent of active PWSs in the US were reported to have violated at least one drinking water standard (EPA, 2024). This noncompliance poses a serious threat to public health, with contaminated drinking water being linked to gastrointestinal illnesses, nervous system or reproductive effects, and chronic diseases (EPA, 2024; Fawell, 2003; Rahman, 2009; Ashbolt, 2004). Waterborne pathogens are estimated to cause 7.15 million illnesses, 118,000 hospitalizations, and 6,630 deaths annually in the US, with 40 percent of these hospitalizations and 50 percent of these deaths being associated with drinking water exposure (CDC, 2024). Collectively, waterborne pathogen exposure results in $3.33 billion in direct health care costs across the country annually (CDC, 2024).

Drinking water violations are split into two categories—health-based violations (HBVs) and non-health-based violations (NHBVs). HBVs include reported issues with maximum contaminant levels, maximum residual disinfectant levels, and treatment techniques. On the other hand, NHBVs concern inadequate water quality monitoring and reporting, public notification, and consumer confidence reporting violations. NHBVs are most common at very small utilities serving under 500 people, indicating potential links between managerial and resource-based constraints and noncompliance (Rubin, 2013). For example, many utilities in rural Alaska receive NHBVs due to supply chain constraints when transporting water samples to laboratories (Spearing, 2022). Poor water quality poses a threat to public health, and proper monitoring and reporting is the first step in recognizing when water has been contaminated and alerting the managers, regulators, and customers of an issue. Understanding what drives NHBVs and taking steps towards their mitigation is crucial for ensuring improved water quality, prompting this study's focus on monitoring and reporting violations, a subset of NHBVs.

Most literature has focused on HBVs, given the immediate health risks associated with such violations. These studies are largely at the state level and focus on community water systems (CWSs), which are a type of PWS that have at least 15 service connections or regularly serve an average of 25 individuals or more for at least 60 days out of the year. Previous research on drinking water violations has explored the demographic factors correlated with water system noncompliance, finding disparate results. One study in California found that HBV rates are several times higher for systems serving low-income areas, even when system size is controlled for (Allaire, 2022). Communities with a higher percentage of the population below the poverty line have also been found to experience increased instances of HBVs (Switzer, 2017). Similar work found high-income areas to be more likely to have better water quality, but this relationship between social vulnerability and compliance did not hold in other areas, where higher educational attainment and increased home ownership were associated with higher odds of HBVs (McDonald, 2018). In another study, evidence that HBVs were associated with socioeconomic status was not found; however, smaller CWSs serving rural areas were less likely to be compliant (Statman-Weil, 2020).

In addition to sociodemographic trends, ownership has been tied to non-compliance. CWSs can be managed publicly, privately, with a combination of public and private management, or by Native American tribes, with each ownership type having a unique impact on the probability of violation. Public/private systems have been identified as having the highest level of compliance to health-based regulations, potentially due to the mix of private capital and institutional support that maximizes resources provided by public/private partnerships (Rahman, 2010). Similar findings identify state ownership, groundwater dependence, and rural location as factors in noncompliance at the state level (Kirchhoff, 2019).

Few studies have focused on NHBVs, such as monitoring and reporting violations. However, researchers have found that most facilities experiencing any noncompliance in 2011 had monitoring and reporting violations, with smaller systems being most likely to have such violations (Rubin, 2013). Another study explored the prevalence of monitoring and reporting violations, showing the predicted number of monitoring and reporting violations to be 10 times larger than the predicted number of contaminant violations (Wallsten, 2008). This study also highlighted that risk factors are different across violation types, system sizes, and ownership types, noting that, "privately-owned systems report somewhat fewer contaminant violations than do locally-owned systems, but somewhat more monitoring and reporting violations" (Wallsten, 2008).

The prevalence of monitoring and reporting violations has significant consequences for public health and quality of life. Monitoring and reporting violations might shield HBVs at facilities as these violations may not be found and properly recorded. This historic trend is shown in an EPA audit of drinking water data from 2002 to 2004, which found that only 62 percent of HBVs were reported to the EPA (EPA, 2008). Improper monitoring and reporting of drinking water violations creates gaps in the data that form the basis for previous and ongoing research conducted on HBVs as well as inform federal and state decision-making. Violations in monitoring and reporting also highlight management challenges, particularly in underserved communities. These can be addressed through resource allocation across different ownership types to increase management capacity in communities with sociodemographic characteristics that are linked to a higher prevalence of violation. Lack of monitoring and reporting also puts impacted communities at a heightened risk of exposure to unknown contaminants. As such, communities without reliable monitoring and reporting data are at a significant risk.

The complexity of relationships between monitoring and reporting violations, system ownership, and sociodemographic characteristics of the area served, as well as the lack of research on NHBVs, motivates our analysis. Here, we explore the relationships between sociodemographic factors and monitoring and reporting violations and determine how such relationships differ based on system ownership. We focus on monitoring and reporting specifically because these violations are a first step to understand the system status, with public notification and consumer confidence reporting only being possible after adequate monitoring and reporting. For sociodemographic variables, we focus on population density, education, median household income, employment, homeownership, and health insurance coverage. In this study, we ask the following questions: 1) how does monitoring and reporting compliance change across community water system ownership types? 2) how do sociodemographic characteristics change across system ownership types? and 3) how do trends between sociodemographic characteristics and monitoring and reporting compliance differ across ownership types? To answer these questions, we conducted an exploratory data analysis and Mood's Median tests.

2. METHODS

We used publicly available data from the American Community Survey and EPA's Safe Drinking Water Information System (SDWIS) accessed through the National Historical Geographic Information System and the EPA's Enforcement and Compliance History Online (ECHO) database (NHGIS, 2025; ECHO, 2025). We limited our analysis to only CWSs that were listed as active and currently serve residential communities year-round, making our comparison to demographics more accurate as these systems serve relatively stable communities. This resulted in a sample size of 47,969 utilities. Non-compliance was determined based on whether a facility had a monitoring and reporting violation that began between 2019 and 2023, represented as a binary variable (1—had a violation, 0—did not have a violation). We grouped ownership into three categories: public (i.e., federal, state, or local government), private, and public/private. Native American-owned systems were removed due to the small sample size, which limited statistically inferable results. The sample distribution across ownership types and compliance status are shown in Table 1.

Table 1: CWSs by Ownership Type and Monitoring and Reporting Violation Status

Violation Status/ Ownership Type	Total	Public	Private	Public/ Private	Native American
Violation	22,481	11,495	10,239	681	66*
No Violation	25,488	13,207	11,771	497	13*
Total	47,969	24,702	22,010	1,178	79*

*not included in analysis

To collect sociodemographic data, we used the 2023 American Community Survey 5-Year Data, which reflects estimated averages from 2019 to 2023 and is the most recent 5-year data available. Demographics were collected at the county level because geographic matching information was available at this scale through the ECHO database. The sociodemographic variables collected are summarized in Table 2. Geographic codes were gathered from the ECHO database to allow for matching county demographic data

to each system. After combining this information and removing all values that could not be matched, our sample included 47,890 CWSs, with 24,702 public, 22,010 private, and 1,178 public/private.

Table 2: Sociodemographic Variables of Interest

Variables	Metric	Mean	Median	Std Dev
Population Density	Total population divided by county area (population/km^2)	136	38.0	276
Education	Proportion of total population with at least a high school diploma/GED	0.896	0.907	0.051
Median Household Income	Median household income in the past 12 months (2023 US$)	73,300	70,300	19,700
Employment	Proportion of civilian labor force aged 20-64 years that is employed	0.953	0.956	0.021
Homeownership	Proportion of total occupied housing units that are owner-occupied	0.712	0.723	0.083
Health Insurance Coverage	Proportion of total population with any form of health insurance	0.912	0.923	0.046

To analyze the data, we first conducted a visual analysis by creating pie and bar charts of monitoring and reporting violations by ownership type. We then performed a Shapiro-Wilks test for normality, revealing that most of the variable distributions were likely not normal. Only median household income and employment values for total systems without violations had a p-value over 0.05 when tested against the null hypothesis of normality (Riffenburgh, 2006). These results prompted us to use Mood's Median test to determine the differences between median demographic values in communities surrounding systems with and without monitoring and reporting violations. Mood's Median is a type of hypothesis testing that compares the observed distribution of data for two different groups, with the null hypothesis that both groups have the same underlying median. This test determines the probability that our observed data would have its current distributions if the null hypothesis were true (Colgate, 2025). Once it was determined that there were statistically significant differences in median values of many sociodemographic factors across groups, we created 95 percent confidence intervals, based on 10,000 bootstrap replicas, to indicate directionality and variation in these medians for comparison. This analysis was designed to evaluate if community characteristics are similar between systems with and without monitoring and reporting violations and across different ownership types.

3. RESULTS AND DISCUSSION

Figure 1 shows descriptive statistics of utilities' ownership and monitoring and reporting compliance. Most systems are either entirely publicly or privately owned, with only about 2.5 percent of systems being managed through public/private partnerships. In total, 22,481 systems were found to have at least one monitoring and reporting violation that began between 2019 and 2023, accounting for about 47 percent of our sample. The highest number of violating systems were privately owned, but public/private systems had the highest proportion of systems in violation, with 57.8 percent of these systems experiencing at least one monitoring and reporting violation (see Figure 1). This finding is contrary to previous evidence that public/private systems have a higher rate of compliance to maximum contaminant level regulations due to the structural support of public ownership combined with the financial backing of private investors (Rahman, 2010). The differences in the proportion of violations across ownership types are because different factors influence HBV versus NHBV compliance. Monitoring and reporting are largely management tasks that require organizational capacity to complete. HBVs are not only correlated with management capacity, but also technical capability, source water quality, operator decision-making, storage, land cover, and other environmental factors (Pike, 2004).

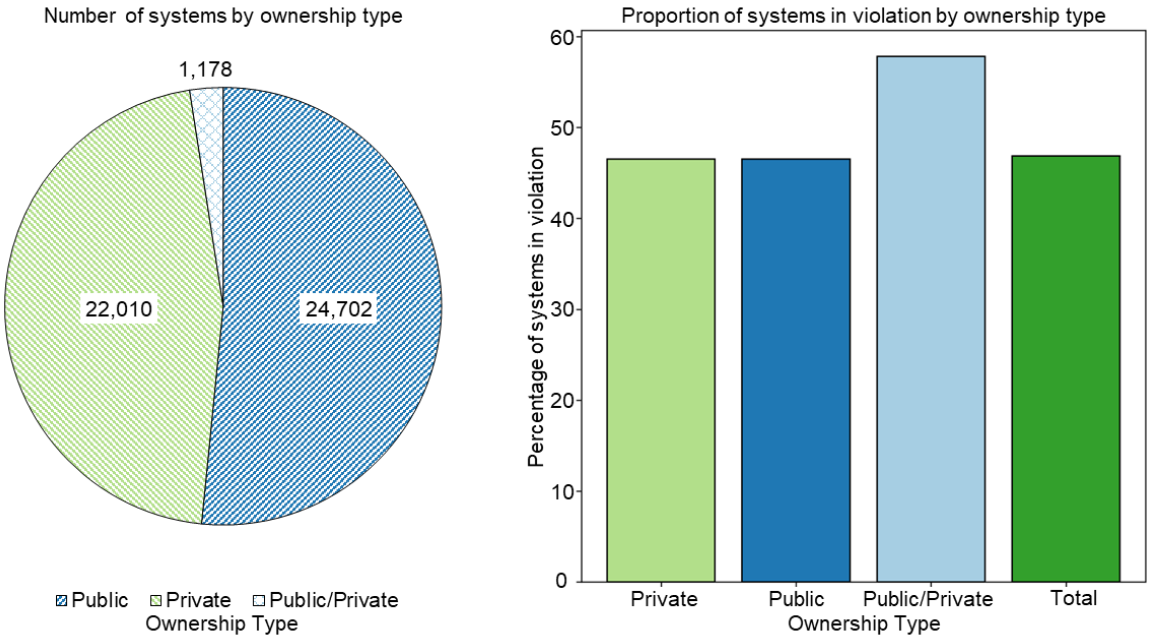

Figure 1: Monitoring and Reporting Violations in Active CWSs by Ownership Type

Between public and private systems, the proportion of systems with monitoring and reporting violations is very similar, with each having about 46.5 percent of systems in violation. This differs from some evidence that public systems are more likely to be in violation compared to private systems when considering HBVs (Allaire, 2018). Still, despite much debate over the privatization of water systems, this finding largely aligns with at least one previous study that found little difference in regulatory compliance between public and private water systems with all else being equal (Wallsten, 2008).

Moods Median test results are shown in Table 3. Confidence intervals for the median sociodemographic values in each violation and ownership categories were calculated at the 95 percent level (see Figure 2). When looking at all systems, regardless of ownership type, every variable analyzed had a p-value under 0.001, suggesting strong evidence against the null hypothesis. This indicates that the medians of these sociodemographic factors are statistically significantly different between systems with and without monitoring and reporting violations. The same is largely true for private systems, with the exception that both employment and health insurance medians are not statistically significantly different between violators and non-violators. In contrast, public/private systems had fewer variables significant, with only employment having a p-value lower than 0.05.

Table 3: Mood's Median Test p-values for Violators vs. Non-Violators

Variables	Total	Public	Private	Public/Private
Median Household Income	<0.001*	<0.001*	<0.001*	0.906
Health Insurance	<0.001*	<0.001*	0.606	0.115
Population Density	<0.001*	<0.001*	<0.001*	0.378
Home Ownership	<0.001*	<0.001*	<0.001*	0.116
Education	<0.001*	<0.001*	0.001*	0.362
Employment	<0.001*	<0.001*	0.072	0.013*
*statistically significant				

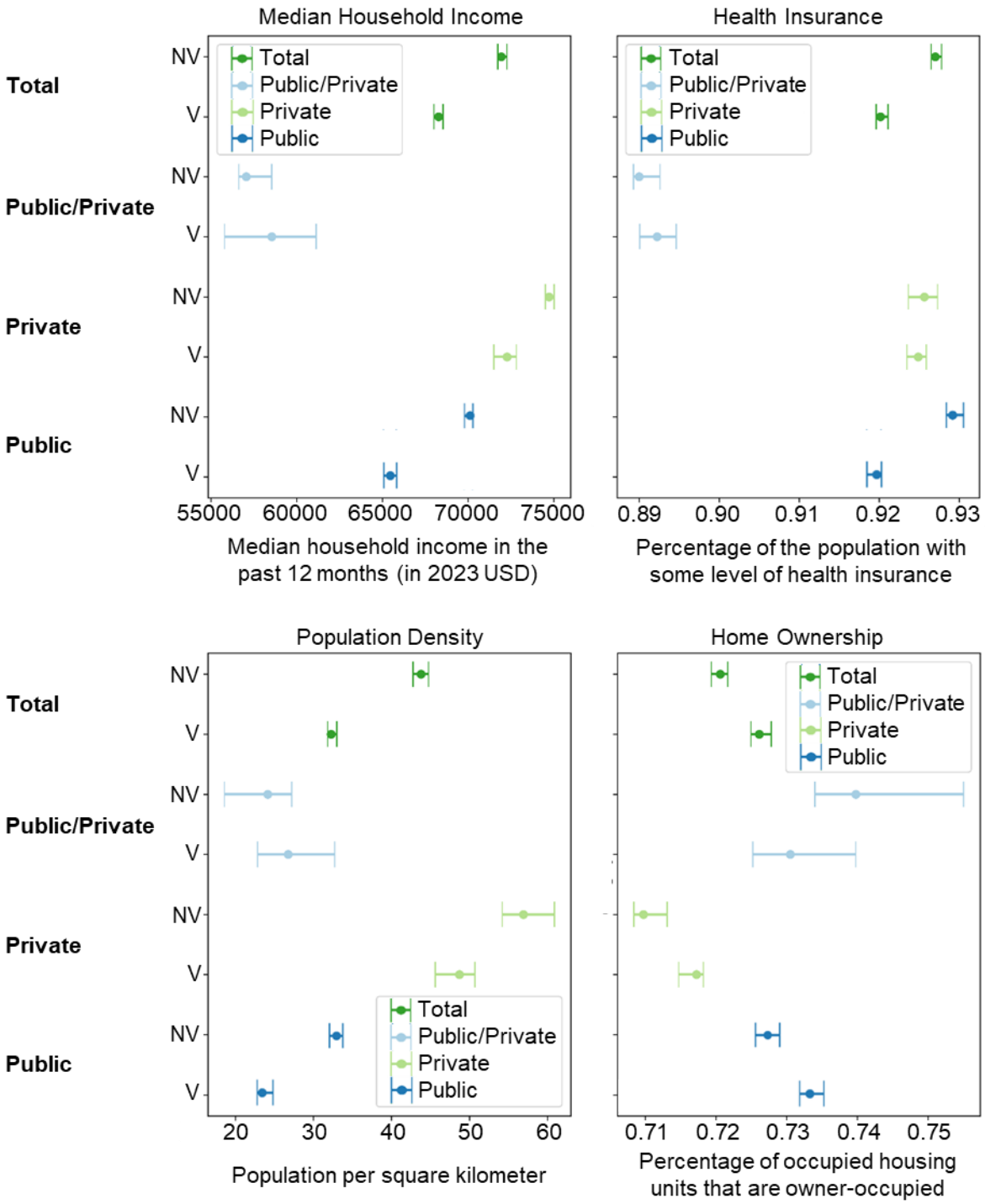

Figure 2 (continued on the next page): 95% Confidence Intervals for Median Sociodemographic Values by Ownership and Violation Status

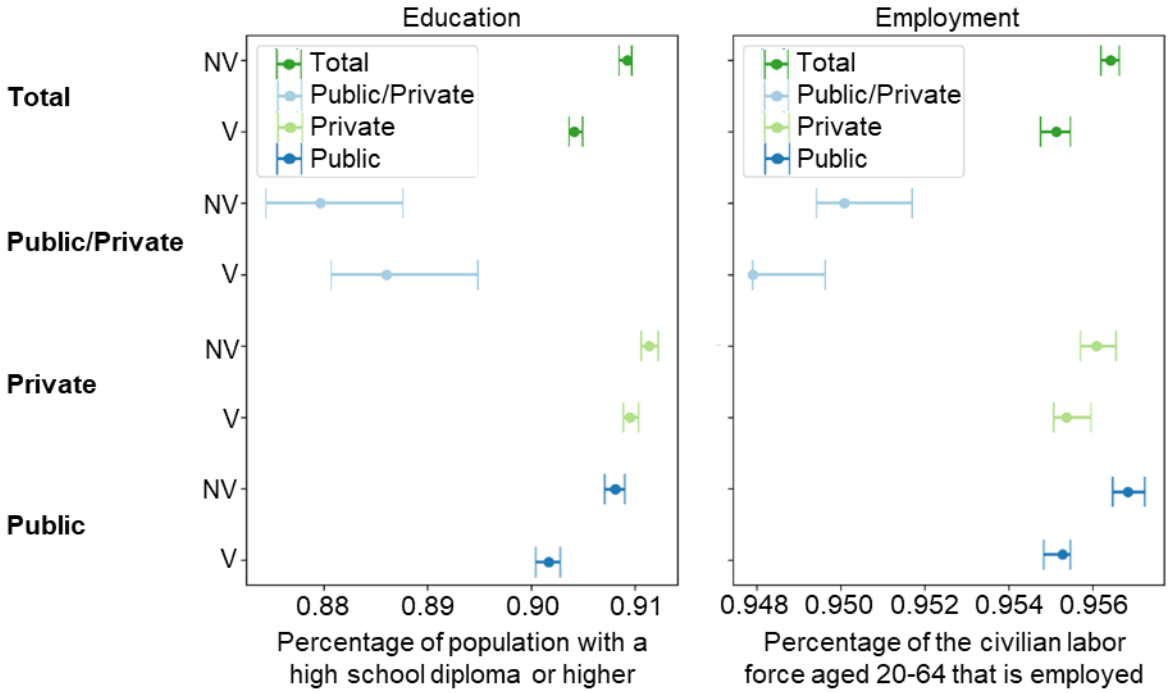

Figure 2 (continued from the previous page): 95% Confidence Intervals for Median Sociodemographic Values by Ownership and Violation Status

Exploring how sociodemographics change across ownership types, regardless of violation status, paints an interesting picture about water system characteristics in the US. Median household income was found to be significantly higher for those served by private systems, followed by public systems, with public/private systems tending to serve the lowest-income communities. The lower income levels seen in public systems versus private systems, combined with the higher likelihood of utility violations in lower income communities, may explain previous findings that public systems are more likely to be in violation compared to private systems (Allaire, 2022; Allaire, 2018). Further, we found that private utilities tend to serve more densely populated communities compared to both public and public/private CWSs, and, in turn, may have access to additional resources present in more urbanized areas (e.g., workforce availability).

The levels of health insurance coverage in the county served were similar for public, private, and overall systems. In contrast, public/private systems serve populations with a substantially lower level of health insurance compared to other ownership types. This may be influenced by the fact that public/private systems are common in lower-income communities where historic efforts have pushed to utilize public/private partnerships as a tool to increase infrastructure performance (Franceys, 2003; Castro, 2007). In low-income communities served by public/private systems, there are likely lower levels of health insurance overall (Berdahl, 2013). These findings are echoed across education and employment, with total, public, and private systems each having similar median values. In contrast, public/private systems tend to serve counties with lower education and employment levels than other ownership types. This aligns with evidence that the lower-income communities are likely to have lower educational achievement and employment levels (Workman, 2023; Huynh, 2020). Previous literature has linked lower education and income with a higher probability of SDWA violations, which aligns with our finding that public/private systems, which had the highest proportion of systems with a monitoring and reporting violation, are more likely to serve populations with lower income and education levels (Switzer, 2017).

Results show that across multiple ownership types, economic and social vulnerability in the surrounding county is associated with higher levels of monitoring and reporting violations. This finding is seen most clearly in differences in median household income, health insurance, education, and employment, where,

across the most common ownership types, the estimated median values in communities with violating utilities are lower than the estimated median values in communities with compliant systems. For private systems, only median household income and education showed statistically significant results indicating the underlying medians are lower in communities with violating systems. However, 95 percent confidence intervals were overlapping for both health insurance coverage and employment in private systems. For public/private systems, employment was the only variable with at least a 95 percent confidence level, indicating the median employment level for counties with systems in violation is lower than the median in counties with compliant systems.

Overall, many of our findings are consistent with previous results concerning HBVs, indicating that communities with lower socioeconomic status are often served by utilities with more violations (Switzer, 2018). One explanation for this could be that utilities with higher funding levels have greater fiscal capacity to tackle monitoring and reporting challenges. Health insurance, education, and employment are each indicative of higher income, which explains why these characteristics align with findings pertaining to median household income (Workman, 2021; Huynh, 2020; Berdahl, 2013). High-income communities often use more water and pay higher water bills, which could contribute to increased resources at their respective utilities and a higher ability to comply with monitoring and reporting requirements (Rachunok, 2023).

Population density is seen to have a similar relationship with violation status among public, private, and total CWSs, with monitoring and reporting violations being more prevalent in systems serving lower-density populations. These findings align with existing literature on HBVs, which shows noncompliance often occurs in rural areas (Kirchhoff, 2019; Statman-Weil, 2020; Allaire, 2018). For public/private systems, we found monitoring and reporting violations to be associated with more densely populated communities, a noteworthy difference from the other ownership types. However, our findings are not conclusive. We recommend further study of public/private systems, for which there is less data (see Table 1). This could entail potentially reaching out to individual operators to learn about their experiences and supplement the data available from the SDWIS. Our findings on homeownership were surprising. Homeownership is often thought of as a privilege, with evidence that it contributes to increased access to opportunity (Rohe, 2002). Still, we find that across public, private, and overall CWSs, communities with a higher percentage of residents who own their homes tend to be served by utilities with monitoring and reporting violations. This finding may be explained by the fact that homeownership is more common in rural versus urban areas, and rural systems are more commonly in violation (Mazur, 2017).

4. LIMITATIONS

While our results uncover meaningful information, there are factors that limit our analysis. Data availability, specificity, and quality are a concern. Due to the self-reported nature of monitoring and reporting, there are often gaps in this data due to improper reporting (EPA, 2004). The sociodemographic data is also measured at the county level, which may oversimplify local variations compared to more granular spatial units. Future work should increase spatial resolution. Our choice of presenting violations as binary also limits the amount of nuance that is reflected in our results by ignoring severity, length of noncompliance period, and the number of violations. Despite this, we see statistically significant differences in median demographic values across violation status and ownership types. Additionally, while we can determine with high confidence that many of our demographic factors have different distributions across these groups, our results cannot be used in predicting violations. Lastly, we do not include technical data related to each system, such as system size, source water, and age of the system. Future inferential modeling should include these factors.

4. CONCLUSIONS

This study provides novel insights about the relationships between sociodemographic factors and prevalence of monitoring and reporting violations across different water system ownership types. To do so, we used Mood's Median testing and confidence intervals for the median value of various demographic factors across system ownership type and violation status. The Mood's Median test revealed statistically significant differences in the medians of each of our six demographic variables (i.e., population density,

education, median household income, employment, homeownership, and health insurance coverage) between violators and non-violators in both total systems and public systems. Similar results were found in private systems, where health insurance coverage and employment were the only demographic factors that did not have significant differences in median values across violators and non-violators. For public/private systems, employment in the surrounding county was the only variable with a statistically significant difference in medians with and without violations.

Our confidence intervals revealed that among all ownership types, violating systems are more likely to be in more socially vulnerable counties that have a lower population density, a higher proportion of the population without health insurance, a lower proportion of the population with at least a high school diploma, a higher unemployment level, and lower median household income. These findings have implications for regulatory and management decisions both at the government and utility levels. The high overall prevalence of monitoring and reporting noncompliance indicates a need for targeted compliance efforts across all system types, but the need is most urgent in already socially vulnerable communities and especially among those systems under public ownership, where the disparities in demographics between violating and compliant systems are most conclusive. Public/private systems are also a particular area of concern due to the high proportion of utilities in noncompliance. Targeted compliance efforts, such as increased management capacity, more frequent inspections, targeted funding, and operator trainings should be explored. Improving monitoring and reporting at water utilities can contribute to ensuring that all American communities have access to safe and reliable drinking water.

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