Drinking Water Equity in New Mexico: Access, Quality and Affordability

Nahid Samimi
Ph.D. Candidate, Department of Economics
University of New Mexico

Celeste Lucero
Master's Student, Department of Economics
University of New Mexico

Alex Kaltenbach
Undergraduate Student, Department of Economics
University of New Mexico

Jingjing Wang
Associate Professor, Department of Economics
University of New Mexico
wangj@unm.edu

Version: August 11, 2025

Acknowledgments: The authors would like to acknowledge funding from the New Mexico Legislature (UNM Research and Public Service Project) and the National Science Foundation (Grant No. 1914490). The opinions expressed in this paper are solely those of the authors. All errors are our own. The authors thank the Albuquerque Bernalillo County Water Utility Authority for providing access to water usage data.

Keywords: Drinking water, public water systems, equity, access, quality, affordability

DEPARTMENT OF ECONOMICS

Table of Contents

List of Tables

List of Figures

1. Executive summary

Water is vital to human survival and economic development, especially in arid regions like the Southwest United States. However, regions around the world are facing water shortage challenges, exacerbated by growing populations and changing weather patterns. Meanwhile, disadvantaged communities significantly lag in access to clean drinking water due to the lack of reliable water infrastructure and increasing water scarcity resulting from water pollution and climate change. Furthermore, water affordability is a growing concern across the country. This study assesses drinking water equity in public water systems in New Mexico by evaluating access, quality, and affordability of water. We develop a new tool of drinking water equity metrics and use it to assess drinking water equity both within the state and within the largest city in the state. We outline how the assessment can inform the ongoing water policy and action discussions in New Mexico.

Key Findings

- Public drinking water access and violations in New Mexico
    - Community water systems in New Mexico that rely on surface water sources experience higher rates of drinking water violations, including those with direct health implications.
    - Community water systems in New Mexico that serve low-income, non-white, and rural populations are associated with higher drinking water violation rates compared to those serving higher-income, predominantly white, and urban communities.
- Public drinking water violations on Tribal lands in New Mexico
    - Higher proportions of Tribal land within census block groups are associated with lower rates of drinking water violations.
- Urban drinking water equity in Albuquerque
    - About 2% of 411 census block groups in Albuquerque show signs of water-related vulnerability, with no areas experiencing multiple overlapping stressors. Individual water vulnerabilities are detected in underuse (2 block groups), affordability (1 block group), and climate vulnerability (5 block groups), revealing localized disparities.
    - Water services are broadly affordable in Albuquerque using the basic needs of 50 gallons of water per capita per day and the 4.5% water bill to median-income ratio affordability threshold.

Implications for Water Management

- Targeted investment should prioritize community water systems that rely on surface water and serve at-risk populations to reduce health risks associated with unsafe drinking water.
- Small community water systems face persistent regulatory and operational challenges; regional consolidation or shared services among neighboring systems may enhance compliance and service delivery.
- Federal, state, and local agencies should strengthen support for Tribal nations as sovereign water managers, recognizing the importance of Tribal governance in ensuring safe and equitable water access.
- The adoption of equity-oriented tools, such as the Water Poverty Index, can help water utilities and policymakers identify specific dimensions of vulnerability and allocate resources more effectively.
- Additional research and targeted policy action are urgently needed to address the needs of communities lacking access to public drinking water infrastructure.

2. Part I: Public Drinking Water Access and Violations in New Mexico

2.1. Introduction

The U.S. Environmental Protection Agency (EPA) defines a public drinking water system as a system that provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serving an average of at least 25 people for at least 60 days a year (EPA 2024). Such a public water system may be publicly or privately owned. EPA classifies these water systems into three types based on the number of people they serve, the source of their water, and whether they serve the same customers year-round or on an occasional basis: community water systems (e.g., publicly and privately owned water utilities), non-transient non-community water systems (e.g., schools and hospitals that have their own water systems), and transient non-community water systems (e.g., a gas station or campground) (EPA 2024). Community water systems (CWS) are defined as systems that provide water to the same population year-round. According to the EPA Safe Drinking Water Information System (SDWIS), drinking water in the U.S. is supplied by approximately 156,000 public water systems to about 306 million people or 90 percent of its population, with about 50,000 public water systems being CWS that serve close to 300 million people or 88 percent of its population (EPA SDWIS 2025).

According to the EPA SDWIS, there are 563 currently active CWS serving almost 95% of New Mexicans, and residual of the population is mostly served by private wells. The five largest systems in descending order are those serving Albuquerque, Rio Rancho, Santa Fe, Las Cruces, and Roswell, which together serve 999,310 people or 47% of the state's population (EPA SDWIS 2025).

CWS within New Mexico's jurisdiction are regulated by the New Mexico Environment Department (NMED) Drinking Water Bureau. The regulations they enforce could significantly impact communities. Studies across the US have found drinking water violations decrease school attendance, increase household bills, and increase healthcare expenditure (Kim et al. 2023; Allaire et al. 2019; Alzahrani et al. 2020). New Mexico and the southwestern region have been identified as areas with higher violation rates nationally (Allaire et al. 2018). This is concurrent with significant drought and aging water systems within New Mexico (Kenney and Sanchez 2023, ASCE 2025; Lujan Grisham 2024). In March 2025 alone, the NMED Drinking Water Bureau issued 50 violation notices related to CWS, more than any other regulatory department within NMED that month (Estrada 2025). In 2023, 729 violations occurred across the state and 235 were health-related, averaging over 60 total and 20 health-related violations a month. Drinking water issues can often be highly concentrated, as exemplified by the Sunland Park drinking water crisis in 2016, which exposed up to 20,000 people to arsenic levels detrimental to health, totaling 79 violations for a single system that year and making headlines (Paterson 2016); it is one of many CWS in the state that have experienced significant long term health-related failure. The risk to safe drinking water these violations pose necessitates an assessment of the access and quality of New Mexico's drinking water.

This section of the report presents geographic hotspot analysis to identify spatial areas of concern and econometric analysis to explore correlated factors with total and health-based drinking water violations in New Mexico from 2013 to 2023.

2.2. Background and Literature Review

Several studies have examined CWS drinking water violations at the national level. Allaire et al. (2018) found increases in CWS violations from 1982-2015 correlated with previous violations, rural areas, small systems, public ownership, non-white areas, high market concentration, and using surface water sources. They found a geographical hotspot in the most southwestern corner of New Mexico in the Hidalgo and Grant counties, and multiple other hotspots in neighboring states. They specifically mention New Mexico and the Southwest as high violation regions. A probit model on the occurrence of any violation and coliform violations was used in the study; coliform violations are more accurately reported across systems nationally but introduce a bias as coliform is more commonly found in surface water sources in comparison to groundwater. The panel data contained only CWS serving over 500 people with community information joined at the county level. The use of county level demographics and exclusion of very small systems decreases the resolution of analysis, representing a significant loss of data specificity within the scope of New Mexico. The variables they analyzed, such as market concentration, are not properly bound by county lines within this state, as seen with Rio Rancho Water and Wastewater Utility and the Albuquerque Bernalillo County Water Utility Authority. Community demographics within New Mexico counties is also extremely heterogeneous, as seen in Bernalillo and Santa Fe Counties.

A similar recent study looked at the geographic distribution of water injustice, a measure created through a composite index of CWS violations and environmental justice scores, from 2014 to 2019 (Segrè Cohen et al. 2025). Los Alamos County was ranked with the 5th lowest water injustice score nationally, but all other New Mexico counties are reported to have significantly higher values of both violations and water injustice during the same period. Ignoring Los Alamos County, New Mexico is among the worst performers in the contiguous United States within this study andthe Lower Rio Grande corridor is identified as an area of concern. The primary findings nationally are that private system ownership is spatially correlated with clusters of high violations, but high clusters of water injustice are often surrounded by low proportions of privately owned systems. The data was similarly aggregated at the county level and lacks discussion of other important factors in water violations, such as water source.

This study and others have contributed to a significant body of literature on the societal impacts of water quality violations. Segrè Cohen et al. (2025) found that customer perception of water quality decreases with water system violations as measured by survey. Kim et al. (2023) found that boil water notices increase unexcused absences by 1-10% in Jackson Mississippi and is notable as the only study reviewed using a spatial resolution smaller than county levels. Allaire et al. (2019) found a roughly 14% increase in bottled water purchase correlated to tier one notifications of immediate health risks from water systems. Alzahrani et al. (2020) found that state level per-capita health care expenditures increased with water quality violations using spatial Durbin models. These increases in expenditure are likely to translate into higher long-term household costs for water utility customers compared to the cost a system would face to address quality shortfalls.

Some of the notable gaps in the body of CWS literature are the spatial resolution of community demographics and analysis of patterns within the state of New Mexico. Most studies mentioned aggregate spatial data at county levels or higher, significantly decreasing the resolution of the analysis. McDonald et al. (2022) marked a significant improvement to the spatial resolution of

CWS service boundaries that enables geographic relationships previously stifled by broad level aggregation to be explored.

2.3. Data

This study pairs CWS violation reports from the EPA SDWIS with CWS service areas and National Historical Geographic Information System (NHGIS) data for community characteristics for the state of New Mexico.

The National Safe Drinking Water Act (SDWA) was passed in 1974, and good data of New Mexico CWS violation records starts around 1980; records of violations within New Mexico began in 1979, and an erroneous violation exists dated to 1901. The federal level SDWA has been significantly modified over the years: the list of regulated contaminants has increased almost 4-fold since the SDWA was initially passed, individual states are now allowed to set more stringent regulations and regulate the systems within their boundaries, and medium or larger systems (serving >3,300 people) must now report risk assessments and protect water sources. For this study, the entire Violation Report of CWS within New Mexico's legal jurisdiction were fetched from the SDWIS. The result contains all safe drinking water violations from 1979 to 2024 within New Mexico and violations noted as invalid by the SDWIS are filtered out.

Federal regulations were last modified in 2013 with the Revised Total Coliform Rule (Anon 2019). A Per- and Poly-fluoroalkyl Substances (PFAS) maximum contaminant level (MCL) was legally passed in 2024, and best practices are under development, but they are not yet included in CWS violation data reported by the EPA or state (EPA 2021; Beisner et al. 2024). For these reasons, this study focuses on water violation data from 2013-2023 under New Mexico's jurisdiction.

Reporting standards for CWS vary significantly based on system size, which is classified into five distinct categories (Table 1). Large and very large systems serve roughly the same proportion of New Mexicans at 38% and 36% respectively. New Mexico has a significantly higher share of very small systems compared to the rest of the country, as seen a higher share of both CWS and population served. A total of 379 currently active community water systems serve less than 500 people; these very small systems serve a total of 67,765 New Mexicans in 2024, which equates to about 3% of the population. Those serving less than 500 people (very small) typically experience reduced data accuracy, stemming from less intense sampling and risk reporting requirements, which can lead to measurement errors for later analysis. Very small systems constitute roughly 65% of observations in our panel dataset, justifying breaking down of systems by those serving less than 500 people and those serving more than 500 people. Analyses will be conducted across all CWS and stratified by the 500-person service threshold to isolate measurement error and examine heterogeneity associated with system size.

Table 1. Community water systems in New Mexico.

Category (Population Served)	Number of CWS	Population served	% of CWS	% of New Mexicans
Very small (25-500)	379	67,765	67.32	3.18
Small (501-3,300)	119	163,774	21.14	7.69
Medium (3,301-10,000)	33	208,339	5.86	9.78
Large (10,000-100,000)	30	805,018	5.33	37.79
Very Large (>100,000)	2	767,086	0.36	36.01
Total	563	2,011,982	100.00	94.45

New national and state level datasets of CWS service areas were recently published, allowing for greater granularity in large scale spatial analysis of drinking water which is not currently seen in the literature (McDonald et al. 2022). The EPA ECHO service area map was selected, as it contains the highest number of matching records at 563. Some boundaries are missing or inaccurate; 7 CWS were removed for this reason. Only 6 CWS within New Mexico's primacy have federal ownership; they are subject to different regulatory structure and have high violations that can bias econometric estimates[1]. Therefore, the 6 federally owned CWS are omitted from the data. This brings our panel dataset to 550 CWS with annual total and health violations over 11 years. The compliance period beginning date is used to assign the temporal attribute for each violation, as recommended by the EPA and literature.

Figure 1 displays CWS boundaries overlaid with population density in people per square mile calculated from 2020 census block data. Areas of high population density without community water services lie within tribal boundaries and are served by tribal water systems outside of NMED Drinking Water Bureau's jurisdiction. It presents the spatial disparity in access to public water systems in New Mexico.

Figure 2 displays the 550 CWS available service area boundaries under New Mexico's jurisdiction, the color representing the average number of violations per year for a given system from 2013 to 2023. The sum of all valid violations is used to calculate yearly averages, both health related and not, and divided by the number of years in the study. County and state boundaries are sourced from census TIGER/lines Shapefiles.

Data on CWS characteristics is also fetched from the 2025 SDWIS System Summary Report to add three time-invariant variables of water system characteristics: the current population served by the water system, ownership category, and an indicator for whether a system uses surface or ground water. Some systems use multiple water sources, and these CWS characteristics may change over time, SDWIS reports only the current state of these variables.

Figure 3 displays the CWS in New Mexico by system characteristics. It shows the distribution of system sizes, ownership, and water source. Ownership and water sources have some clusters: the northwest corner of the state near Farmington has many surface water systems, and multiple counties contain only publicly owned water systems.

Figure 4 displays New Mexico counties by average annual drinking water violations per person served by CWS. The average violation per person served is used to compare the burden of drinking water violations across counties.

The CWS panel dataset was appended with 2020 percent rural data calculated from the IPUMS National Historical Geographic Information System (Manson et al. 2024) at the block group level. The annual American Community Survey (ACS) tract level median income and percent white data was added by averaging the 2010 census tract boundaries served for the period from 2013-2019 and the 2020 census tract boundary for 2020-2023[2]. All median income was inflation adjusted to

[1] These federally owned CWS are regulated by NMED, but they are legally a federal entity. This complicates the institutional relationships and enforcement. For example, NMED and NMDOJ is currently suing the Air Force for contamination at Cannon AFB: https://www.env.nm.gov/wp-content/uploads/2025/06/2025-06-23-COMMS-NMED-and-NMDOJ-file-new-lawsuit-against-Air-Force.pdf.

[2] In this study's tabulation of racial demographics, the percentage of individuals categorized as "White" was calculated on an inclusive basis. Respondents who identified with multiple racial categories, one of which was White, were included in the "White" count.

2023 dollars. The average community characteristics for the census tracts or block groups served by a CWS were assigned to each CWS[3].

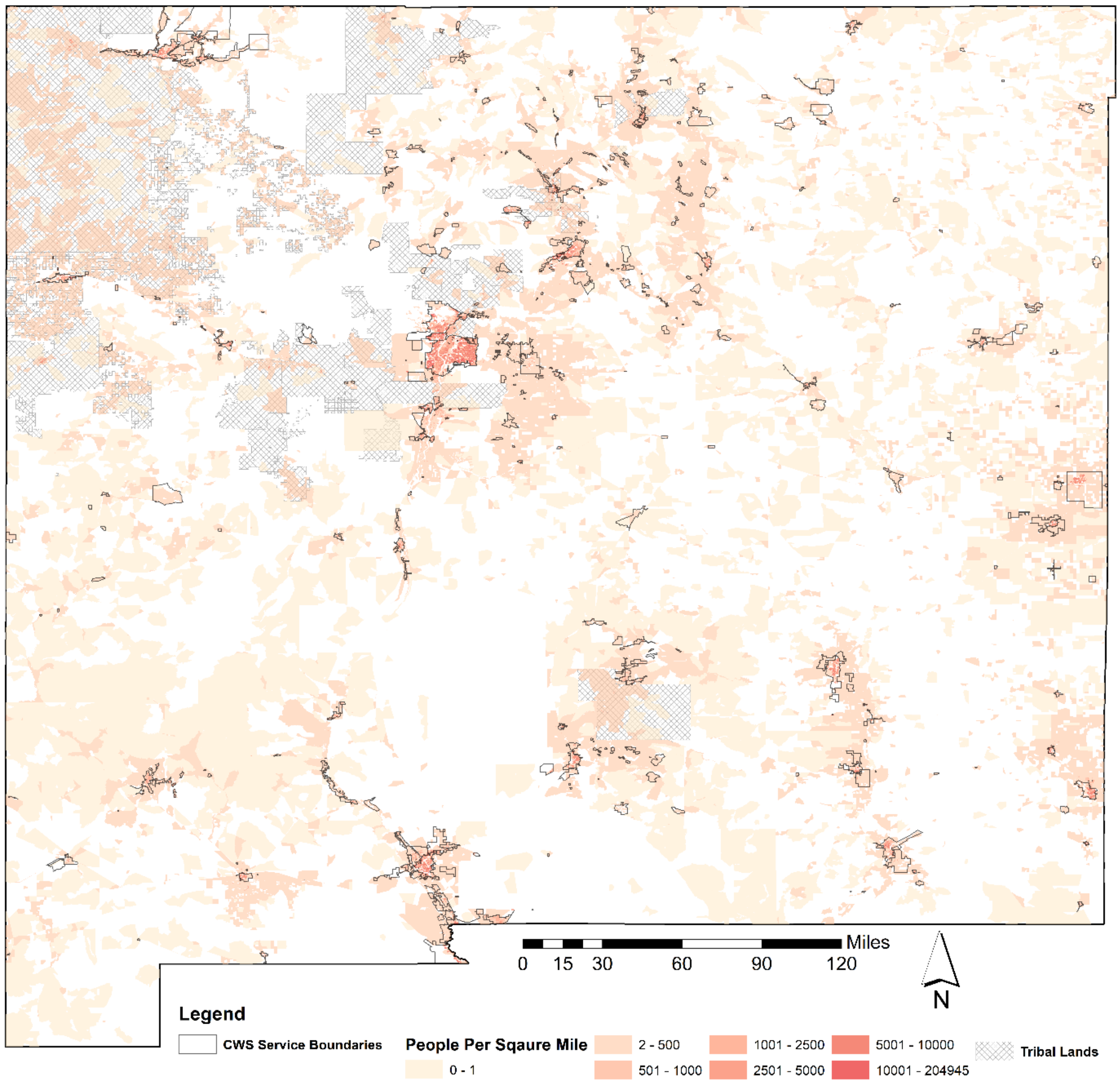

Figure 1. Community water systems and population density measured by people per square mile in New Mexico.
Note: Tribal lands are included in the map to identify potential access disparity.

[3] The ACS from 2020 onward has errors resulting from pandemic interactions corrected for by averaging *t-1* and *t+1* if available in year *t*, else the last reported level (*t-1*). Inflation adjustment was done prior to correction.

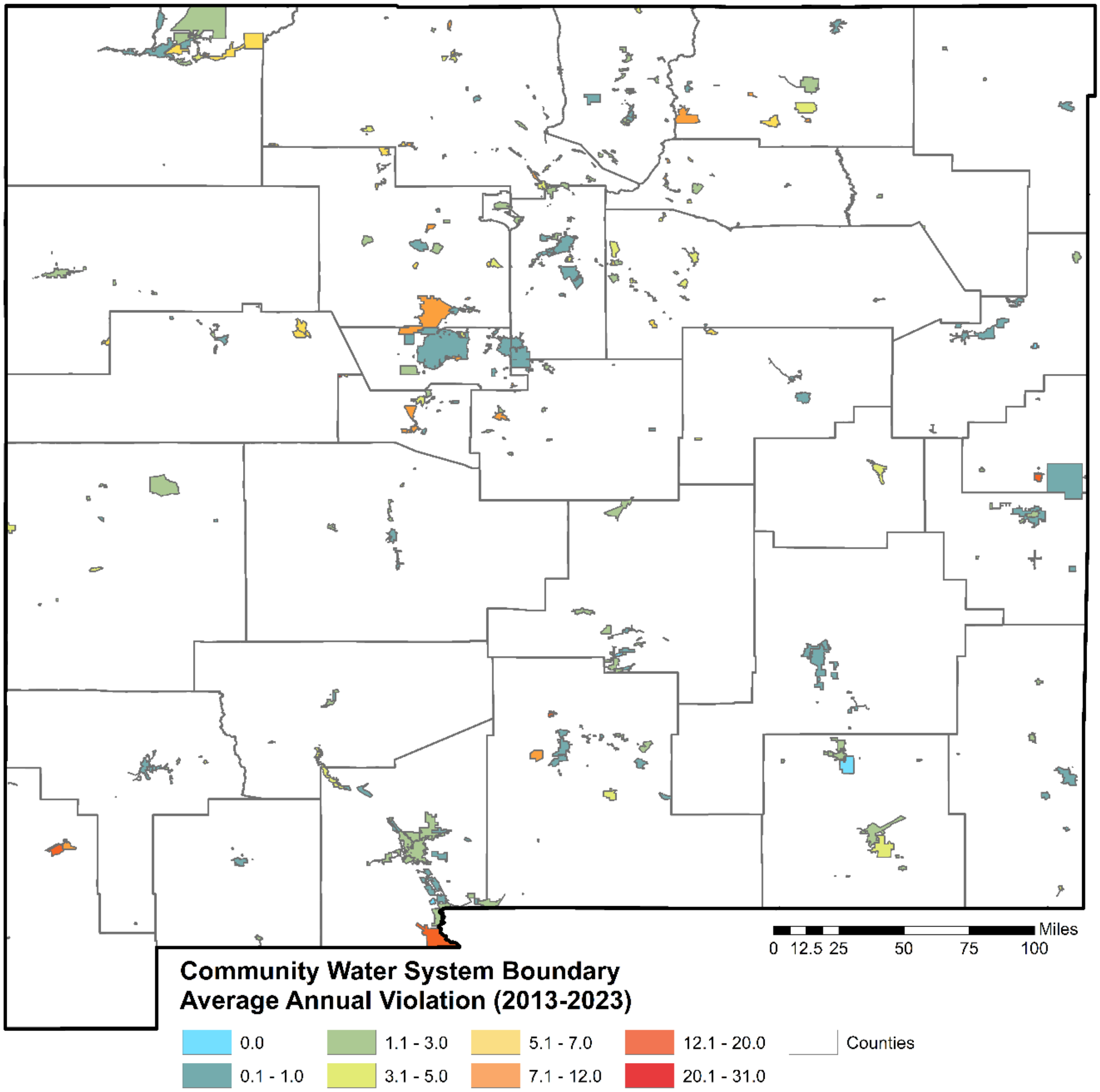

Figure 2. Community water systems in New Mexico and the average annual number of drinking water violations from 2013 to 2023.
Data source: U.S. Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS).

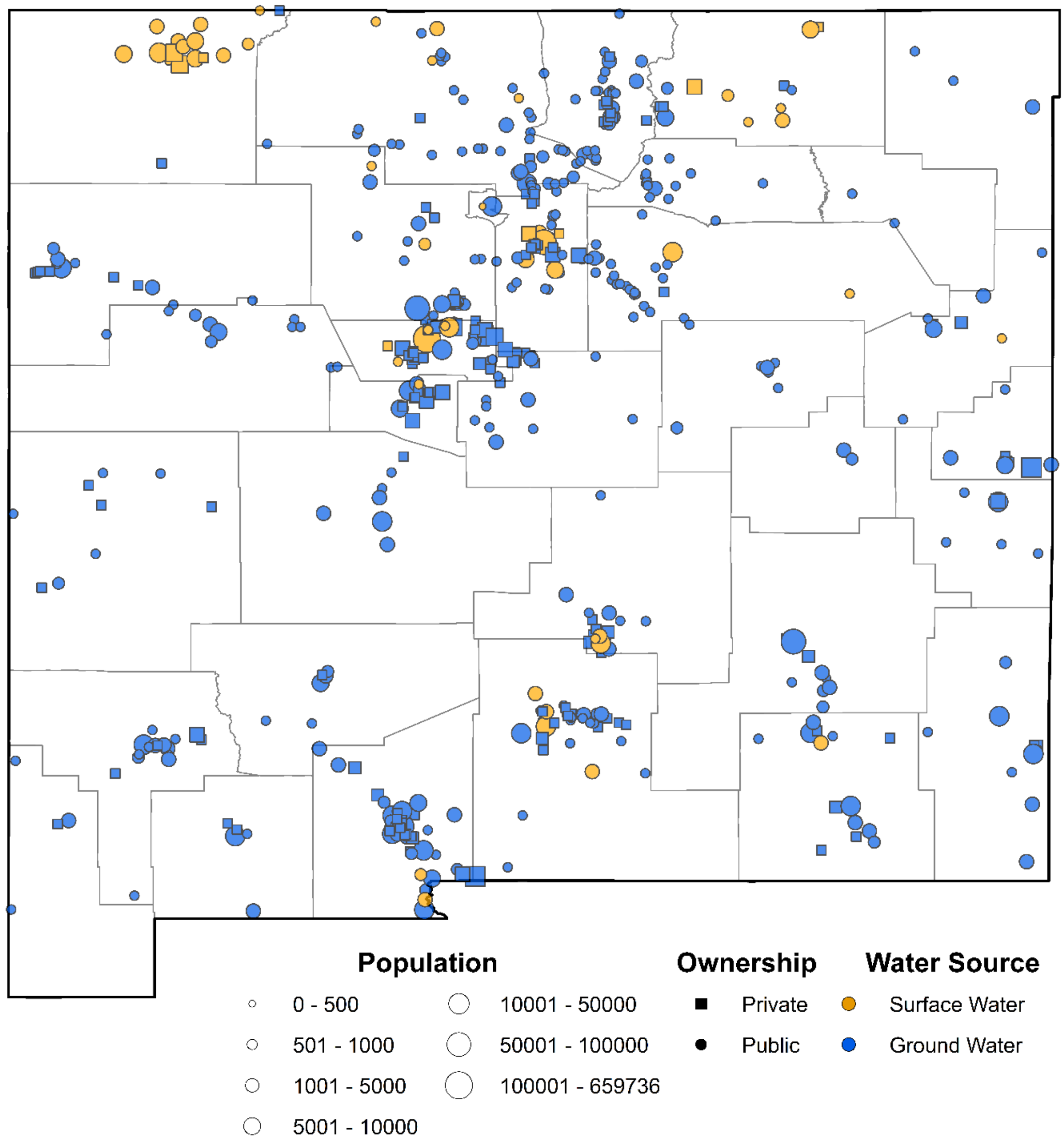

Figure 3. Community water systems in New Mexico by system characteristics.
Data source: U.S. Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS).

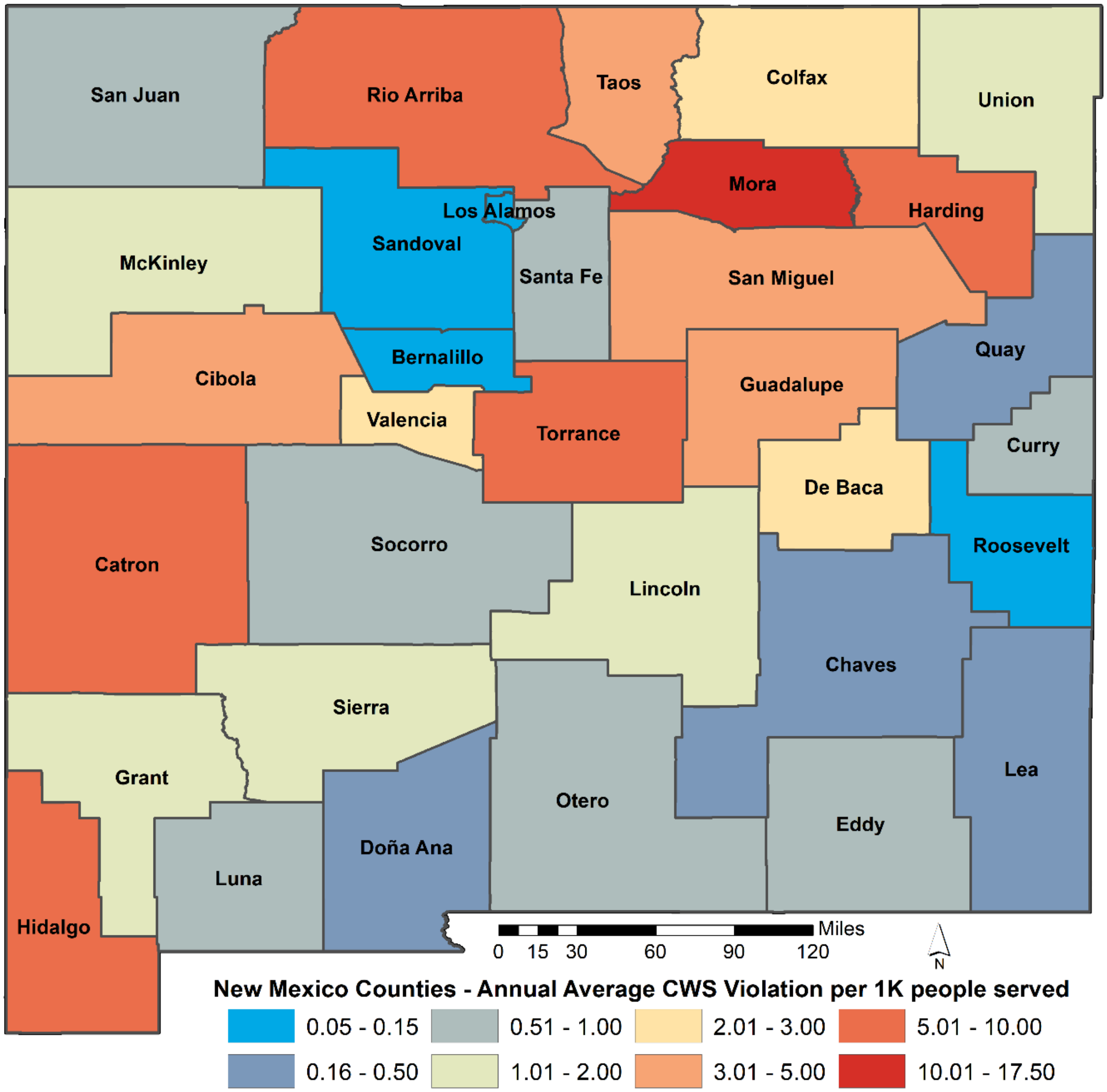

Figure 4. New Mexico counties by average annual drinking water violations per one thousand people served by community water system.
Data source: U.S. Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS) and American Community Survey (ACS).

Table 2 provides summary statistics of the dataset used for the study. On average, New Mexican CWS have 2.62 violations in a year with 0.6 of these being health related. Table 3 presens the statistics by system size categories, and Table 4 presents the statistics by ownership and water source.

Table 2. Summary statistics of community water systems in New Mexico.

CWS Variables	Total Violations	Health Violations	Population Served by System	Percent Rural	Percent White	Median Income
Unit	Count	Count	Thousand people	[0-1]	[0-1]	Thousand 2023 Dollars
Mean (SD)	2.62 (5.12)	0.596 (1.89)	3.5 (29.3)	0.738 (0.361)	0.73 (0.198)	57.5 (22.9)
Median [Min, Max]	1.00 [0, 83.0]	0 [0, 38.0]	0.246 [0.26, 660.00]	1 [0, 1]	0.781 [0.147, 1]	52.1 [21.4, 282.0]

Table 3. Summary statistics of community water systems in New Mexico by size.

Community Water System Variables	Very Small (N=370)	Small (N=120)	Medium (N=31)	Large (N=28)	Very Large (N=1)	Total (N=550)
Total Violations (Count)						
Mean (SD)	2.83 (5.45)	2.07 (3.55)	2.52 (5.32)	2.36 (5.95)	0.0909 (0.302)	2.62 (5.12)
Median [Min, Max]	1.00 [0, 83.0]	1.00 [0, 29.0]	0 [0, 39.0]	0 [0, 79.0]	0 [0, 1.00]	1.00 [0, 83.0]
Health Violations (Count)						
Mean (SD)	0.618 (1.87)	0.573 (1.81)	0.437 (1.31)	0.601 (2.78)	0 (0)	0.596 (1.89)
Median [Min, Max]	0 [0, 24.0]	0 [0, 22.0]	0 [0, 9.00]	0 [0, 38.0]	0 [0, 0]	0 [0, 38.0]
Population (Thousand People)						
Mean (SD)	0.178 (0.123)	1.35 (0.769)	6.29 (1.92)	30.1 (24.3)	660 (0)	3.50 (29.3)
Median [Min, Max]	0.142 [0.0260, 0.500]	1.10 [0.506, 3.25]	6.08 [3.41, 9.73]	19.3 [10.7, 98.1]	660 [660, 660]	0.246 [0.0260, 660]
Percent Rural						
Mean (SD)	0.778 (0.358)	0.790 (0.299)	0.521 (0.276)	0.253 (0.246)	0.00987 (0)	0.738 (0.361)
Median [Min, Max]	1.00 [0, 1.00]	1.00 [0, 1.00]	0.449 [0.151, 1.00]	0.173 [0.00561, 1.00]	0.00987 [0.00987, 0.00987]	1.00 [0, 1.00]
Percent White						
Mean (SD)	0.722 (0.203)	0.746 (0.201)	0.747 (0.150)	0.748 (0.154)	0.700 (0.0642)	0.730 (0.198)
Median [Min, Max]	0.776 [0.00868, 1.00]	0.808 [0.00147, 1.00]	0.779 [0.267, 0.983]	0.786 [0.196, 0.943]	0.730 [0.556, 0.750]	0.781 [0.00147, 1.00]

Median Income (Thousand 2023 Dollars)						
Mean (SD)	56.9 (23.7)	55.8 (18.9)	63.7 (22.2)	64.4 (26.3)	68.8 (2.22)	57.5 (22.9)
Median [Min, Max]	51.2 [21.4, 282]	51.4 [23.2, 144]	58.5 [32.5, 181]	56.9 [29.5, 175]	68.3 [66.1, 72.7]	52.1 [21.4, 282]

Table 4. Summary statistics of community water systems by ownership and water source.

	Locally Owned		Privately Owned		State Owned		All Ownership	
	GW (N=313)	SW (N=35)	GW (N=190)	SW (N=8)	GW (N=3)	SW (N=1)	GW (N=506)	SW (N=44)
Total Violations (Count)								
Mean (SD)	2.66 (4.63)	3.90 (7.44)	2.27 (5.25)	3.43 (7.11)	3.30 (3.88)	3.45 (3.50)	2.51 (4.87)	3.80 (7.31)
Median [Min, Max]	1.00 [0, 79.0]	1.00 [0, 83.0]	0 [0, 72.0]	2.00 [0, 50.0]	2.00 [0, 14.0]	2.00 [0, 11.0]	1.00 [0, 79.0]	2.00 [0, 83.0]
Health Violations (Count)								
Mean (SD)	0.603 (1.89)	1.09 (2.54)	0.484 (1.73)	1.01 (1.95)	0.242 (0.614)	0 (0)	0.556 (1.83)	1.05 (2.42)
Median [Min, Max]	0 [0, 38.0]	0 [0, 21.0]	0 [0, 24.0]	0 [0, 8.00]	0 [0, 2.00]	0 [0, 0]	0 [0, 38.0]	0 [0, 21.0]
Total Population Served (Thousand People)								
Mean (SD)	2.45 (9.01)	26.7 (110)	0.776 (3.380)	2.44 (3.14)	8.13 (11.4)	35 (0)	1.86 (7.49)	22.4 (98.6)
Median [Min, Max]	0.293 [0.028, 98.1]	2.27 [0.044, 660]	0.150 [0.026, 43]	0.978 [0.054, 8.82]	0.280 [0.102, 24]	35 [35, 35]	0.226 [0.026, 98.1]	1.79 [0.044, 660]
Percent Rural								
Mean (SD)	0.835 (0.295)	0.699 (0.351)	0.585 (0.406)	0.731 (0.261)	1.00 (0)	0.00561 (0)	0.742 (0.361)	0.689 (0.349)
Median [Min, Max]	1.00 [0.00525, 1.00]	0.912 [0.00987, 1.00]	0.680 [0, 1.00]	0.789 [0.347, 1.00]	1.00 [1.00, 1.00]	0.00561 [0.00561, 0.00561]	1.00 [0, 1.00]	0.894 [0.00561, 1.00]
Percent White								
Mean (SD)	0.717 (0.204)	0.698 (0.167)	0.756 (0.191)	0.708 (0.197)	0.849 (0.0908)	0.823 (0.0617)	0.732 (0.200)	0.703 (0.172)
Median [Min, Max]	0.770 [0.00147, 1.00]	0.746 [0.195, 0.932]	0.820 [0.00868, 1.00]	0.760 [0.0876, 0.963]	0.872 [0.563, 0.970]	0.841 [0.700, 0.894]	0.785 [0.00147, 1.00]	0.755 [0.0876, 0.963]
Median Income (Thousand 2023 Dollars)								
Mean (SD)	53.1 (17.5)	59 (17.5)	63.1 (28)	72.9 (29.9)	65.6 (20.7)	159 (11.7)	56.9 (22.6)	63.8 (25.5)
Median [Min, Max]	49.4 [21.4, 148]	56 [23.2, 144]	55.5 [25.7, 282]	60.9 [32.6, 134]	56.9 [43, 118]	157 [146, 175]	51.5 [21.4, 282]	57.3 [23.2, 175]

Note: GW (Ground Water) or SW (Surface Water) denotes water source.

2.4. Methodology

2.4.1. Spatial Hotspot Analysis

The spatial hotspot analyses are conducted at the census tract level to identify geographic areas of concern for drinking water violations. We choose census tracts because of data availability. The average annual total violations α^i and health related violations β^i for a census tract i is calculated following two steps.

First, the annual total violations and health related violations for each CWS are calculated across the study period $t = t_1, \dots, T$:

$$\alpha = \frac{\sum_{t=t_1}^{T} TotalViolationCount_t}{T}$$

$$\beta = \frac{\sum_{t=t_1}^{T} HealthViolationCount_t}{T}$$

Next, for all $k = 1, \dots, K$ CWS in census tract i,

$$\alpha^i = \frac{\sum_{k=1}^{K} \alpha^k}{K}$$

$$\beta^i = \frac{\sum_{k=1}^{K} \beta^k}{K}$$

Census tracts that had high violations compared to their neighbors are found using local Getis–Ord statistic, a Local Index of Spatial Autocorrelation (LISA). This identifies tracts that deviate from their neghbors by comparing each tract's count of violation to the count of tracts directly bordering it. A higher confidence interval signifies a larger deviation from the surrounding rate of violations.

2.4.2. Econometric Analysis

To assess the correlation between drinking water violations and characteristics of communities and water systems, we use fixed effects model as in Equation 2.1:

$$Y_{it} = aX_i + bR_i + cC_{it} + Y_t + \mathcal{E}_{it} \qquad (2.1)$$

where:
Y_{it} is a count of annual violations for water system i in year t,
X_i is a vector of water system characteristics,
R_i is percent rural,
C_{it} is median income and percent white,
Y_t is year fixed effect, and
$\mathcal{E}_{it}$ is the error term.

The two alternative dependent variables (Y_{it}) are total and health-related violations. The water system characteristics (X_i) used as explanatory variables are population served, source of water, and ownership type. The time-invariant blockgroup level community demographic is percentage rural (R_i) and the time-variant tract level demographics (C_{it}) percentage white and median income. Model results are presented with and without year fixed effects.

This model will be regressed to three sets of data and two dependent variables within each set. The first set is all CWS within the state, then separately on systems serving under and over 500 people. Stratification of CWS by size addresses inherited reporting errors in very small systems from EPA regulatory structure. Separately analyzing CWS that serve over 500 people allows results to be compared to existing literature, while analyzing systems serving under 500 people isolates the error and bias within small systems without excluding them from analysis. This will allow comparison of small systems with those that are medium-to-large.

2.5. Results

2.5.1. Geospatial Hotspots in 2023

The hotspot maps are presented in Figure 5 and Figure 6. Hotspots of total violations and health related violations are correlated but not the same, suggesting that spatial patterns of health violations and total violations differ slightly. No cold spots exist. Darker Hotspots represent areas where the true value of the tract differs greatly from the expected value of the tract as calculated from neighboring tracts.

Figure 5 highlights hotspots of total violations. Areas of high tract-level clusters of total violations are:

- Northwestern tracts of San Miguel County that includes the community of Sapello and areas around and in the city of Las Vegas
- A tract in the northeast part of Curry County
- Tract of Cibola and Velencia counties near Cubero, Highland Meadows, and Belen areas.
- Two northwestern tracts of Otero County
- The Hidalgo tract near Lordsburg, likely driven by the Glenn Acres Community Water System

Figure 6 highlights hotspots of health-related violations. Not all areas with hotspots of total violations had hotspots of health violations, but many did. Areas of high tract level clusters of health violations per CWS are:

- The same northwestern tracts of San Miguel County as well as the tract covering the communities of Tererro and Cowles
- The southernmost tract of Bernalillo County is near Isleta
- Only one Valencia tract covering the community of Highland Meadows
- The same tracts of Otero as well as two more near Alamogordo
- The entirety of Hildago County

These census tracts are generally rural, aligning with findings from other studies that identified geospatial bivariate clusters of SDWA violations in New Mexico using a more in-depth LISA method[4].

---

[4]Andrews, L. *Identifying patterns and factors of Safe Drinking Water Act violations in New Mexico* [Poster]. University of New Mexico, Center for Advancement of Spatial Informatics Research & Education. https://aspire.unm.edu/research/student-research/identifying-patterns-and-factors-of-safe-drinking-water-act-violations-in-new-mexico.html

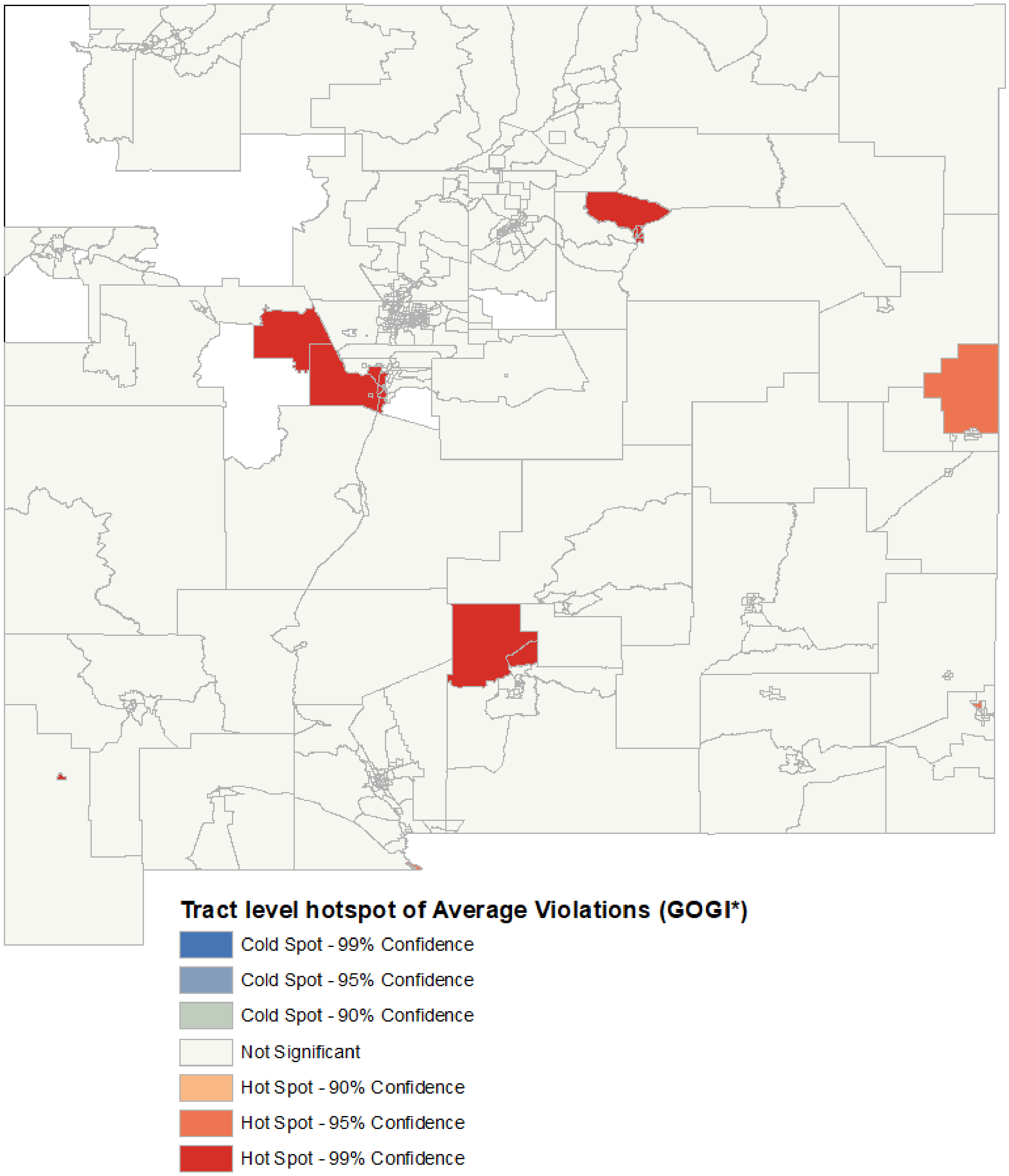

Figure 5. Hotspots of average total drinking water violations for New Mexico census tracts.

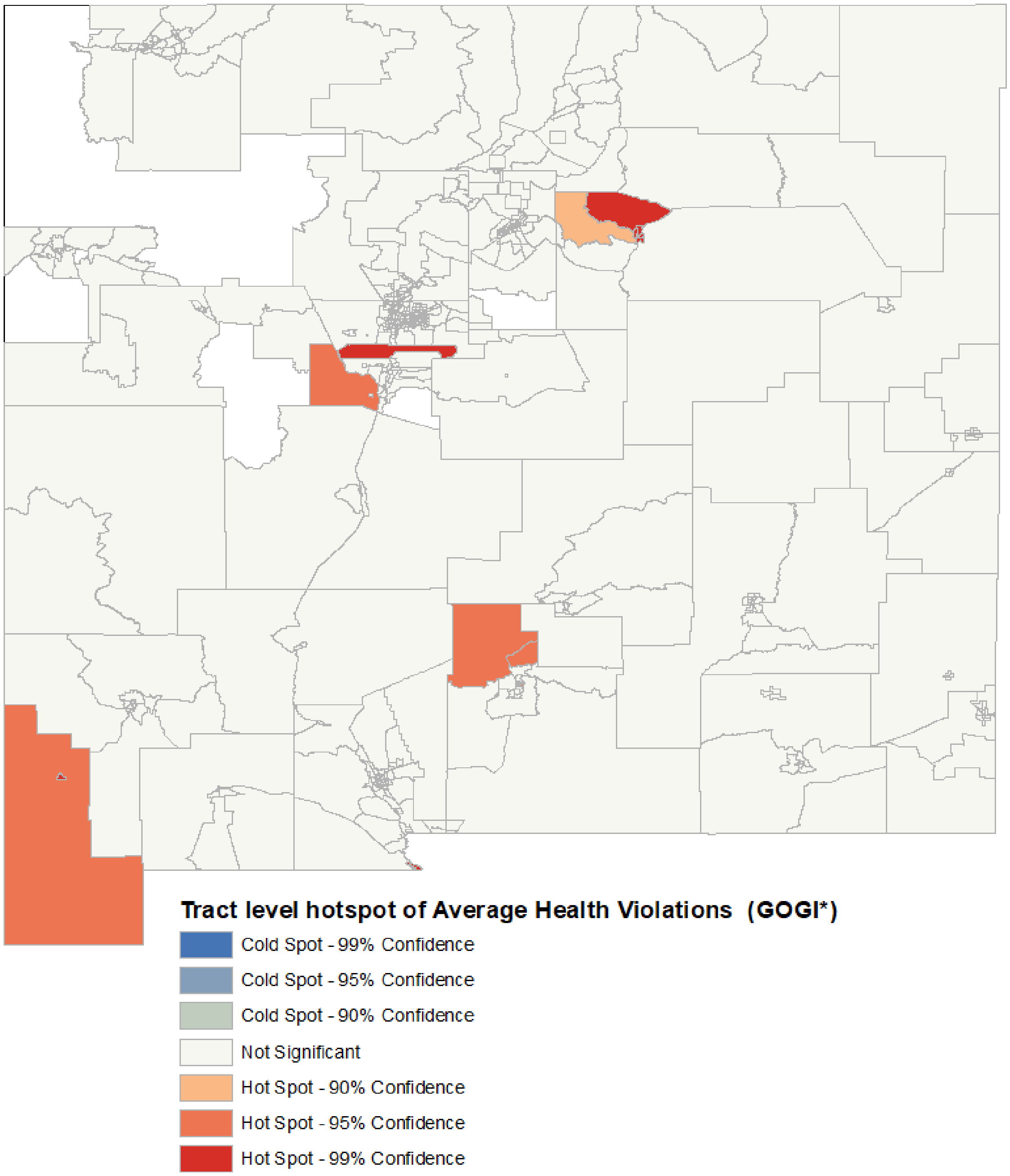

Figure 6. Hotspots of average health related drinking water violations for New Mexico census tracts.

2.5.2. Regression for 2013-2023

The econometric modeling results are presented below. Table 5 presents four models for all New Mexico CWS. Year-fixed effects improved the explanatory power of models for both total and health related violations. Results show that surface water usage, low-income, non-white, rurality, and systems serving smaller customer bases have significant correlations with increases in both violation categories. Interestingly, although there are only four state owned CWS (versus 348 locally public owned and 198 privately owned) in New Mexico, the state ownership highly correlates with more total violations but fewer health related violations compared to other ownership. A possible reason is that state owned CWS are more aware of and thus comply better with health related regulations but are weak in complying with non-health related requirements.

Table 5. Results for all New Mexico community water systems.

	Total Violations		Health Related Violations	
Population	-0.004*	-0.004***	-0.002**	-0.002***
	(0.002)	(0.001)	(0.001)	(0.000)
Surface Water	1.526***	1.444***	0.561***	0.546***
	(0.248)	(0.174)	(0.092)	(0.092)
Privately Owned	-0.008	-0.015	-0.045	-0.045
	(0.148)	(0.129)	(0.055)	(0.049)
State Owned	1.075	1.010**	-0.377	-0.384***
	(0.778)	(0.450)	(0.288)	(0.117)
Percent Rural	0.883***	0.953***	0.144**	0.157***
	(0.195)	(0.227)	(0.072)	(0.048)
Median Income	-0.018***	-0.011***	-0.004***	-0.003***
	(0.003)	(0.002)	(0.001)	(0.000)
Percent White	-0.043	-1.310***	-0.100	-0.339**
	(0.339)	(0.391)	(0.125)	(0.150)
Year Fix Effect	N	Y	N	Y
# Observations	6050	6050	6050	6050
Adj. R^2	0.016	0.049	0.010	0.021

Note: * p < 0.1, * *p < 0.05, *** p < 0.01

Table 6 presents four models for small to very large water systems in New Mexico (serving roughly 91% of the state's population). Results show that surface water usage, low-income, rurality, and systems serving smaller populations are similarly correlated to higher total and health-related violations. However, compared to local public and state ownership, private ownership is found to be correlated with fewer violations, health related or not. This indicates the important role of ownership for CWS serving over 500 people.

Table 6. Results for New Mexico community water systems serving over 500 people.

	Total Violations		Health Related Violations	
Population	-0.003	-0.003***	-0.001*	-0.001***
	(0.002)	(0.000)	(0.001)	(0.000)
Surface Water	1.392***	1.306***	0.453***	0.442***
	(0.265)	(0.250)	(0.118)	(0.104)
Privately Owned	-1.078***	-1.114***	-0.233**	-0.238***
	(0.241)	(0.122)	(0.107)	(0.064)
State Owned	0.423	0.229	-0.205	-0.235*
	(0.977)	(0.460)	(0.436)	(0.115)
Percent Rural	0.743***	0.814**	0.114	0.123
	(0.283)	(0.263)	(0.127)	(0.073)
Median Income	-0.014***	-0.009***	-0.007***	-0.006***
	(0.005)	(0.003)	(0.002)	(0.001)
Percent White	0.315	-0.914*	0.168	0.018
	(0.527)	(0.456)	(0.235)	(0.198)
Year Fix Effect	N	Y	N	Y
# Observations	1980	1980	1980	1980

	Total Violations		Health Related Violations	
Adj. R^2	0.032	0.048	0.014	0.016

Note: * $p < 0.1$, * *$p < 0.05$, *** $p < 0.01$

Table 7 presents the last four models for very small systems serving less than 500 people. These systems have the largest impact from surface water sources and population, with the magnitudes much higher than those for systems serving over 500 people. Rural, low-income, and non-white serving systems see increased total violations; for non-white and rural, this translates into health-related violations as well. Ownership has limited impacts, with state ownership only decreasing total violations when year fixed effects are accounted for.

Table 7. Results for New Mexico community water systems serving 500 or less people

	Total Violations		Health Related Violations	
Population	-1.487**	-1.412*	0.048	0.061
	(0.699)	(0.658)	(0.241)	(0.175)
Surface Water	2.434***	2.353***	0.932***	0.915***
	(0.462)	(0.562)	(0.159)	(0.142)
Privately Owned	0.095	0.115	-0.011	-0.004
	(0.203)	(0.205)	(0.070)	(0.065)
State Owned	1.574	1.745**	-0.289	-0.251
	(1.159)	(0.708)	(0.400)	(0.217)
Percent Rural	0.846***	0.941***	0.140	0.159**
	(0.275)	(0.277)	(0.095)	(0.066)
Median Income	-0.019***	-0.011***	-0.002*	-0.001
	(0.004)	(0.002)	(0.001)	(0.001)
Percent White	-0.065	-1.290***	-0.200	-0.465**
	(0.433)	(0.389)	(0.149)	(0.164)
Year Fix Effect	N	Y	N	Y
# Observations	4070	4070	4070	4070
Adj. R^2	0.017	0.055	0.010	0.026

Note: * $p < 0.1$, * *$p < 0.05$, *** $p < 0.01$

In sum, CWS and community characteristics are found to be statistically significant in modeling total and health-related drinking water violations in New Mexico. The most robust finding within the CWS characteristics is water source; CWS using surface water are correlated with higher total and health violations across all models. The results for all CWS show that those CWS relying on surface water experience an average of 1.44 more total violations annually, of which 0.54 are health related. These correspond to a 57.5% increase in total violations and a 98.2% increase in health related violations for CWS relying on surface water compared to those relying on groundwater as the primary water source. The negative impacts of surface water sources are most pronounced among very small CWS, which exhibit increases of 2.3 total violations and 0.9 health-related violations annually compared to CWS relying on groundwater. A Z-test comparing surface water coefficients between total violations in very small systems [2.345, (0.560)] and small to very large systems [1.303, (0.249)] results in -1.7; the two coefficients for source water on total violations is statistically significant at the 10% level. This translates into small CWS struggling to properly treat surface water when compared to larger systems. CWS size in terms of population served negatively correlates with drinking water violations for large and medium sized systems. The statistical significance of this relationship does not hold for small systems, but the negative relationship still holds. CWS serving 500 or more people exhibit a significant reduction in violations as system size increases, which may suggest a critical size threshold beyond which scale explicitly contributes to better regulatory outcomes.

Compared to local public ownership, private ownership is associated with fewer violations among medium and large CWS, which experiences one fewer total violation and 0.3 fewer health-related violations on average per year. However, no statistically significant relationship between private ownership and violations is observed in models that include all CWS or focus exclusively on very small systems. State ownership yields mixed results; across all model specifications, state-owned systems exhibit higher total violations but lower health-related violations. However, the magnitude and statistical significance of these associations vary considerably across system size categories and model specifications, warranting further investigation.

Rurality is associated with higher total and health-related violations, but this relationship is primarily observed in very small systems serving 500 or less people. Similarly, the percentage of the community served being white exhibits a negative association with violations, suggesting fewer violations in whiter communities, but this effect is again limited to very small systems. These patterns are consistent with existing literature on environmental injustice and disparities in water system compliance, underscoring that such inequities are most pronounced in the smallest water systems.

As the median income increases, the number of health and total violations decreases. This contradicts previous findings of no significant relationship between income and violations. The magnitude of the coefficient is small across all models with a $1,000 dollar increase in median income correlating to a 0.01 decrease in annual violations with an order of magnitude less impact on health violations.

2.6. Conclusion

Our results generally align with the literature. The impact of surface water usage is uniformly significant; policy for smaller surface water CWS implement more robust source water treatment, such as funding for new or renovated treatment facilities, or for these systems to partially switch to groundwater, could be considered. The decreased violations in private CWS showcase that current regulation is less effective in addressing quality issues in publicly owned CWS, particularly for systems serving over 500 people. The centralization of resources and consolidation of CWS can reduce violations and enhance drinking water quality among neighboring small and very-small systems.

This work comes with significant limitations. First, small water systems may exist that serve 25 or more people which are not monitored by existing regulatory structures and remain uncaptured in this analysis, and likely those in the future if not formally incorporated (e.g. communal wells, colonias, and accidental CWS). Second, a handful of NMED enforcement actions that have included fines, alongside many funding mechanisms to improve water systems, have occurred throughout the years but are not controlled for in the econometric analyses. Future work could expand this dataset to improve analysis of both enforcement action and incentives, as well as incorporate various other factors of interest.

3. Part II: Public Drinking Water Violations on Tribal Lands in New Mexico

3.1. Introduction

Water is life, this is a common saying among Indigenous peoples. However, many communities struggle to access clean water. Globally, 2.2 billion people face challenges in accessing clean safe drinking water (United Nations 2023). In the American Southwest, approximately 42% of aquifers are polluted by arsenic with over 90% of New Mexico utilizing groundwater as their main drinking water source (Mayer et. al 2019). Access to clean safe drinking water is essential to Indigenous ways of life. However, understanding access to clean drinking water within Tribal lands is complex.

This research contributes to the economics of clean drinking water access in the context of Safe Drinking Water Act (SDWA) violations, which includes those that are health-related, acute health-based, public notice, and monitoring and reporting. Future access to safe drinking water is becoming increasingly uncertain due to the impacts of climate change especially in the American Southwest.

There is a growing literature of Indigenous access to clean drinking water in the fields of economics, sociology, and public health. However, much of the existing literature is outside of the field of economics and does not study the influence of Tribal lands and EPA funding regions. In this study we seek to address these gaps by analyzing the relationship of percentage of Tribal lands and drinking water violations at a higher granularity and considering the potential effect of EPA funding regions.

About 30% of families in the Navajo Nation lack access to running water (Navajo Water Project 2022). Understanding the current state and future of their access to water requires an understanding of the available infrastructure, treaties, and rules and regulations. In this research, the data is cross-sectional and does not distinguish the violations by type limiting the understanding of how the communities are being impacted and the projection of violations.

This study utilized robust regression models to understand the relationship between SDWA violations and Tribal lands in New Mexico. To assess the influence of EPA funding regions, Tribes were separated by EPA funding regions. The findings indicate that as the percentage of Tribal lands increased, drinking water violations decreased.

These findings suggest that Tribes may be the best providers for their communities. State and Federal governments should continue to support Tribal water management through providing resources and technical support. Although funding regions were not found to be a significant indicator, the disparities between Tribes in these regions should be further considered to account for variables not included in this study. This research also supports previous literature in that the effect of income is nonlinear, calling for increased oversight in communities at both ends of the income spectrum.

SDWA violations are also only one indicator of access to safe drinking water, and it is crucial to note that although clean drinking water may be available, the percentage of households with access to this water is unknown in this study. Future research should consider the percentage of households with piped water, violation types, and the water source for future security.

3.2. Background

This study examines the relationship between SDWA violations and the percentage of Tribal lands per block group within New Mexico. It also examines the impact of EPA primacy and federal funding regions.

3.2.1. Federal Regulations

The EPA has ten regional offices that execute EPA programs, which include distributing federal funding. New Mexico falls under EPA Region 6. However, the Navajo Nation, being the largest Tribal reservation in the United States, crosses into New Mexico, Arizona, and Utah, not perfectly fitting into the assumptions of funding regions. The Navajo Nation is funded under EPA Region 9 rather than Region 6.

The Safe Drinking Water Act was enacted in 1974, establishing federal drinking water standards to protect drinking water across the United States. Under the act, Tribal sovereignty is honored, in that Tribes can establish their own drinking water quality standards and also apply for primacy. Currently, the Navajo Nation is the only federally recognized Tribe that has applied for and received primacy. A Primacy agency is the reporting agency for its systems and is responsible for the enforcement of the SDWA, responding to violations formally and informally. Tribes who have not been granted primacy turn to EPA regional offices to implement Public Water System Supervision.

SDWA violations are those that violate the operating, reporting, and public notification requirements under the SDWA. Violation types can be health-based, monitoring and reporting, public notice, or others. Health-based violations are those that exceed the maximum contaminant levels or the maximum residual disinfectant in drinking water and do not meet the treatment technique requirements. Monitoring and reporting violations are those that fail to conduct regular monitoring of drinking water quality or submit their results in a timely manner to the primacy agency. Public notice violations are those in which the systems do not alert consumers to serious problems with their drinking water. Other violations include those that violate other parts of the SDWA, such as failing to issue annual consumer confidence reports.

3.2.2. Literature Review

A recent publication by Gaytan Tellez (2024) utilized Geographic Information Systems (GIS) to identify overburdened CWSs in New Mexico. Their study found that non-Tribal water systems experienced greater levels of burden compared to Tribal water systems, possibly due to tribal CWSs receiving a dedicated source of grant funding and a high level of technical assistance from multiple entities. Lower population size is found to not always correlate with increased system burden.

It is crucial to consider the sources of drinking water in New Mexico. Over 90% of New Mexico water systems rely on groundwater sources (Price and Heberling, 2018). Groundwater is vulnerable to contamination and depletion in the Southwest, which faces prolonged drought and climate change. The Navajo Nation has a shallow aquifer, which has been found to have increased levels of arsenic and other pollutants (Mayer et al. 2019). As the effects of climate change intensify, reliance upon groundwater as a drinking water source is increasingly uncertain. Baracho et al. (2024) noted that water access disparities are indicators of health, hygiene, and poverty. Their work emphasizes that the presence of water infrastructure does not guarantee reliable access. This is important to note, especially when considering Tribal communities.

This study builds upon their studies by investigating the influence of federal funding regions and primacy on compliance with the Safe Drinking Water Act (SDWA), utilizing economic analysis tools.

3.3. Data

3.3.1. Data Sources

This study utilizes data from the EPA Environmental Justice screening tool, which compiles data from the 2022 American Community Survey, the EPA Office of Air Quality Planning and Standards, NASA's Health and Air Quality Applied Services Team, and EPA's Toxic Release Inventory. For granular analysis, this study extracts data at the census block group level. Figure 7 displays drinking water violations in New Mexico by block groups on both tribal and non-tribal lands.

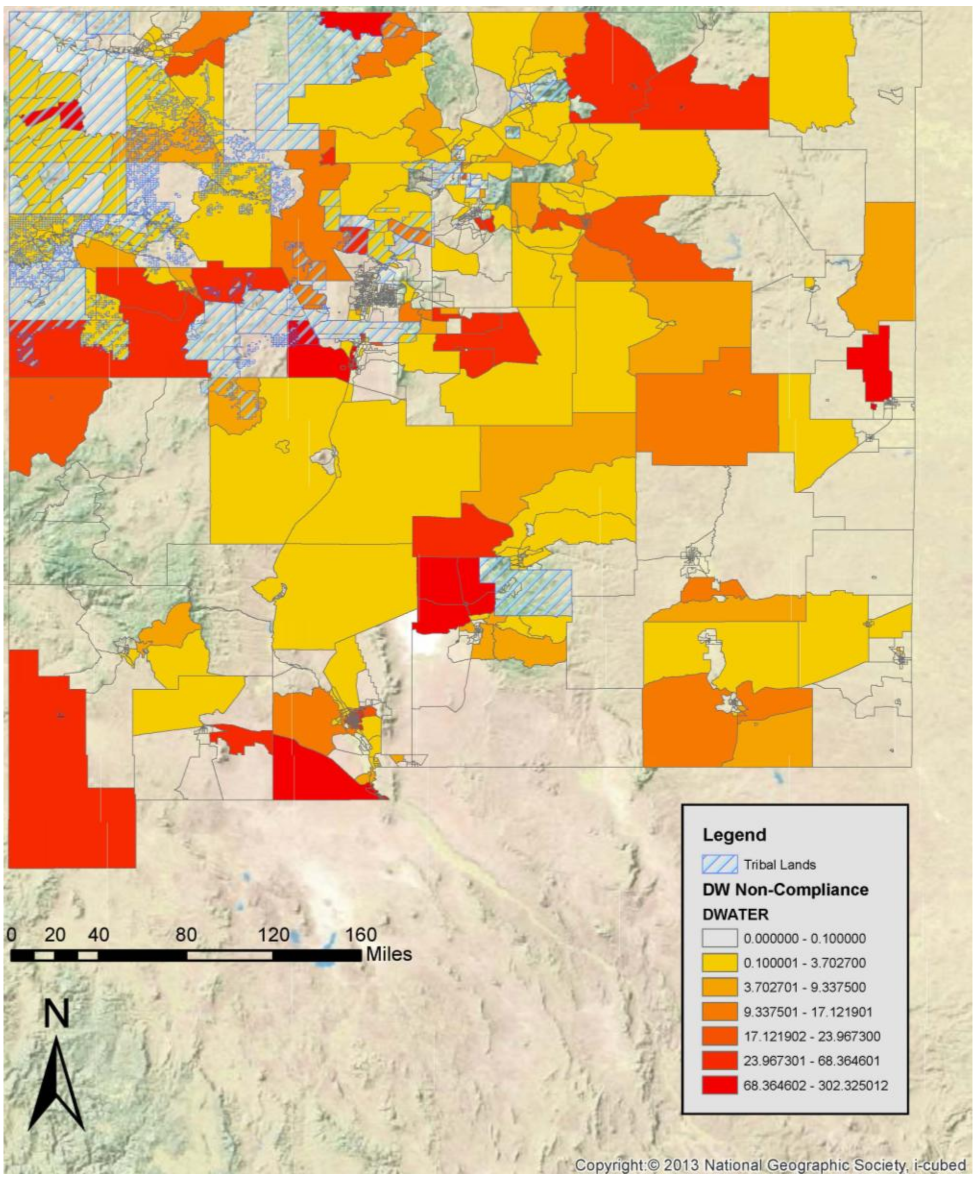

Figure 7. Tribal lands and drinking water violations in New Mexico by block groups (2022).

3.3.2. Model Variables

This model utilizes the variables $NonWater_i$ representing the number of drinking water non-compliance violations within a block group, $TotPop_i$ is the total population within a block group per the 2022 American Community Survey, $HMedIncome_i$ is the average household median income in thousands dollar within a given block group, NPL_i is a dummy variable equal to 1 if a superfund site is present within the block group and zero otherwise, $TSDF_i$ is a dummy variable equal to 1 if a hazardous waste site is present in the block group and zero otherwise, and $Region9_i$ is a dummy variable equal to 1 if a Tribal land is part of EPA funding Region 9 and zero otherwise.

The variable $TribePercent_i$ is the percentage of Tribal lands within a given block group and was calculated in GIS from the field geometry of the shapefiles from the U.S. Census for reservations and block groups. Then, calculating the new field percentage by following Equation (3.1). Figure 8 displays the percentages of tribal lands for New Mexico block groups. Table 8 displays the summary statistics of all the variables for a sample size of 1,401.

$$\frac{Tribal\ land\ area}{Total\ land\ area\ of\ block\ group} = Percentage\ of\ Tribal\ Lands \tag{3.1}$$

Table 8. Summary statistics of the Tribal land analysis variables.

Variable	Description	Unit	Mean	Std. Dev.	Min	Max
NonWater	Drinking Water Violations	Violations	5.57	19.19	0	302.32
TribePercent	Tribal Percent	%	7.16	24.38	0	100.00
TotPop	Total Population	People	1,309	660	0	5,524
HMedIncome	Household Median Income	Thousand $	64.06	32.57	12.02	250.00
NPL	equal to 1 if a superfund site is present within the block group and zero otherwise	Dummy variable	.036	0.186	0	1
TSDF	equal to 1 if a hazardous waste site is present in the block group and zero otherwise	Dummy variable	.036	0.186	0	1
Region 9	equal to 1 if within EPA region 9 and zero otherwise	Dummy variable	0.37	0.485	0	1

3.4. Methodology

Two sets of alternative models are used for the analysis, to understand the relationship between tribal lands and drinking water violations. The main model regression allows for analysis between Tribal and non-Tribal lands, whereas the second model explores the impact of EPA funding regions on Tribal land violations.

3.4.1. Main Model

The main model for this study utilized a robust regression model with drinking water non-compliance violations ($NonWater_i$) as the dependent variable and the percentages of Tribal land ($TribePercent_i$) , total population $TotPop_i$, household median income in thousands $HMedIncome_i$, superfund sites dummy (NPL_i) and hazardous waste sites $TSDF_i$ dummy as independent variables. A Breusch-Pagan test determined heteroskedasticity, calling for a robust regression rather than an ordinary least squares regression.

$$NonWater_i = \beta_0 + \beta_1 TribePercent_i + \beta_2 TotPop_i + \beta_3 HMedIncome_i + \beta_4 NPL_i + \beta_5 TSDF_i + \epsilon_i \quad (3.2)$$

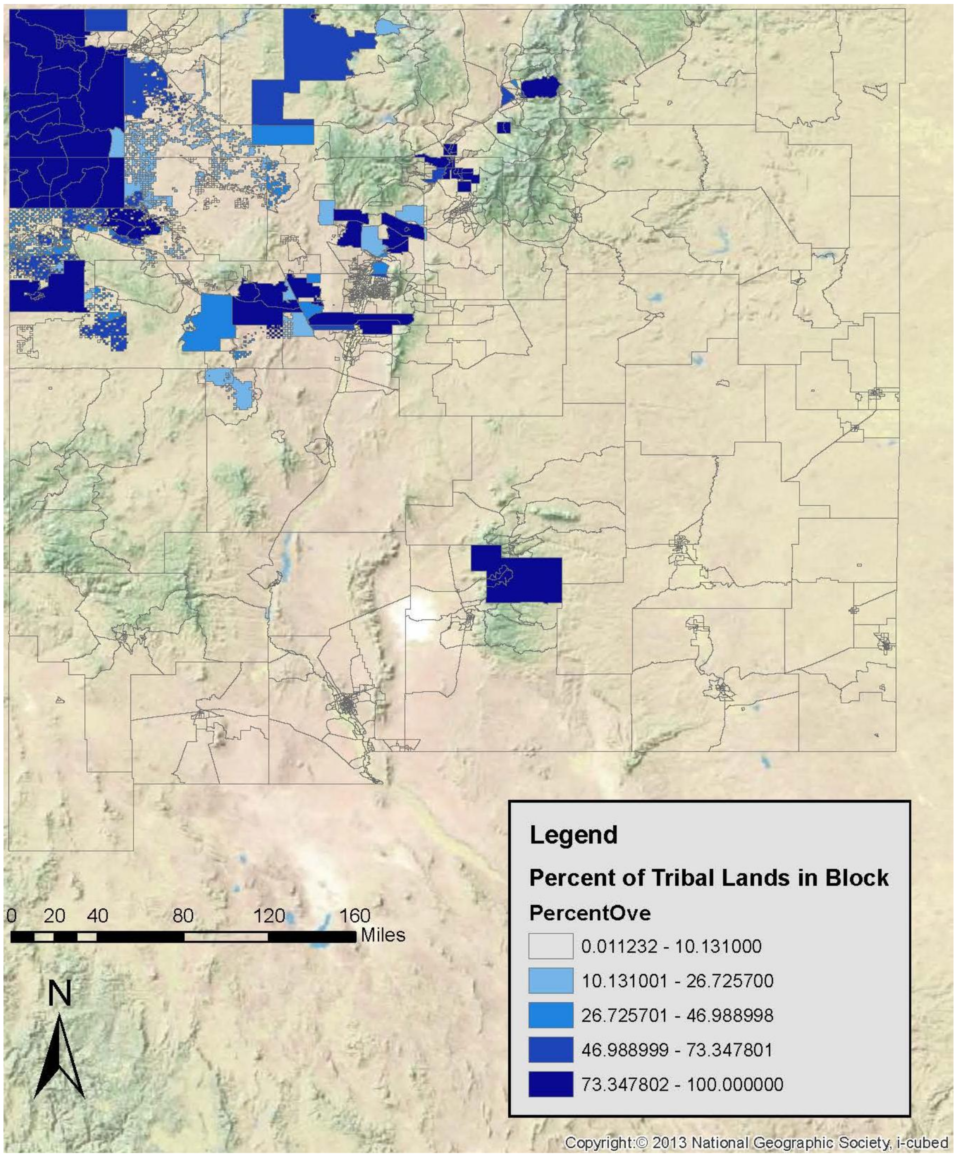

Figure 8. Percentage of tribal lands for New Mexico block groups.

3.4.2. Tribal Lands Model

A second robust regression model was run, which only included block groups that have tribal land, i.e., any block group with $TribePercent_i > 0$. In this model, EPA funding for region 9 tribal lands was a dummy variable ($Region9_i$).

$$NonWater_i = \beta_0 + \beta_1 Region9_i + \beta_2 TotPop_i + \beta_3 HMedIncome_i + \epsilon_i \quad (3.3)$$

Robust standard errors were used, and the model excluded interaction or nonlinear terms due to the smaller subsample size. This specification isolates the role of EPA Region 9 designation in predicting violations among Tribal areas only.

3.4.3. Main Model Robustness Checks

To improve the model's robustness, several robustness checks were conducted.

Drinking water non-compliance violations were estimated for Tribal lands within a given block group at 25%, 50%, 75%, and 90% to assess whether the relationship between tribal lands and drinking water noncompliance remains consistent. Dummy variables were used in separate regressions to test the influence of the Tribal land percentage on compliance. This allowed for an evaluation of whether effects were concentrated in areas with higher percentages of Tribal lands. A T-Test to compare the average drinking water non-compliance between region 6 and region 9 was also performed.

A non-linear relationship of household median income and drinking water non-compliance violations was also tested by including a squared term for median household income. This allowed for a better understanding of whether income and water violations exhibit a non-linear relationship.

To further determine the significance of hazardous waste sites and superfund sites, the following robustness checks were performed: 1) whether hazardous waste and superfund sites differ depending on whether Tribal lands are present, which allows for the analysis of environmental injustices that may be present on Tribal lands; 2) whether including or excluding superfund and hazardous waste sites would enhance the overall significance of the model. The model utilized interaction terms for tribal land percentage and hazardous waste sites. To do this, We used interaction terms between the percentage of Tribal land and the presence of superfund (NPL) and hazardous waste (TSDF) sites, which were created to test whether environmental hazards modified the relationship between Tribal land and drinking water non-compliance. 3) a log transformation of the dependent variable was estimated to account for the skewed distribution of violations and test the consistency of results under an alternative functional form.

These robustness checks strengthened the overall validity of this study's findings by testing model assumptions and consistency.

3.5. Results

The following regression results offer insight into the determinants of drinking water non-compliance across New Mexico census block groups, particularly in relation to percentage of Tribal lands, household median income, and environmental hazardous waste sites.

3.5.1. Main Model Results

The baseline linear regression model examines drinking water violations as a function of the percentage of tribal land, total population, household median income in thousands of dollars, and the presence of superfund sites and hazardous waste treatment facilities at the block group level. Table 9 summarizes regression results of two alternative model specifications. For the linear model (Model 1 in the second column), the results indicate that a one percentage point increase in the percentage of tribal land is associated with a 0.043 unit decrease in drinking water violations. As household median income increases by thousand dollars, drinking water violations decrease by 0.066 units. The presence of superfund sites and hazardous waste treatment facilities was not a statistically significant predictor.

Table 9. Main model results for block group drinking water violations in New Mexico.

	Drinking Water Violations	
	(1)	(2)
Tribal Percent	-0.043***	-0.461***
	(0.01539)	(0.01562)
Total Population	0.2551	0.4428
	(0.9901)	(0.99643)
Household Median Income	-0.066***	-
	(0.01353)	
Household Median Income Centered	-	-0.0890**
		(0.02279)
Household Median Income Squared	-	0.0005***
		(0.0002)
NPL Dummy	-1.6225	-1.9504
	(1.6105)	(1.6586)
TSDF Dummy	-0.7360	-0.6706
	(2.9513)	(2.9508)
# Observations	1401	1401
Adj. R^2	0.0123	0.0143

Note: * p < 0.1, **p < 0.05, *** p < 0.01

To test for non-linearity in the effect of income, the household median income variable was mean-centered and squared (Model 2 in the third column of Table 9). In this specification, the mean-centered household median income is a statistically significant variable with a negative coefficient of -0.089 as is the squared term with a positive coefficient of 0.0005. These findings indicate a U-shaped association between household median income and drinking water violations, with the inflection point at $89,000, which is almost 40% higher than the mean sample median income at $64,060. This suggests a general negative correlation between household median income and drinking water violations in New Mexico, except for block groups with very high incomes (i.e., higher than $89,000) in the region.

The percentage of tribal land remained a highly significant predictor, with a negative coefficient of -0.046 and a p-value of 0.003. To assess whether the impact of tribal lands on water quality varied by concentration, the model was re-estimated for block groups with tribal land percentages exceeding 25%, 50%, 75%, and 90%. In block groups with more than 25 percent tribal land, drinking water non-compliance decreased by 4.41 units with a p-value of 0.001. At the 50 percent threshold, it decreased by 4.31 units with a p-value of 0.002. For block groups with greater than 75 percent tribal land, the reduction was 4.02 units with a p-value of 0.011, and for those above 90 percent, the decrease was 4.41 units with a p-value of 0.007. These consistent adverse effects highlight a robust inverse relationship between the percentage of tribal land and drinking water violations.

To test the sensitivity of the results to skewness in the violation distribution, a model was estimated utilizing a log-transformed dependent variable, $\lg(NonWater + 1)$. In this specification, the percentage of Tribal land remained negatively associated with drinking water violations, though the result was marginally insignificant at the 10% level (p = 0.097). Median household income and its squared term retained their statistical significance, confirming the non-linear relationship observed in the main model. These results indicate that the income-violation relationship is robust, and the effect of Tribal land remains directionally consistent even under distributional transformation.

To further test the impact of hazardous waste sites, models including interaction terms between the percentage of tribal land and indicators for environmental hazards (superfund site presence and hazardous waste treatment facilities) showed no statistically significant interaction effects. Additionally, the interaction between being in Environmental Protection Agency Region 9 and the percentage of tribal land was not significant, with a p-value of 0.513, indicating no differential effect for region 9 tribal areas.

3.5.2. Tribal Lands Model

When the regression was run with only Tribal lands, some differences between drinking water violations were observed. As shown in Table 10, the overall model had limited explanatory power as the R-squared value is 0.0486, and the F-statistic is relatively low.

EPA Region 9 had a higher mean drinking water violation of 1.69, compared to Region 6 Tribes, however this was not statistically significant. This finding indicates that the EPA regional designation alone does not have an evident effect on compliance outcomes within Tribal areas.

Total population is the only statistically significant predictor in the model, as a larger population has lower drinking water violations. Median income is not statistically significant.

Additionally, a two-sample t-test was conducted to compare the average drinking water non-compliance between EPA Region 6 and Region 9 Tribal areas. The test did not reveal a statistically significant difference, reinforcing the regression results that funding region designation does not significantly affect compliance outcomes among Tribal block groups.

Table 10. Tribal model results for block group drinking water violations in New Mexico.

	Violations
Region 9	1.69
	(2.71)
Total Population	-4.87***
	(0.0028)
Household Median Income	.053
	(0.089)
# Observations	72
Adj. R^2	0.0486

Note: * p < 0.1, **p < 0.05, *** p < 0.01

3.6. Discussions

3.6.1. Interpretation of Results

The regression analysis indicates that the percentage of tribal land within a census block group and the median household income are predictors of drinking water violations across New Mexico. Specifically, higher concentrations of tribal land are consistently associated with lower rates of violations. Meanwhile, higher household median income are generally associated with fewer violations.

The inverse relationship between tribal land concentration and water violations complicates environmental justice and water policy literature assumptions that all tribal communities are inherently more vulnerable to regulatory neglect. This finding suggests tribal jurisdictions may possess governance practices or land management strategies conducive to better compliance outcomes. While the Clean Water Act's Treatment as a State provision allows tribes to establish their water quality standards, only a few tribal governments have obtained this status. Diver (2018) notes that Tribal communities often develop water quality standards that reflect ceremonial and cultural water uses and exert influence over upstream pollution sources. The results are consistent with that narrative, implying that even without formal regulatory control, tribal self-determination and community-level oversight may yield meaningful improvements in water system performance.

The nonlinear relationship between income and violations also merits attention. The negative coefficient on the mean-centered income term and a positive squared term indicate diminishing returns to income concerning water compliance. Communities with household median income below $89,000 or 1.4 times of the regional average household median income will have improved drinking water compliance as income increases, likely due to improved access to infrastructure, better administrative capacity, and increased fiscal flexibility to maintain water systems. However, for block groups above that threshold, increased income is related to a decrease in drinking water compliance. This may reflect political or geographic factors, such as decentralized or private systems in wealthier communities lacking administrative oversight found in more urban, upper-class areas. The result challenges linear assumptions common in policy frameworks that allocate funding strictly on income tiers, suggesting instead that vulnerability to water violations is most acute in moderately poor communities rather than uniformly decreasing with higher income.

Additional models provide further context to these findings. In the model limited to Tribal block groups, population size was the only statistically significant predictor, with larger populations associated with fewer violations. Median income and EPA Region 9 designation were not significant, suggesting that other unobserved institutional or infrastructural factors may shape outcomes within Tribal lands. When applying a log transformation to the dependent variable, results remained directionally consistent: Tribal land percentage was still negatively associated with violations, and the non-linear income pattern persisted; however, it was not statistically significant. This provides additional support for the robustness of the income-compliance relationship and affirms that the Tribal land effect is not sensitive to distributional skew in the outcome variable.

3.6.2. Robustness and Sensitivity Analyses

To test the tribal land impact, regressions were estimated for subsamples with increasing tribal land concentration, greater than 25, 50, 75, and 90 percent. In each case, the coefficient on tribal land remained negative and statistically significant, suggesting that the observed relationship is consistent across varying levels of tribal land intensity and not driven by any subset of block groups.

Interaction terms were also included to test whether the effect of tribal land on compliance was conditional on the presence of environmental hazards such as superfund sites or treatment, storage, and disposal facilities (TSDFs). These interaction terms were not statistically significant, indicating that these hazard exposures do not modify the association between tribal land and water violations. Similarly, no significant interaction was found between tribal land and EPA Region 9, suggesting that this relationship holds regardless of regional regulatory administration. In addition to specifications substituting the proportion of low-income households for median income, the original mean-centered income model performed better in statistical significance and explanatory power. These studies support the use of nonlinear income specifications over simpler poverty measures when modeling water system compliance.

A log-transformed model of drinking water non-compliance was also estimated to address skewness in violation counts. The results of this model were consistent with the main specification: tribal land percentage remained negatively associated with violations, and income terms retained statistical significance. Additionally, a separate regression was conducted using only block groups containing Tribal land. In that model, the total population was the only significant predictor of SDWA compliance. Neither EPA Region 9 status nor income showed significant effects, pointing to the potential influence of unobserved institutional or system-level characteristics unique to Tribal communities.

3.6.3. Extending the Literature

The findings expand upon previous literature in both environmental justice and water economics. Studies such as Mayer et al. (2019) and Conroy-Ben and Richard (2018) have documented water quality monitoring and enforcement disparities across tribal and non-tribal lands. However, the current results suggest that in New Mexico, higher concentrations of tribal land are associated with improved drinking water compliance. This may reflect informal regulatory regimes, traditional ecological stewardship, or a stronger emphasis on source water protection, consistent with literature on Indigenous governance and natural resource management. Diver (2018) emphasizes how tribal water quality standards, even when developed within federal frameworks, often reflect a hybrid of cultural priorities and regulatory tools.

This is also consistent with Gaytan Tellez (2024), who found that CWS located in tribal areas across New Mexico exhibited fewer drinking water violations and rarely appeared among the most burdened systems, despite being situated in socioeconomically disadvantaged census tracts. Her GIS-based vulnerability analysis revealed that tribal CWS tended to receive more targeted technical assistance and dedicated grant funding, which may buffer against compliance failures even in the presence of poverty or environmental burdens. This supports the notion that Indigenous governance models and external support networks can enhance regulatory performance in Tribal utilities.

The U-shaped relationship in the regression of income reinforces findings in environmental economics that caution against assuming a uniformly linear relationship between income and infrastructure quality. For example, the economic costs of source water contamination and the benefits of watershed protection have been shown to vary with community wealth and land use patterns (Warziniack et al. 2017; Price and Heberling 2018). These studies suggest that water quality and cost efficiency improvements are greatest when communities invest in preventative strategies, which may be more prevalent among middle-income communities with strong local governance.

3.6.4. Policy Implications

These findings have important implications for public policy understanding and addressing water system performance and compliance. The continuous negative relationship between tribal land concentration and drinking water violations suggests that tribal governance may offer important institutional or cultural advantages that enhance compliance, even without full regulatory authority. This supports broader calls for expanding tribal control over environmental programs and reducing the administrative burdens associated with TAS applications under the Clean Water Act.

The nonlinear relationship between income and drinking water non-compliance calls for more refined policy tools. Funding allocation formulas relying on linear income thresholds may overlook communities that are vulnerable due to inadequate infrastructure or decentralized water systems. Policies looking to address these disparities may require increased oversight of decentralized water systems and increased funding for low-income households. These findings suggest that policy interventions should differentiate between income-poor and infrastructure-poor communities, as the overlap between these groups may not be uniform.

The insignificance of regional and hazardous waste interaction terms suggests that metrics such as EPA region or proximity to environmental hazardous sites may not be sufficient predictors of drinking water compliance. However, government and water manager capacity, household access, and access to operational support appear to be more significant indicators. EPA Region 9 not being statistically significant in Tribal-only models supports the conclusion that regional funding structures alone are not sufficient to explain variation in compliance.

3.6.5. Limitations and Directions for Future Research

This analysis is limited by the lack of data and the granularity of the study. While the regression results are robust to various specifications, the possibility of omitted variable bias remains, particularly concerning unobserved governance characteristics or informal regulatory networks. Some variables such as total population may be insignificant due to the granularity of this study, and may be observed when looking at a water system level. Additionally, while tribal land share was used as a continuous variable, this measure does not capture differences in governance structures across tribes or differentiation between trust or allotment lands. It also does not examine water quality at the water system level. Additionally, drinking water non-compliance is only one measure of water quality. This study also does not consider the number of households with access to clean drinking water.

Future research should include datasets to examine whether the associations observed persist over time and whether policy changes or legal settlements affect compliance trajectories. Comparative studies across tribal nations, especially those with and without primacy status, would clarify the institutional mechanisms underlying the observed results. Integrating system ownership and violation severity data could provide greater insight into the dynamics that drive compliance outcomes. Future studies should also consider infrastructure development and access to households. Finally, expanding this research to include health outcomes, cost burdens, and public perceptions would deepen the understanding of how drinking water violations translate into broader disparities.

3.7. Conclusion

This study examines the critical issue of clean water access in Indigenous communities, focusing on the socioeconomic and environmental conditions that shape disparities in drinking water quality. Special attention is given to the Navajo Nation, which falls into a different EPA funding region than most other Tribes in New Mexico.

We analyze the relationship between drinking water noncompliance and various predictors using robust linear regression models. Key variables include the percentage of tribal lands, total population, household median income (and its nonlinearity), and proximity to superfund and hazardous waste sites. Robustness checks are conducted through subsample analyses and comparisons between EPA Regions 6 and 9.

Results show that household median income is a consistent predictor of water system compliance. Higher income levels are associated with fewer drinking water violations, reaffirming that financial capacity plays a critical role in infrastructure quality. The percentage of tribal lands within a block group also shows a statistically significant negative relationship with violations suggesting that contrary to common assumptions, Tribal areas may not always experience worse water system performance. This finding complicates deficit-based narratives and points to potential strengths in Tribal governance or targeted federal support. However, this should not be interpreted as evidence that Indigenous communities have sufficient access to safe water. Noncompliance is only one indicator of quality of water for communities who have access to public drinking water and does not capture whether water is reliably delivered, culturally accessible, or safe to drink.

The absence of statistically significant effects for superfund and hazardous waste sites suggests that proximity to environmental hazards may not directly translate into higher water system violations or that violations may be mediated through governance and infrastructure factors not captured in this dataset.We also explored differences between Tribal areas in EPA Regions 6 and 9. While descriptive statistics suggested higher average noncompliance in Region 9, this difference was not significant when controlling for other variables. This indicates that regional funding or oversight structures may not be the primary drivers of compliance disparities. Rather, localized economic and institutional conditions appear to be more important.

From a policy perspective, these finding highlight that generally income remains a crucial indicator of compliance and that infrastructure investments should still be prioritized in under-resourced Tribal communities. While some Tribal areas may report fewer violations, this does not guarantee equitable access. Many continue to experience unreliable service, inadequate infrastructure, and legal or jurisdictional complexity. Investment should be coupled with support for Tribal self-determination in water governance, particularly in advancing infrastructure planning, data sovereignty, and decision-making authority.

In conclusion, Indigenous peoples know the needs of their communities. The key component in addressing water disparities is ensuring Indigenous communities have access to the resources to address these needs. Clean water is not only a basic human right, but also a cultural resource crucial to the ways of life of Indigenous peoples. Access to clean water in Tribal communities is a measure of our commitment to justice and upholding the Federal government’s Tribal trust responsibility. This research contributes to that effort by identifying key socio-economic drivers of water system performance and pointing to opportunities for reform grounded in equity and sovereignty.

4. Part III: Urban Drinking Water Equity: A Case Study of Albuquerque

4.1. Introduction

Water equity refers to the fair and just distribution of access to safe, affordable, and reliable water services. It is a critical issue at both global and national levels, touching on core concerns of environmental justice, public health, and social sustainability. According to UN-Water (2023), over 2 billion people worldwide lack access to safely managed drinking water, and more than 3.5 billion people do not have access to safe sanitation. UNICEF (2021) reports that nearly one in four children globally live in areas experiencing extremely high water-stress, exposing them to heightened risks of disease, malnutrition, and displacement. While the United States is widely regarded as a high-income country with advanced infrastructure, millions of people still face water insecurity, the inability to access or afford adequate water for basic needs.

In the U.S., disparities in water access and affordability persist along lines of geography, infrastructure investment, and governance. According to the U.S. Water Alliance (2019), more than 2 million Americans live without basic running water or indoor plumbing. This burden falls disproportionately on marginalized communities, particularly Native American households, who are 19 times more likely to lack piped water than white households. These inequities are compounded by rising utility rates, aging infrastructure, and increasing strain on water systems due to climate change. Addressing water equity is thus essential not only for public health and human dignity but also for achieving long-term environmental and economic resilience.

These challenges are particularly pronounced in New Mexico and the broader U.S. Southwest, a region characterized by arid and semi-arid conditions, chronic drought, and long-term climate vulnerability. In New Mexico, many communities face a dual burden of water scarcity and economic hardship, which intensifies concerns about water affordability. The state's water systems are under growing pressure from rising temperatures, reduced snowpack, and the high fixed costs of maintaining and upgrading aging infrastructure, particularly in underserved areas. These pressures are especially visible in Albuquerque, the state's largest city, where conservation pricing strategies, seasonal demand fluctuations, and socioeconomic inequalities interact to shape household water burdens. Despite these risks, the water equity challenges of the Southwest and of cities like Albuquerque remain understudied in national water affordability research. This study addresses that gap by providing a localized, data-driven assessment of water poverty in Albuquerque, offering insight into how affordability challenges play out at the neighborhood level in a climate-stressed and economically vulnerable urban environment.

4.2. Background

The concepts of water equity and water poverty are increasingly central in discussions of environmental justice and public utility policy in the U.S. While often associated with low-income countries, water poverty defined as the lack of reliable, affordable, and safe access to water is a persistent issue even in high-income nations. In the U.S., this condition is often experienced by marginalized communities, particularly along racial and socioeconomic lines, and reflects deeper patterns of infrastructural neglect and systemic inequality. The literature on water equity provides a critical framework for understanding how affordability, access, and quality of water services intersect with race, income, and geography.

A central concern in the water equity literature is affordability, particularly as rising utility costs outpace income growth. Mack and Wrase (2017) find that many U.S. households pay more than the EPA's recommended threshold of 4.5% of monthly income on water and wastewater services, disproportionately affecting low-income and vulnerable communities. Teodoro (2018) critiques conventional affordability metrics and develops a more nuanced index that better captures the financial burden on households. Expanding on these findings, Cardoso and Wichman (2022) provide a comprehensive national assessment of water affordability, analyzing utility billing data alongside household income distributions. Their study reveals that a significant share of U.S. households faces unaffordable water bills even at average consumption levels, highlighting affordability stress across diverse geographic and socioeconomic contexts. These findings demonstrate that water affordability challenges are more widespread than previously recognized and emphasize the need for pricing reforms that explicitly incorporate household income to promote equitable water access.

Beyond affordability, a significant body of research examines how water quality and access disproportionately disadvantage communities of color. Switzer and Teodoro (2017) using national Safe Drinking Water Act compliance data, find that areas with higher proportions of Black and Hispanic residents are more likely to experience water quality violations, even after controlling for income and utility characteristics. Similarly, Allaire et al. (2018) show that water violations tend to cluster in historically underserved regions, suggesting entrenched environmental injustice and structural disrepair. These findings mirror broader trends in environmental justice, where critical infrastructure, such as water and sanitation systems, reflects legacy patterns of racial segregation, underinvestment, and political marginalization.

Another dimension of water poverty arises from unequal infrastructure access. Jepson and Vandewalle (2016) provide an on-the-ground account of such disparities in peri-urban Texas, where low-income Latino communities face inadequate water service despite being geographically near urban utility networks. These cases underscore how historical neglect, institutional fragmentation, and discriminatory land use policies can produce spatial water poverty.

Despite the growing body of research on water equity and poverty in the U.S., many studies emphasize national or large metropolitan contexts, leaving important regional disparities underexplored. In this regard, the case of Albuquerque, New Mexico, offers a critical lens into how water poverty manifests in semi-arid cities facing long-standing challenges related to affordability, infrastructure, and climate vulnerability. Building on this gap, the present study contributes to the literature by examining block group-level water poverty in Albuquerque, using a combination of daily water use data, NOAA climate records, and socioeconomic indicators. The study focuses on measuring water affordability using a Water Poverty Index (WPI) framework adapted to the U.S. urban context, offering a novel approach to quantify block group level water stress. By centering a region often overlooked in national studies, this research provides a methodologically rigorous and geographically specific contribution to the literature on water equity and water poverty, advancing tools for evaluating affordability and guiding equitable water policy in climate-stressed urban environments.

4.3. Methodology

This study develops a localized Water Poverty Index (WPI) to assess spatial variation in water-related hardship across Census block groups in Albuquerque. While the term "Water Poverty Index" was introduced by Sullivan (2002) to assess national-level water stress by combining physical, social, and economic indicators, our approach adapts the WPI concept to an urban U.S. context with a focus on household-level vulnerabilities. Specifically, we follow recent scholarship on water affordability and equity in the U.S. (e.g., Teodoro 2018; Cardoso and Wichman 2022) to construct a simplified, three-component WPI that captures distinct but interrelated dimensions of water insecurity: underuse, affordability, and climate vulnerability. Unlike previous WPI applications that often emphasize macro-scale water availability or institutional capacity, our index is designed to identify spatially disaggregated patterns of water hardship in a climate-stressed urban area within a high-income country, where many neighborhoods still experience economic and infrastructural vulnerability. Thus, the index is not a direct replication of Sullivan's original model, but a novel adaptation tailored to the specific policy and equity challenges facing U.S. cities like Albuquerque.

4.3.1. Underuse

Underuse captures inadequate water consumption relative to human needs. Following the literature (Teodoro 2018; Cardoso and Wichman 2022), block groups are flagged as underusing water if average daily per capita consumption falls below 50 gallon per capita per day (GPCD). Equation (4.1) defines how daily per capita water use is calculated for each block group j:

$$GPCD_j = \frac{Total\ Daily\ Water\ Use_j}{Population_j} \tag{4.1}$$

This equation divides the total daily water use by the population in the block group to estimate how much water, on average, each person uses per day. Block groups with per capita water use less than 50 gallons per day were marked as underuse = 1, otherwise 0.

4.3.2. Affordability

Affordability assesses the financial burden of essential water and sewer services relative to household income. In this analysis, we follow the U.S. Environmental Protection Agency (EPA 1997, 1998) and recent studies (Teodoro 2018; Cardoso and Wichman 2022), which identify a threshold of 4.5% of monthly household income as the maximum acceptable burden for water and sewer services. To compute affordability, we estimate the affordability ratio for each block group as:

$$Affordability\ Ratio_j = \frac{Average\ Monthly\ Expenditure\ for\ Basic\ Water\ Needs_j}{Monthly\ Median\ Household\ Income_j} \tag{4.2}$$

where the numerator is the household expenditure associated with a basic water need of 50 gallons per capita per day (GPCD). This threshold is commonly used in the water affordability literature as the minimum quantity necessary for basic health and hygiene (e.g., Gleick 1996). We calculate the monthly water use per household based on this 50 GPCD benchmark and then multiply it by the block group level residential water and sewer rates to derive the estimated monthly expenditure for basic water needs.

This approach ensures that affordability reflects access to essential water services, rather than broader consumption levels, which may include discretionary or non-essential uses. A block group is flagged as inaffordable (coded as 1) if the affordability ratio exceeds 4.5%; otherwise, it is coded as 0.

4.3.3. Climate Vulnerability

Climate vulnerability in this study reflects limited adaptive capacity to extreme heat, particularly the inability to maintain or increase essential water use during high-temperature periods. Following U.S. public health and climate literature, heatwave periods are defined as days when the maximum daily temperature reaches or exceeds 90°F a threshold widely used by the Centers for Disease Control and Prevention (CDC 2000), the U.S. Environmental Protection Agency (EPA 2016), and the National Weather Service (NWS 2022) to indicate elevated risk to public health.

To operationalize this concept, Equation (4.3) calculates the difference in per capita water use between hot (≥90°F) and non-hot days for each block group:

$$\Delta Use_j = \ Per\ Capita\ USe_{j,heat\ days} - Per\ Capita\ Use_{j,non-heat\ days} \tag{4.3}$$

If $\Delta Use_j < 0$, the block group is flagged as climate vulnerable (vulnerability = 1), indicating that water use declines during periods when it would typically be expected to increase to support hydration, cooling, and sanitation needs. This pattern may suggest constrained or suppressed usage, likely due to economic or infrastructural limitations consistent with frameworks in the energy poverty literature (Negaunee et al., 2022), where lower-than-expected electricity use during hot weather reveals unmet cooling demand and limited adaptive capacity.

Conversely, if $Use_j \geq 0$, the block group is not flagged (vulnerability = 0), indicating that water use during heatwave periods met or exceeded baseline levels, suggesting greater resilience to heat-related stress. This methodology is aligned with established findings that water demand generally increases with temperature (Hondula et al., 2015; Vahmani and Jones, 2017), and that a failure to do so under heat stress may reflect social or economic vulnerability.

4.3.4. WPI Construction

A simplified WPI was constructed at the block group level by summing three binary indicators: underuse, affordability, and climate vulnerability, following multidimensional framework like Sullivan (2002). As shown in Equation (4.4), the WPI score for each block group is computed as the sum of the three individual binary components:

$$WPI_j = Underuse_j + Affordability_j + Climate\ Vulnerability_j \tag{4.4}$$

The resulting WPI score ranges from 0 to 3, where a score of 0 indicates no observed water-related hardship, and a score of 3 indicates that all three dimensions of water poverty are present. In this study, a block group is defined as water poor if its WPI score is greater than or equal to 1, meaning it experiences at least one form of water-related deprivation. This composite index allows for a geographically disaggregated identification of areas facing water stress, informing targeted policy interventions.

4.4. Data

The WPI is applied to Albuquerque, New Mexico as a case study to identify neighborhoods at risk of water poverty in a semi-arid urban environment. This study utilizes high-resolution water consumption data from the Albuquerque Bernalillo County Water Utility Authority for the calendar year 2019. The dataset includes hourly usage records collected from smart meters installed across 88,670 residential water accounts—both single-family and multi-family dwellings—throughout the Albuquerque metropolitan area. Each record contains a unique account identifier, time-stamped volume of water used (in gallons), and service address information. This detailed spatial data enables aggregation at the Census block group level using geographic information system (GIS) methods, allowing for neighborhood-level analysis. In total, the dataset encompasses 411 block groups, offering granular insight into household water use patterns.

To evaluate disparities in water affordability across neighborhoods, the water utility data were merged with block group-level socioeconomic data from the American Community Survey (ACS). Key variables include median household income, population, and average household size. These indicators support the construction of affordability metrics and help contextualize water usage across different demographic and economic conditions.

Daily per capita water consumption was calculated at both the account and block group levels. For account-level estimates, a household size of 2.63 persons was assumed, based on 2019 U.S. Census Bureau estimates for New Mexico. To control for environmental influences on water demand, daily weather data for Albuquerque in 2019 were obtained from the National Oceanic and Atmospheric Administration (NOAA). This information allows the analysis to examine how temperature variability—particularly in a semi-arid environment—affects household water use and may contribute to affordability pressures.

4.5. Results

4.5.1. Underuse

Table 11 shows that only two block groups (0.49%) reported an average daily water use below 50 gallons per capita per day (GPCD). Details on these two block groups are provided in Appendix A.1. At the account level, 311 accounts (0.35%) fell below the same threshold.

Table 11. Summary of low per capita water use in Albuquerque, 2019

Level	Total Observations	Observations < 50 GPCD	Percent Below 50 GPCD
Block Group	411	2	0.49%
Residential Account	88,670	311	0.35%

Note: GPCD = Gallons per capita per day. Per capita estimates are based on an average household size of 2.63 persons (U.S. Census Bureau, 2019).

The reasons behind such low per capita usage are not immediately clear. These cases may reflect high-efficiency water use, limited or restricted access to water, or unoccupied housing units during the observation period. While representing a small fraction of the total, these low-use cases may warrant further investigation, particularly in the context of water affordability, service equity, or infrastructure reliability.

4.5.2. Affordability

Table 12 shows out of 411 block groups included in the study, only one block group was flagged as unaffordable. Details on this block group are provided in Appendix A.2. This means that in 99.76% of block groups, the average household pays less than 4.5% of their income on water bills, while only 0.24% of block groups exceed this threshold.

Table 12. Water affordability assessment by block group

Affordability	Number of Block Groups	Percentage (%)
0 (Affordable)	411	99.76%
1 (Unaffordable)	1	0.24%
Total	411	100%

The findings suggest that, at a macro scale, the water system in the study area remains largely affordable based on median income levels. However, the presence of even a single block group where affordability is a concern highlights the importance of not relying solely on averages or aggregated metrics. Localized affordability issues may reflect broader structural inequalities such as low-income households, high fixed service charges, or disproportionate water use patterns that require targeted investigation and potentially policy intervention.

While most national studies assess water affordability at the household level, our analysis is conducted at the block-group level, using the average household income and water expenditure within each geographic unit. For instance, Teodoro (2018) estimates that approximately 12–14% of U.S. households face unaffordable water bills based on a 4.5% income threshold. In contrast, our block-group-level analysis finds that only one out of 411 block groups (0.24%) exceeds this threshold. Although these figures are not directly comparable due to differences in scale, the result suggests that, on average, water remains affordable across nearly all neighborhoods in the Albuquerque Bernalillo County Water Utility Authority service area. However, block-group-level averages may mask affordability burdens experienced by lower-income households within otherwise affordable areas. Thus, while the finding is encouraging, it underscores the importance of complementing geographic-level analyses with household-level assessments when possible.

4.5.3. Climate Vulnerability

Table 13 shows the distribution of block groups by climate vulnerability status, highlighting the proportion of communities potentially at risk due to limited adaptive responses to extreme heat. Out of the 411 block groups analyzed, five block groups (1.2%) exhibited negative change in per capita use values, meaning that average per capita water use was lower on heatwave days compared to non-heatwave days. These areas were flagged as climate vulnerable (vulnerability = 1), potentially indicating behavioral, economic, or infrastructural constraints in adapting to extreme heat. Details on these five block groups are provided in Appendix A.3. The remaining 406 block groups (98.8%) either maintained or increased their water use during heatwaves, suggesting relatively greater adaptive capacity (vulnerability = 0).

Table 13. Climate vulnerability by block group

Climate Vulnerability	Number of Block Groups	Percentage (%)
Vulnerable (ΔUse < 0)	5	1.2%
Not Vulnerable (ΔUse ≥ 0)	406	98.8%
Total	411	100%

4.5.4. Water Poverty Index (WPI)

Among the 411 block groups analyzed, 2 block groups were flagged for underuse only; 1 block group was flagged for affordability only; and 5 block groups were flagged for climate vulnerability only.

Table 14 summarizes the distribution of WPI scores. As shown, the vast majority of block groups (403 out of 411) did not exhibit signs of water-related vulnerability according to the three dimensions assessed. However, eight block groups (1.9%) were identified as having a WPI score of 1, meaning they were flagged under a single vulnerability category either underuse, affordability, or climate vulnerability.

Table 14. Distribution of Water Poverty Index (WPI) by block group

WPI Score	Description	Number of Block Groups
0	No vulnerability	403
1	One vulnerability (Underuse, Afford., or Climate)	8
2	Two vulnerabilities	0
3	All three vulnerabilities	0
Total		411

The absence of any block groups with WPI scores of 2 or 3 indicates that compound vulnerability, where multiple water-related stressors converge, is currently not observed in the study area. This could suggest that water poverty in this context is more isolated than systemic, but it also emphasizes the importance of early intervention, as even a single vulnerability can signal risks to household well-being—particulwarly in marginalized or climate-sensitive communities.

These results underscore the need for targeted water policy responses that address the specific dimension of vulnerability present in each flagged block group, rather than a one-size-fits-all approach.

4.6. Conclusion

This study offers a localized, data-driven assessment of water poverty in Albuquerque, New Mexico, applying a multidimensional framework to identify areas of potential vulnerability across underuse, affordability, and climate sensitivity. Although the findings suggest that widespread water poverty is not prevalent in the city only 1.9% of block groups exhibited a WPI score of 1 and none showed compounded vulnerability, this should not be interpreted as evidence that Albuquerque is free from systemic water equity challenges. Instead, it may reflect the strength of local water management practices or the use of conservative thresholds in our methodology. It may also suggest that some previously vulnerable areas have benefited from targeted improvements. However, vulnerability at the household level may still be masked by block-group-level aggregation, and even isolated hardship can signal early warning signs of deeper systemic stress particularly in climate-sensitive and economically stratified regions like Albuquerque. These findings underscore the importance of continued monitoring and localized intervention to prevent future convergence of affordability, access, and climate-related stressors.

The presence of even a small number of block groups flagged for affordability, underuse, or climate vulnerability signals early warning signs of stress in a region already facing persistent water scarcity and economic challenges.

Importantly, this research advances the national conversation on water equity by shifting analytical focus to an often-overlooked geographic region: the semi-arid urban Southwest. Through integration of high-frequency water usage data, climate records, and socioeconomic indicators at the block group level, the study demonstrates the value of granular analysis in uncovering localized disparities that might be masked in broader metropolitan or national statistics. Albuquerque's experience reveals how climate stressors, income inequality, and behavioral patterns interact to shape water security outcomes, and it underscores the need for nuanced, equity-aware water governance.

The WPI introduced here provides a flexible and replicable tool for assessing water-related vulnerabilities in other urban environments. It supports policymakers, utility managers, and researchers in identifying at-risk neighborhoods and tailoring interventions, whether through infrastructure investment, affordability assistance, or public outreach to address specific dimensions of water insecurity. As climate change accelerates and socioeconomic pressures deepen, adopting such spatially sensitive approaches will be vital for ensuring that water systems remain resilient, inclusive, and equitable.

In conclusion, while Albuquerque's water system appears largely resilient today, the emergence of localized vulnerabilities highlights the need for proactive, equity-centered planning. Ensuring that no community is left behind in the pursuit of water security will require sustained investment, interdisciplinary collaboration, and policy innovation—especially in climate-sensitive regions like New Mexico.

5. Summary and Conclusion

This report provides a comprehensive analysis of drinking water equity in New Mexico, focusing on community water systems. We evaluate drinking water access, quality, and affordability across three scales: statewide public water systems, Tribal lands, and the city of Albuquerque. We identify areas of disparity and offer insights to inform policy and investment.

Statewide, community water systems that rely on surface water consistently experience more total and health-related violations than those using groundwater. Smaller systems, especially those serving under 500 people, are particularly vulnerable due to limited resources and treatment capacity. These challenges are more acute in rural, low-income, and less-white communities, underscoring persistent inequities in water quality in terms of drinking water violations. Supporting system consolidation and upgrading infrastructure in high-risk areas should be a top priority.

On Tribal lands, our findings challenge common assumptions. Census block groups with higher percentages of Tribal land are associated with fewer drinking water violations. While this may reflect effective tribal governance or targeted federal support, it does not mean water access is adequate on all Tribal land, as many Tribal households still lack piped water. Moreover, EPA regional designation (Region 6 vs. Region 9) is not a significant factor in water compliance outcomes, suggesting that localized conditions and governance may play a greater role than federal administrative boundaries.

In Albuquerque, water is generally affordable at the median-income level, with nearly all neighborhoods below the 4.5% income threshold for water bills. However, some communities show signs of vulnerability, such as reduced water use during extreme heat, which may signal financial or infrastructural constraints. While no neighborhoods experienced overlapping affordability, underuse, and climate vulnerability, these isolated stressors should not be ignored.

To improve water equity, we recommend prioritizing support for small and surface water-dependent systems, investing in Tribal water infrastructure and self-determination, and adopting tools like the Water Poverty Index to proactively identify and assist vulnerable communities. Overall, addressing drinking water inequality in New Mexico will require sustained investment, locally tailored strategies, and a strong commitment to equity. This report aims to support that goal with timely data and actionable policy guidance.

6. References

Allaire, Maura, Taylor Mackay, Shuyan Zheng, and Upmanu Lall. 2019. Detecting community response to water quality violations using bottled water sales. Proceedings of the National Academy of Sciences 116 (42): 20917–22.

Allaire, Maura, Haowei Wu, and Upmanu Lall. 2018. National trends in drinking water quality violations. Proceedings of the National Academy of Sciences 115 (9): 2078–83.

Alzahrani, Fahad, Alan R Collins, and Elham Erfanian. 2020a. Drinking water quality impacts on health care expenditures in the United States. Water Resources and Economics 32: 100162.

Anon. 2019. History of Drinking Water Regulations | Water-related Topics | Healthy Water | CDC. https://archive.cdc.gov/www_cdc_gov/healthywater/surveillance/drinking-water-reg-history.html.

Baracho, Rafaella Oliveira, Anne Karoline Lima Monte, Brunna Eduarda Marques da Fonseca, Thaynara Lorrayne de Oliveira, and Paulo Sérgio Scalize. 2024. Levels of Access to Water and their Impacts on The Quality of Life. Revista de Gestão Social e Ambiental 18 (3): e03277–e03277.

Beisner, Kimberly R, Rebecca E Travis, David A Alvarez, Larry B Barber, Jacob A Fleck, and Jeramy R Jasmann. 2024. Temporal variability and sources of PFAS in the Rio Grande, New Mexico through an arid urban area using multiple tracers and high-frequency sampling. Emerging Contaminants 10 (3): 100314.

Conroy-Ben, Otakuye, and Rain Richard. 2018. Disparities in Water Quality in Indian Country. Journal of Contemporary Water Research & Education 163 (1): 31–44.

Cardoso, Diego S. and Casey J. Wichman. 2022. Water Affordability in the United States. Water Resources Research, 58 (12): e2022WR032206.

CDC. 2000. Heat-related deaths—United States, 1979–1997. Centers for Disease Control and Prevention (CDC). Morbidity and Mortality Weekly Report 49(21), 421–424.

Diver, Sibyl. 2018. Native Water Protection Flows Through Self-Determination: Understanding Tribal Water Quality Standards and "Treatment as a State." Journal of Contemporary Water Research & Education 163 (1): 6–30.

EPA. 2024. Information about Public Water Systems. U.S. Environmental Protection Agency. https://www.epa.gov/dwreginfo/information-about-public-water-systems.

EPA. 2021. Per- and Polyfluoroalkyl Substances (PFAS). U.S. Environmental Protection Agency. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas.

EPA. 2016. Climate Change and Extreme Heat: What You Can Do to Prepare. U.S. Environmental Protection Agency. EPA 430-F-16-061. https://www.epa.gov/sites/default/files/2016-06/documents/extreme-heat-guidebook.pdf

EPA. 1998. Information for States on Developing Affordability Criteria for Drinking Water. U.S. Environmental Protection Agency, Office of Water.

EPA. 1997. Combined Sewer Overflows—Guidance for Financial Capability Assessment and Schedule Development. U.S. Environmental Protection Agency.

EPA SDWIS. 2025. Safe Drinking Water Information System (SDWIS) Federal Reporting Services. https://www.epa.gov/ground-water-and-drinking-water/safe-drinking-water-information-system-sdwis-federal-reporting.

Estrada, Jorge. 2025. Enforcement Watch Alert. New Mexico Enviroment Department New Releases. https://acrobat.adobe.com/id/urn:aaid:sc:VA6C2:d9a7d57a-ec50-4a9b-8319-3720d3af4308.

Gaytan Tellez, Alejandra. 2024. Drinking Water and Wastewater in Socioeconomically Disadvantaged Communities in New Mexico: The Utilization of Geographic Information Systems to Identify Communities Most in Need of Technical Assistance. Water Resources Professional Project Reports.

Gleick, Peter H. 1996. Basic water requirements for human activities: Meeting basic needs. Water International, 21(2): 83–92.

Hondula, David M., Robert C. Balling, Jennifer K. Vanos, and Matei Georgescu. 2015. Rising temperatures, human health, and the role of adaptation. Current Climate Change Reports, 1, 144–154.

Jepson, Wendy, and Emily Vandewalle. 2016. Household Water Insecurity in the Global North: A Study of Rural and Periurban Settlements on the Texas–Mexico Border. The Professional Geographer 68 (1): 66–81.

Kim, M, R De Vito, F Duarte, K Tieskens, M Luna, A Salazar-Miranda, M Mazzarello, S Showalter Otts, C Etzel, S Burks, K Crossley, N Franzen Lee, and ED Walker. 2023. Boil water alerts and their impact on the unexcused absence rate in public schools in Jackson, Mississippi. Nature Water 1 (4): 359–69.

Mack, Elizabeth A, and Sarah Wrase. 2017. A Burgeoning Crisis? A Nationwide Assessment of the Geography of Water Affordability in the United States. PLoS ONE 12 (1): e0169488.

Manson, Steven, Jonathan Schroeder, David Van Riper, Katherine Knowles, Tracy Kugler, Finn Roberts, and Steven Ruggles. 2024. National Historical Geographic Information System: Version 19.0. Minneapolis, MN: IPUMS.

Mayer, Brian, Lorencita Joshweseoma, and Gregory Sehongva. 2019. Environmental Risk Perceptions and Community Health: Arsenic, Air Pollution, and Threats to Traditional Values of the Hopi Tribe. Journal of Community Health 44 (5): 896–902.

McDonald, Yolanda J, Kayla M Anderson, Mariah D Caballero, Ke Jack Ding, Douglas H Fisher, Caroline P Morkel, and Elaine L Hill. 2022. A systematic review of geospatial representation of United States community water systems. AWWA Water Science 4 (1): e1266.

National Weather Service. (2022). Heat Index—What Is It? https://www.weather.gov/ama/heatindex

Navajo Water Project. 2022. About the Project. Navajo Water Project. https://www.navajowaterproject.org/project-specifics.

Paterson, Kent. 2016. Is Sunland Park the border's Flint, Michigan? NMPolitics.net, June 6.

Price, James I, and Matthew T Heberling. 2018. The Effects of Source Water Quality on Drinking Water Treatment Costs: A Review and Synthesis of Empirical Literature. Ecological Economics 151: 195–209.

Segrè Cohen, Alex, Catherine E Slavik, Sami Kurani, and Joseph Árvai. 2025. Mapping risks of water injustice and perceptions of privatized drinking water in the United States: A mixed methods approach. Risk Analysis.

Sullivan, Caroline. 2002. Calculating a Water Poverty Index. World Development 30 (7): 1195–1210.

Switzer, David, and Manuel P Teodoro. 2017. The Color of Drinking Water: Class, Race, Ethnicity, and Safe Drinking Water Act Compliance. Journal AWWA 109 (9): 40–45.

Teodoro, Manuel P. 2018. Measuring Household Affordability for Water and Sewer Utilities. Journal AWWA 110 (1): 13–24.

United Nations. 2023. Clean Water and Sanitation. United Nations Sustainable Development Goal 6: Ensure Access to Water and Sanitation for All. https://www.un.org/sustainabledevelopment/water-and-sanitation/.

UNICEF. 2021. Running dry: The impact of water scarcity on children in the Middle East and North Africa. UNICEF Regional Office.

UN-Water. 2023. World Water Development Report 2023: Partnerships and Cooperation for Water. United Nations Educational, Scientific and Cultural Organization (UNESCO).

U.S. Water Alliance. 2019. Closing the Water Access Gap in the United States: A National Action Plan. U.S. Water Alliance.

Vahmani, Pouya, and Andrew D. Jones. 2017. Water conservation benefits of urban heat mitigation. Nature Communications, 8(1), 1072.

Warziniack, Travis, Chi Ho Sham, Robert Morgan, and Yasha Feferholtz. 2017. Effect of Forest Cover on Water Treatment Costs. Water Economics and Policy.

7. Appendix

A.1 Water usage by block groups in Albuquerque, New Mexico (2019)

Figure A.1 presents the spatial distribution of water usage across block groups in Albuquerque, New Mexico, for the year 2019. The map categorizes block groups by their average daily per capita water consumption, with blue areas indicating usage greater than 50 gallons per capita per day (GPCD) and red areas representing usage below 50 GPCD. Two block groups are specifically labeled to illustrate contrasting demographic and land-use characteristics associated with differing water consumption levels.

Block group 350010037292, located in the northern part of the city and shaded in red, had a population of 1,164 in 2019. Despite having a relatively high median household income of $123,000, its water consumption was lower than 50 GPCD. This suggests that factors beyond income such as household behavior, housing density, or efficiency practices may be contributing to reduced water use in this area. The presence of higher-income households does not necessarily translate to excessive domestic water consumption, highlighting the complexity of water use determinants in urban environments.

In contrast, block group 350010008012, also shaded in red, is located in the southeastern region and primarily encompasses Kirtland Air Force Base. With a 2019 population of 611 and no reported median household income likely due to its institutional and non-residential land use the low water consumption is consistent with its function as a federal military facility. The base's restricted residential access and structured utility management likely result in lower per capita water use figures compared to typical civilian neighborhoods.

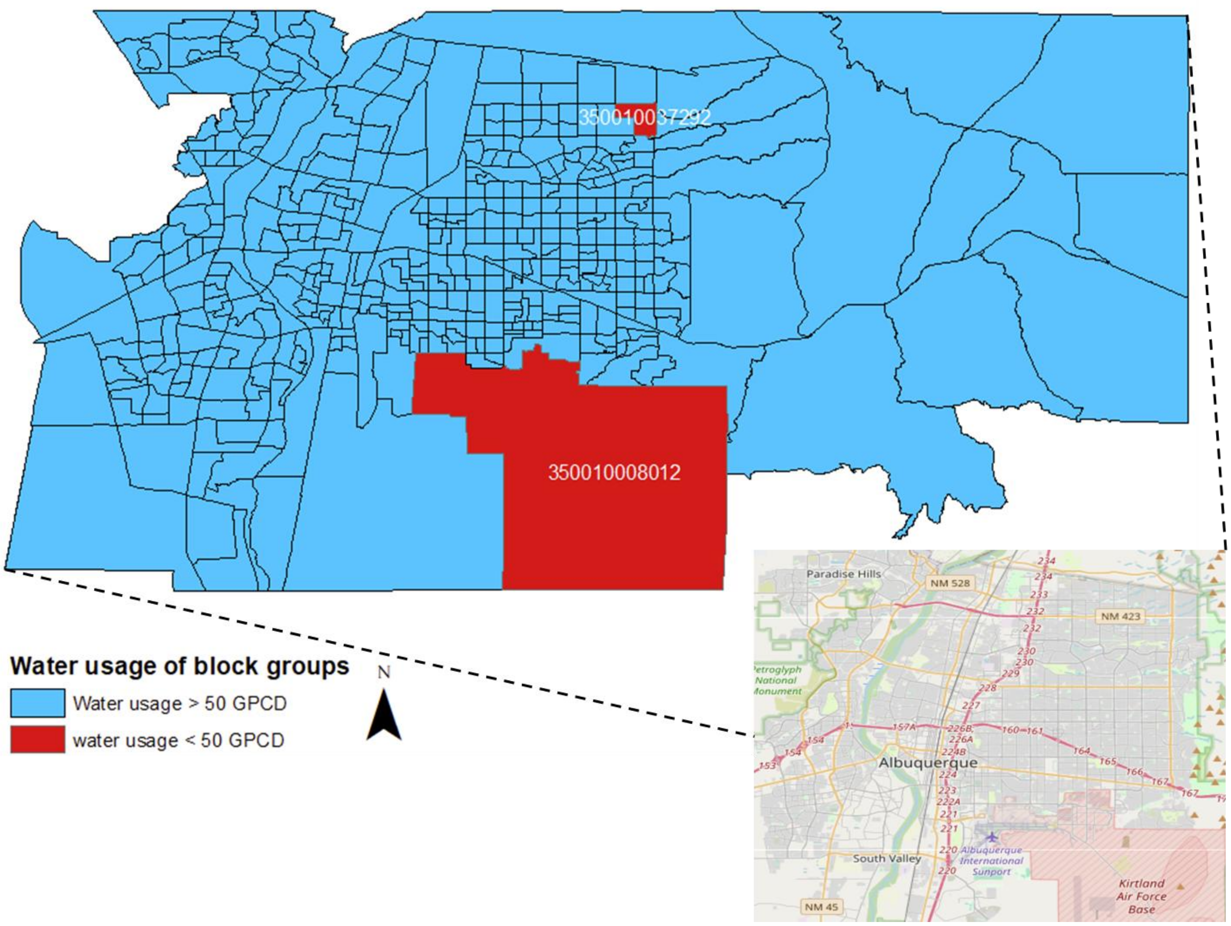

Figure A.1. Map of water usage of block groups in Albuquerque, New Mexico (2019)

A.2 Water affordability by block groups in Albuquerque, New Mexico (2019)

Figure A.2 presents a spatial representation of water affordability across block groups in Albuquerque, New Mexico, using 2019 data. The map categorizes each block group as either affordable (blue) or not affordable (red) based on a predefined affordability threshold, typically calculated as a percentage of median household income spent on basic water needs. Out of the 411 block groups assessed, only one block group identified by GEOID 350010027001 was found to be unaffordable. This block group, located in the central-western part of Albuquerque, is visually distinct in red amid a city otherwise shaded entirely in blue, indicating the widespread affordability of water services across the region.

The unaffordable block group is characterized by a median household income of $10,161 (in 2019 inflation-adjusted dollars) and a total population of 705. This extremely low-income level renders residents particularly sensitive to water rate changes, even when consumption levels are low. The identification of this outlier underscores the limitations of broad-based affordability assessments and highlights the necessity of adopting income-sensitive metrics.

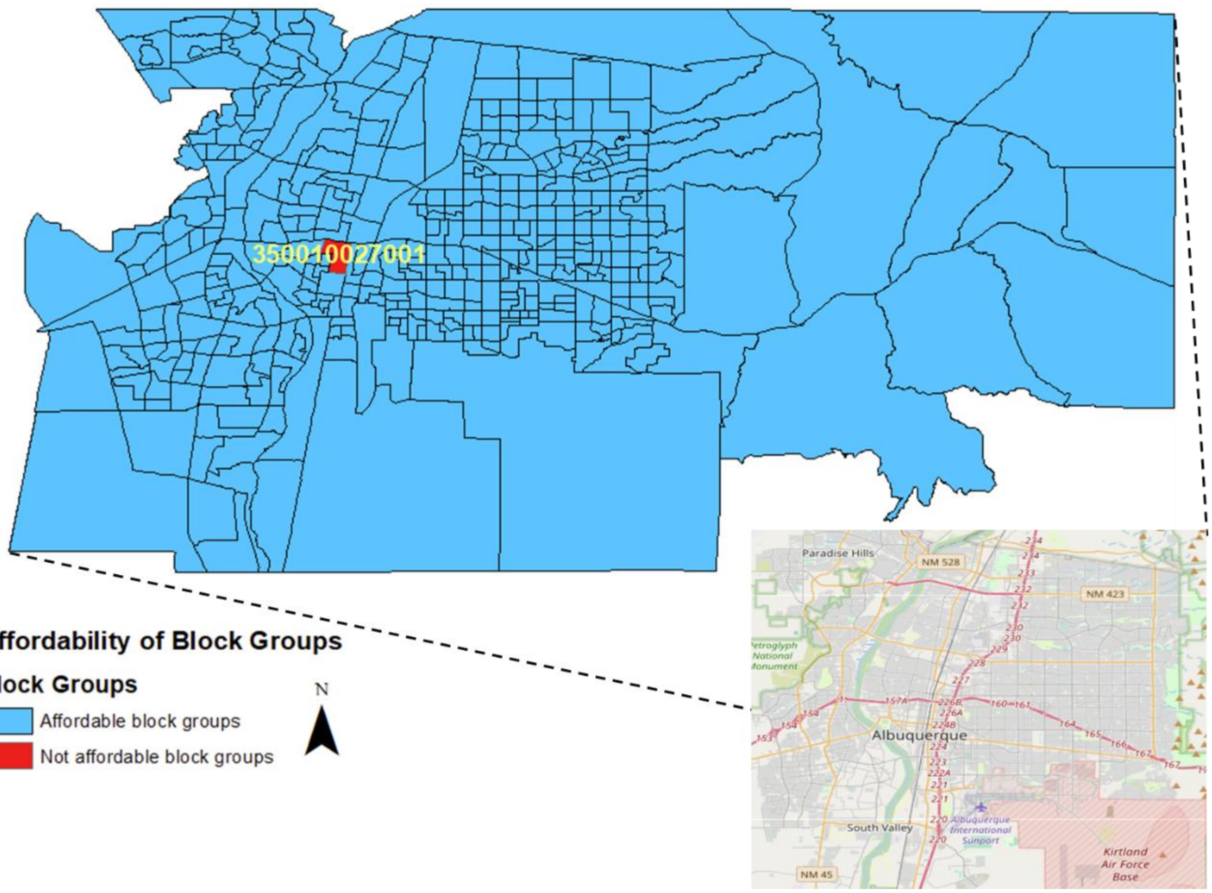

Figure A.2. Map of water affordability of block groups in Albuquerque, New Mexico (2019)

A.3 Climate vulnerability by block groups in Albuquerque, New Mexico (2019)

Figure A.3 illustrates the spatial distribution of climate vulnerability across block groups in Albuquerque, New Mexico, using 2019 data. Block groups are categorized as either climate vulnerable (red) or not vulnerable (blue) based on changes in per capita water use during extreme heat events. Of the 411 block groups analyzed, five were identified as climate vulnerable, meaning that their average per capita water use declined during heatwave days compared to non-heatwave days. This counterintuitive behavior suggests limited adaptive responses to extreme heat, potentially due to economic or structural constraints.

The five climate-vulnerable block groups are geographically concentrated in the central-southern and southwestern areas of the city and exhibit a range of demographic characteristics. Population estimates for these areas range from roughly 800 to 3,400 residents. Median household incomes also vary significantly: three block groups earn less than $32,000 annually with reported incomes of $19,041, $31,150, and $31,274 while the remaining two earn moderately higher incomes of $51,466 and $63,897. This variation implies that while climate vulnerability is not confined strictly to low-income communities, economic disadvantage may play a substantial role in limiting adaptive capacity. Households with lower income levels may lack access to cooling infrastructure or may consciously reduce water use during heatwaves to manage costs, thereby intensifying exposure to heat-related risks. The map underscores the importance of considering socioeconomic disparities when designing climate resilience and public health interventions.

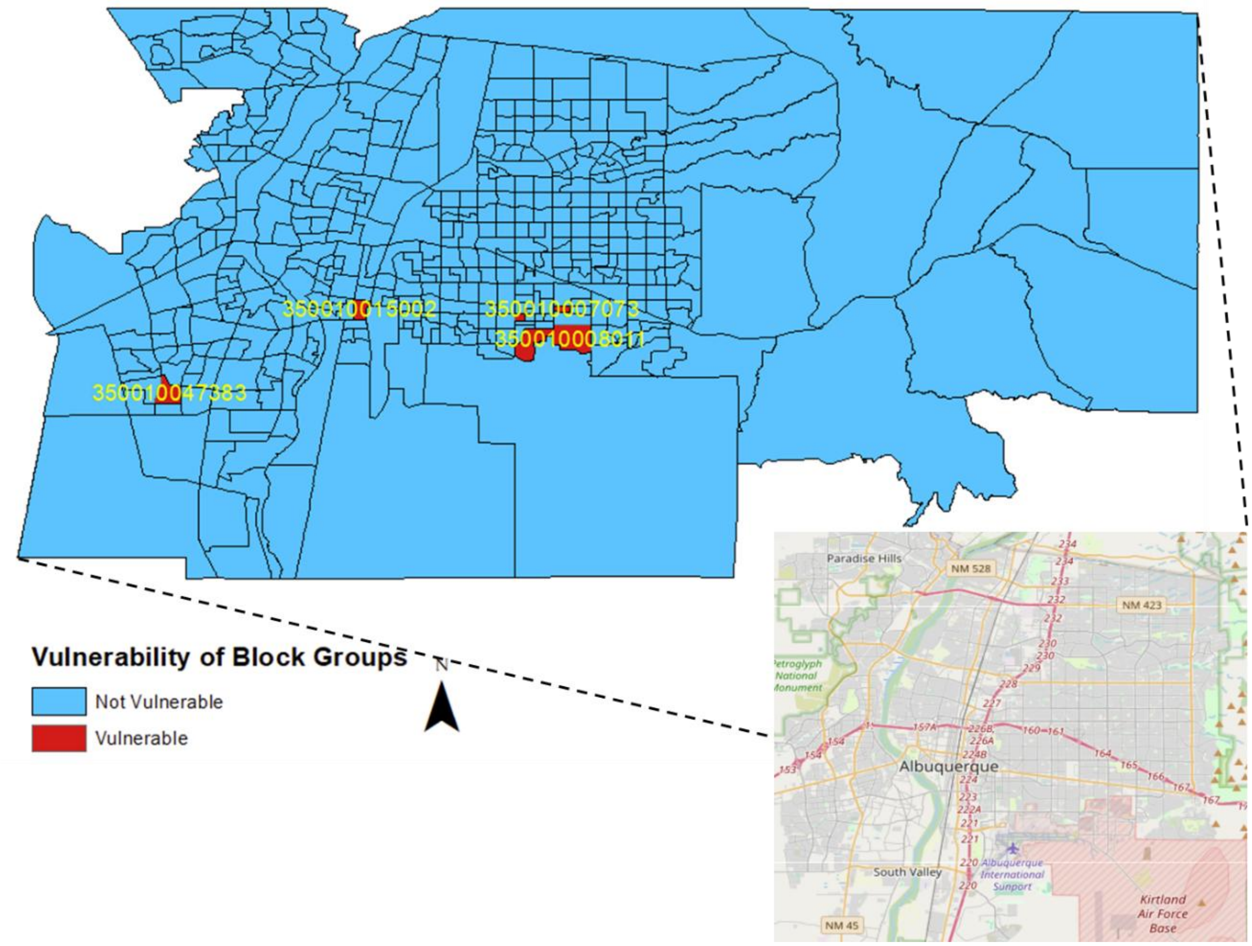

Figure A.3. Map of climate vulnerability of block groups in Albuquerque, New Mexico (2019)