

# High-resolution Analysis of Demographic and Socioeconomic Characteristics of Households with Private Wells in the USA

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## ABSTRACT

Private domestic wells supply drinking water to roughly 15% of the United States population, yet remain largely unregulated, and poorly characterized in terms of the populations they serve. While prior national studies describe broad patterns of domestic well use, they are generally limited to coarse regional resolutions or smaller geographic extents. Here, we present a national, high-resolution analysis of the demographic and socioeconomic profiles of households with private wells in the United States. We integrate geospatial data from a national database of groundwater wells with block- and block group- level demographic information from the 2020 U.S. Census and American Community Survey. Domestic wells are identified and spatially linked to population characteristics including race, educational attainment, and household income, with results aggregated to the county level. We further stratify findings by urban-rural classification to examine patterns across population density gradients. Our analysis revealed substantial spatial variation in the demographic characteristics of well users as compared to nonwell users. Overall, well users are more likely than their public water counterparts to identify as White and to reside in households with higher incomes than county medians. Differences in educational attainment are more variable across states and counties, but are generally modest in magnitude. Across counties, increases in educational attainment and in the proportion of White-identifying well users are associated with higher household incomes. These findings provide a demographic context for domestic well reliance and may support the development of more targeted policies and resources for domestic testing, treatment, and maintenance for populations dependent on private wells.

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## GENERAL AUDIENCE ABSTRACT

Approximately 15% of the United States population lives in homes that do not receive treated drinking water from a public utility. Instead, these households rely on private wells for their water supply. In these cases, well owners are responsible for testing their water, treating it when necessary, and maintaining their well systems. Despite the importance of private wells, little is known about the demographic and socioeconomic characteristics of the households that rely on them, particularly at the county level or across urban and rural areas. In this study, we use a database of private wells locations and link these data to demographic information from the U.S. Census Bureau at the finest available resolution. We compare the characteristics of households using private wells with those of nearby households served by public water systems. Results are summarized by county and by urban and rural classifications at the state level. We find that private well users are more likely to identify as White and have higher household incomes than others residing in the same general area. In contrast, differences in educational attainment do not follow a consistent pattern and are generally modest. The results of this research provide a clearer picture of who relies on private domestic wells across the United States and may help county and state health departments and policymakers develop more targeted policies and resources to support well stewardship among private well users.

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## List of Abbreviations

ACS	American Community Survey
AHS	American Housing Survey
CDC	Centers for Disease Control and Prevention
EPA	Environmental Protection Agency
GED	General Educational Development
IPUMS NHGIS	Integrated Public Use Microdata Series, National Historical Geographic Information System
LBCS	Land-Based Classification System
SDWA	Safe Drinking Water Act
TIGER	Topologically Integrated Geographic Encoding and Referencing
USCB	United States Census Bureau
USGS	United States Geological Survey
USGWD	United States Groundwater Well Database

# 1. Introduction

The vast majority of people in the United States receive their drinking water from either publicly supplied water utilities or privately supplied wells (U.S. Census, 1990). The exact number of individuals reliant on private (domestic) wells is unknown, as the last national survey detailing how Americans get water within their homes was conducted in 1990 (U.S. Census, 1990). Since then, many studies have aimed to estimate the number of individuals reliant on domestic well water, with the most recent study by Murray et al. estimating that approximately 45.8 million individuals, or about 15% of the U.S. population, rely on domestic wells as their primary source of water (Dieter et al., 2018; Johnson & Belitz, 2017; Johnson et al., 2019; Murray et al., 2021; Murray et al., 2025). These systems are common in rural areas, where low population densities or challenging terrain make public water systems economically or physically impractical. However, domestic wells are also prevalent in peri-urban fringes of metropolitan areas, mobile home communities, and other developments that fall outside the footprint of community water infrastructure. As a result, domestic wells are a critical yet often invisible component of the U.S. water infrastructure landscape.

Like any drinking water source, private wells are vulnerable to both naturally occurring and anthropogenic contaminants, including arsenic and other metals, nitrates, septic leachate, and industrial pollutants. National groundwater assessments by the U.S. Geological Survey (USGS) indicate that nearly one in five groundwater samples from aquifers used for drinking water contain at least one contaminant at levels exceeding a potential human-health benchmark (USGS 2015; USGS, 2019). Unlike community water systems, which are regulated under the Safe Drinking Water Act (SDWA) and subject to routine monitoring, reporting, and enforcement, private wells are largely unregulated. Responsibility for monitoring, maintaining, and treating these wells falls almost entirely on individual well owners, who must recognize potential risks, arrange appropriate testing, and interpret and act on results (U.S. Environmental Protection Agency [EPA], 2025; Bowen et al, 2019).

The U.S. Centers for Disease Control and Prevention (CDC) recommend that well owners test their water at least once a year for total coliform bacteria and nitrates, and consider testing for additional contaminants such as arsenic or metals, particularly where local geology or land use

suggests an elevated risk (CDC, 2024a). In practice, however, testing is infrequent. A population-based survey in Wisconsin found that while more than 95% of private-well users reported using their tap water daily, only one in ten users had tested their well within the past year and roughly half had not tested in the past decade (Malecki et al., 2017). When testing and treatment occur, they often focus on aesthetic or “secondary” issues such as iron or hardness that affect taste, color, or staining, rather than on contaminants of primary health concern (Malecki et al., 2017).

In the absence of federal regulations governing the testing or treatment of domestic wells, states may implement programs and policies to oversee domestic well use or provide support to well users. State agencies often delegate key responsibilities—such as permitting, well construction standards, and oversight of well-testing programs—to county or local health departments, with varying levels of enforcement and capacity (Bowen et al., 2019). Even where local programs offer testing subsidies, educational workshops, or technical assistance, well owners may be unaware of available services or may not be effectively reached by outreach strategies. Additional barriers, including inconvenient sampling logistics, uncertainty about how or which contaminants to test for, the cost of comprehensive testing, and a low perceived risk of contamination, further inhibit widespread well testing (Flanagan et al. 2020; Kreutzwiser et al., 2011; Malecki et al., 2017).

Because well owners are individually responsible for testing, treating, and maintaining their wells, a clearer understanding of the household and population characteristics of well users can help states and local agencies better target educational resources and assistance programs to support well stewardship. To date, only one study has examined demographic patterns of well users across the United States. Hernandez and Pierce (2023) used the 2019 American Housing Survey (AHS) to produce a national analysis of households reliant on private wells and septic systems. They found that households using wells and septic systems were more likely to be non-Hispanic White, to reside outside metropolitan areas, and have slightly higher incomes on average (Hernandez and Pierce, 2023). Their analysis, however, is constrained by the structure of the AHS. Although the survey includes nearly 50,000 households and is intended to be nationally representative, it oversamples large metropolitan areas, whereas wells are more prevalent in rural or peri-urban communities. Results are reported at the national scale, for broad geographic

regions (e.g., West, Midwest, South, Northeast), and by metropolitan versus non-metropolitan status, but not at the county level or across finer gradients of population density. Consequently, while this work provides important baseline information, it offers only a coarse view of the demographic and socioeconomic patterns associated with domestic well use. Other studies that examine demographic patterns among well users focus on testing patterns, contaminant vulnerability, or limited geographic areas (Nigra et al., 2020; Peer et al., 2024; Hayes et al., 2024; Flanagan et al., 2020). Thus, a gap remains for a national, high-resolution characterization of patterns of race, educational attainment, and economic status among domestic well users, and how these characteristics vary across counties and along the rural-to-urban continuum.

In this study, we address these gaps by combining identified domestic wells locations with nationally available demographic data at their finest recorded resolution. By linking domestic well counts to statistics on race, educational attainment, and household income, and then aggregating results to the county level, we generate a detailed portrait of the social landscape of domestic well reliance across the United States. We further stratify these patterns by rural and urban classifications to see how patterns vary across population densities. Our research is guided by two questions: (1) How do demographic profiles (race, educational attainment, and economic status) of U.S. domestic well users differ from those with public water supply? and (2) How do these demographic profiles vary across counties and between rural and urban areas? By answering these questions, our analysis aims to provide a geospatial understanding of who is most likely reliant on domestic wells to inform the design of more equitable and effective well stewardship, testing, and protection policies.

## 2. Methods

### 2.1 Data Sources

We drew domestic well information from *A Database of Groundwater Wells in the United States* (USGWD; Lin et al., 2024). USGWD includes the geospatial locations and attributes (e.g., water use category, activity status) for over 14.2 million wells, including more than 6.8 million domestic wells and over 1.8 million with unspecified use.

We obtained demographic data from U.S. Census Bureau (USCB) products through the Integrated Public Use Microdata Series and National Historical Geographic Information System (IPUMS NHGIS; Schroeder et al., 2025). The 2020 Decennial Census provided block-level counts of total population, population by age, population by race, and number of households, as well as an urban-rural designation for each block (U.S. Census Bureau, 2020c; U.S. Census Bureau, 2020d; U.S. Census Bureau, 2020e). Blocks are the smallest unit of Census tabulation. Of the over 8 million blocks across the United States, over 2 million have a population of zero, and blocks with a population have on average 57 residents. Table 1 explains the various levels of geography used in this analysis, including what data was obtained at that scale. Urban areas are defined by the USCB as regions with at 2,000 housing units or 5,000 residents and 425 housing units per square mile; blocks adjacent or nearby to urban areas may also be classified as urban if additional criteria are met (U.S. Census Bureau, 2024). Blocks that do not meet urban criteria are classified as rural. The USCB's Topologically Integrated Geographic Encoding and Referencing (TIGER) database delineated block boundaries (U.S. Census Bureau, 2020a).

**Table 1. Description of Nested Geographic Divisions.** All units of geography are fully contained within the next largest unit. For example, a block group fully encompasses multiple blocks, several adjacent tracts make up a county, etc. Census geographical unit descriptions reference definitions provided by the U.S. Census Glossary (U.S. Census Bureau, 2025).

Unit of Geography	Data Available	Description
Parcel	Well location (limited)	A unit of land that can be bought and sold; accessed through Regrid data (LOVELAND Technologies, 2025).
Block	Well location	The smallest unit of Census tabulation. Blocks are defined spatially and bounded by features such as streets, rivers, or property lines. They are not determined by population size, and some blocks have a population of zero. The 2020 census included over 8 millions blocks; over 2 million recorded a population of zero, and blocks with a nonzero population had on average 57 people per block.
	Race	
	Population by age	
	Households	
Block Group	Urban/Rural classification	A collection of adjacent blocks that generally contain between 600 and 3,000 people and 240 and 1,200 housing units. This is the finest resolution for which American Community Survey (ACS) sample data is reported. All blocks are fully contained within one block group.
	Educational attainment	
	Median household income	
Tract	Group quarters population	Composed of several block groups and nested within counties. Census tracts generally contain about 4,000 people and 1,600 housing units.
	n/a	
County	Median household income	A geographic subdivision of states that contain several cities and towns. This is the finest level at which well user demographic data is summarized in this study.
State	Median household income (rural areas)	A political entity with its own government that falls under sovereignty of the United States.
	Median household income (urban areas)	Demographic data is summarized by urban/rural classification at the state level.

To characterize educational attainment and income, we used the American Community Survey (ACS) 2018–2022 5-year estimates at the block-group level. Block groups are the finest scale at

which the ACS publishes educational attainment (the highest level of education achieved among the population of individuals 25 years and older) and median household income, in 2022 inflation-adjusted dollars (U.S. Census Bureau, 2022a; U.S. Census Bureau, 2022b). Group quarters population, also available at the block group level (though obtained via the 2020 Decennial Census) represent individuals who do not reside in a typical household (e.g., nursing homes, military barracks, institutional facilities) (U.S. Census Bureau, 2020a).

We supplemented these datasets with Regrid data, which provides parcel-level boundaries and attributes such as land use and function (LOVELAND Technologies, 2025). Coverage and attribute completeness vary by state, so we used Regrid to supplement domestic well classification but not as a foundation for detailed analysis.

## ***2.2 Geospatial Analysis and Summarization***

We conducted spatial data processing in ArcGIS Pro and analytical workflows in Python (JupyterLab). First, we overlaid USGWD well points with TIGER census blocks and Regrid parcels, assigning each well to a block and, when available, to a parcel.

We defined domestic wells as either (a) wells labeled “Domestic” in USGWD or (b) wells with unknown use that fell on parcels whose Land-Based Classification System (LBCS) function was “private household” or “residence or accommodation,” as determined from the Regrid dataset. This increased our sample of domestic wells, particularly in states with many wells with unknown uses. If multiple wells were “stacked” (had the same latitude and longitude, to six decimal places), we assumed that the datasets included duplicate records, which may have arisen during property sales or well reconstruction. Thus, only one well per geographic coordinate pair was retained for analysis.

We assumed that each domestic well serves one household. This provides a conservative estimate of the population reliant on wells, as domestic wells may serve up to 25 individuals with up to 15 connections (CDC, 2024b). According to USCB definitions, the number of occupied

housing units is equivalent to the number of households (U.S. Census Bureau, n.d.). Average household size was computed at the block group level as

$$\textit{Average Household Size} = \frac{\textit{Total Population} - \textit{Group Quarters Population}}{\textit{Number of Occupied Housing Units}}$$

The *Average household size* was used to estimate the total number of individuals using domestic wells. To avoid unrealistic average household size values computed using imperfect census data (e.g., housing units mislabeled as vacant or occupied, incorrectly recorded group quarters populations, etc.), we capped block-group average household size at the 99th percentile within each state to reduce sensitivity to rare denominator mismatches. We additionally applied a hard lower bound of one person per household to avoid unrealistic household sizes. While this added uncertainty and potential unreported data issues may influence the specific counts of well users, there is no evidence that the data is systematically biased towards one side or the other, so errors are likely to counterbalance. Additionally, our research focuses on demographic averages over well user counts, the latter of which would be more impacted by inaccuracies in household count.

We derived block-level racial distributions with the categories White, Black, Alaska Native or American Indian, Asian, Native Hawaiian or Pacific Islander, two or more races, and Other (Table 2). We assumed that the racial distribution of domestic well users in a block matches the distribution of that block's overall population. For each block, we allocated the estimated well-user population across racial categories in proportion to the block's racial composition.

**Table 2. Categories, Universe, and Data Resolution of Analyzed Demographic Features.**

Analysis was originally conducted considering each of specific categories, but findings supported summarization and visualization focused on the binary classification.

Feature Analyzed	Universe	Finest resolution of available data	Binary Classifications (specific categories)
Race	Total Population	Block	<b>White</b> (White)
			<b>Nonwhite</b> (Black, Alaska Native or American Indian, Asian, Native Hawaiian or Pacific Islander, Two or more races, Other)
Educational Attainment	Population above 25 years	Block Group	<b>Non-postsecondary degree</b> (Less than High School, High School Diploma or GED; Some College)
			<b>Postsecondary degree</b> (Associate's Degree; Bachelor's Degree; Masters, Professional, or Doctorate Degree)
Median Household Income	Households	Block Group	N/A

These estimates were aggregated to two spatial partitions. For county-level analysis, we aggregated wells in all blocks within each county. To assess well user differences between areas designated as urban versus rural, we aggregated data across all urban blocks and all rural blocks in each state. Aggregation of wells across all blocks in each county yielded results at finer spatial resolutions relative to previous studies while still providing easily interpretable demographic summaries at the jurisdictional divisions most relevant for domestic well regulations and stewardship support. For each partition, we computed both (a) the estimated racial distribution of individuals using domestic wells and (b) the racial distribution of the non-well using population within the corresponding spatial unit of interest. Here, we identified the public water using population as the total population, minus the identified well using population. Other sources of water, such as springs, have historically supported a marginal (~1%) proportion of households in the United States (U.S. Census, 1990).

We followed a similar procedure for educational attainment at the block group level using ACS data for individuals 25 years and older. We grouped educational attainment into six categories: less than high school diploma, high school diploma or General Educational Development (GED) credentials, some college, associate's degree, bachelor's degree, and graduate degree (master's, professional, or doctoral). Table 2 shows how these categories were grouped into a binary classification. For each block group we assumed that the educational distribution of the population similarly reflected that of its well users, allocated the estimated well-user population across categories, and aggregated the results by county and urban/rural classification.

For income, we used ACS block-group median household income as a proxy for the income of well-reliant households. Within each county and each urban/rural stratum, we compared the estimated median income of well-using households to the published median household income for the total population. Due to data availability, household incomes were compared to the published median incomes of the total population, not only the public water-using population.

### ***2.3 Power and Statistical Analysis***

We evaluated whether each geographic unit had enough wells to support generalized conclusions by conducting a power analysis for each county and for each state-level urban and rural stratum. We prespecified a minimum effect size of 5 percentage points (pp) at 80% power, and used a conservative design effect factor of 2.0 to account for intra-cluster correlation. This analysis identified regions that were withheld from further analysis of race and educational attainment distributions due to their small sample size.

We then ran two-proportion z-tests for the full set of race and educational categories. Results identified which counties saw a significant difference in race or educational patterns of well users as compared to public water users, and to what extent. For visualization and interpretation, we then constructed binary variables: White versus non-White for race, and postsecondary degree versus no postsecondary degree for education (Table 2).

The available data on median household income did not support formal power calculations or parametric hypothesis testing. Instead, we summarized economic differences by calculating percent differences in median household income between well users and the total population.

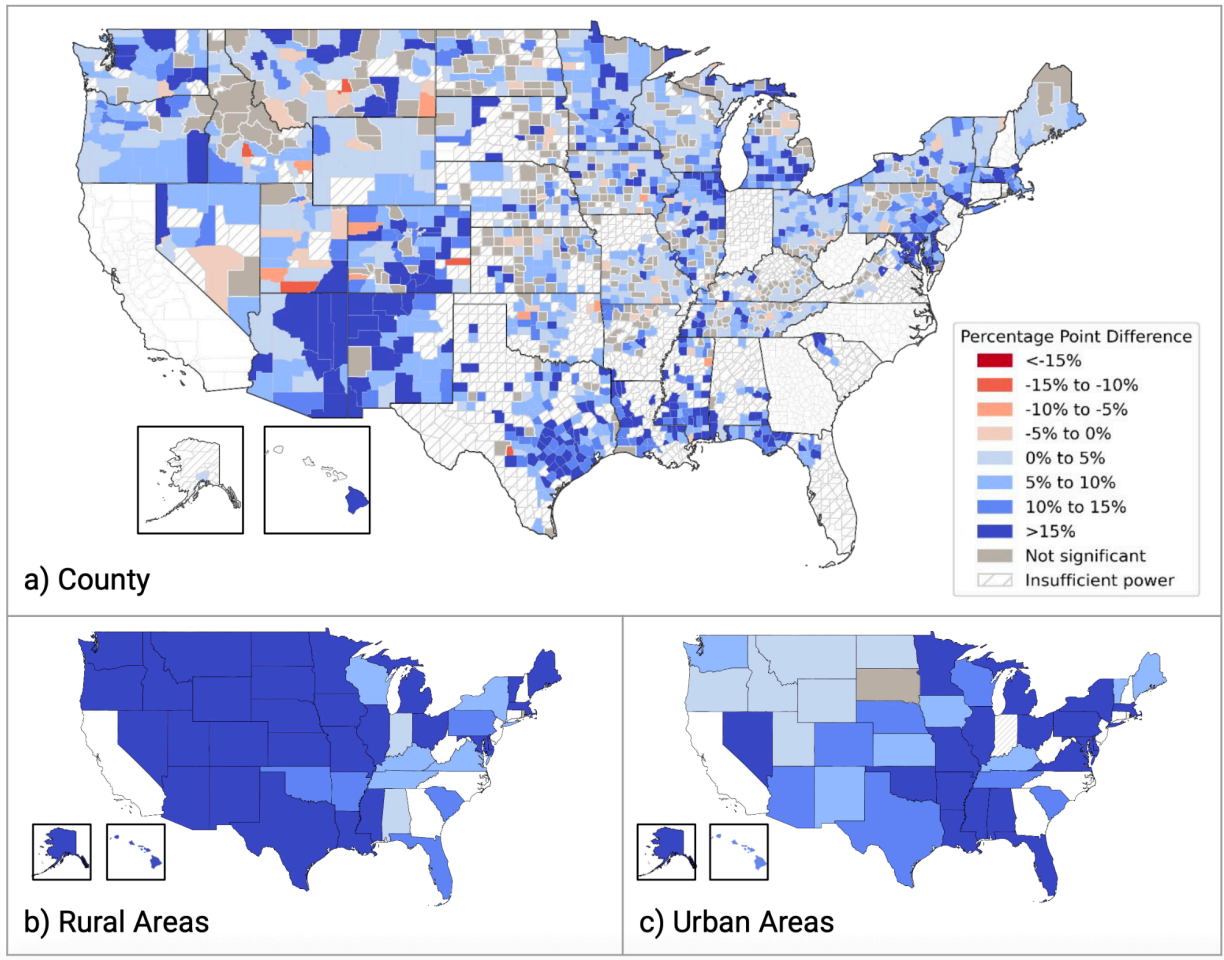
### **3. Results**

We analyzed patterns in all states and counties with a sufficient number of identified domestic wells. Six states (Connecticut, Georgia, New Hampshire, New Jersey, North Carolina, and West Virginia) were excluded because they had very few (less than 10) or no recorded domestic or unknown use wells, and California was excluded as it shares aggregated well locations at a coarse grid scale (Reade-Malagueño et al., 2025). Several counties within analyzed states were also excluded due to insufficient statistical power.

Overall, we identified over 4.4 million unique domestic wells. Of these, 83.1% ( $n = 3,682,831$ ) are located in rural census blocks and 16.9% ( $n = 749,851$ ) in urban blocks. Most (93.1%,  $n = 4,125,018$ ) wells were labeled as domestic in USGWD; an additional 307,664 wells were reclassified as domestic using Regrid parcel land-use information. This represents 24.1% of all wells classified with an “unknown” use category. Unless otherwise noted, all differences reported below describe how the demographic characteristics of domestic well users deviate from those of the non-well using population in the same county or state-level urban/rural stratum.

#### ***3.1 Race***

Domestic well users are more likely to be white than the surrounding population in most counties. Among counties with sufficient power, 89.4% ( $n = 1,554$ ) show a higher share of white well users when compared to public water users; in 47.6% ( $n = 827$ ) of counties this increase exceeds 5 percentage points (Fig. 1a). When investigating other races independently, the vast majority of counties see either lower rates of minority groups among well users, or no significant differences due to their smaller representation across the overall population.



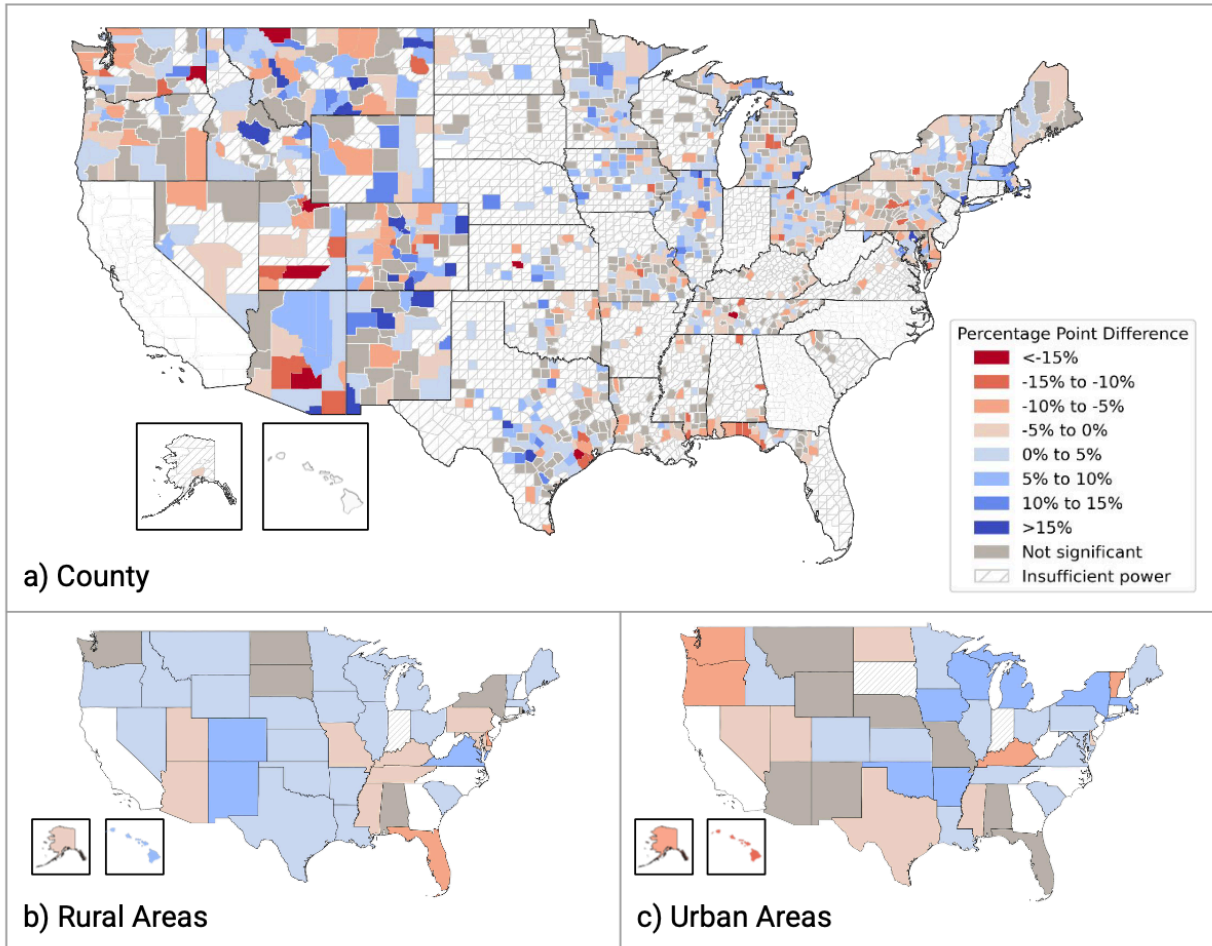
**Figure 1. Comparing the percent of white-identifying domestic well users to the percent of white-identifying individuals of the geographically corresponding population on public supplied water.** *The percent difference is aggregated a) by county, b) among all rural blocks within a state, and c) among all urban blocks within a state. A darker blue indicates higher proportion of white-identifying individuals among well users, while a darker red indicates a lower proportion of white-identifying individuals among well users. States and counties on the maps that are white contain no recorded domestic wells at the requisite level of detail; those with a hatched fill have insufficient wells to support a formal analysis, and those that are grey contain sufficient wells for analysis, but saw no significant difference in racial distribution of white and nonwhite population between well users and public supplied water users.*

At the state level, the overrepresentation of white residents among well users is prevalent across all states, but is even stronger in rural areas than urban areas. On average, the share of white individuals among rural well users is 22.6 percentage points higher than the rural population

supplied by public water (Fig. 1b). In urban areas, this difference averages 13.4 percentage points (Fig. 1c).

### ***3.2 Education***

Patterns in educational attainment vary greatly across counties (Fig. 2a). Using a binary measure of postsecondary attainment (associate's degree or higher), 45.4% (n = 550) of counties show lower educational attainment among well users, whereas 53.2% (n = 645) show higher attainment. Differences are generally modest: in 81.8% (n = 991) of counties, postsecondary attainment among well users falls within  $\pm 5$  percentage points of the county-wide rate.



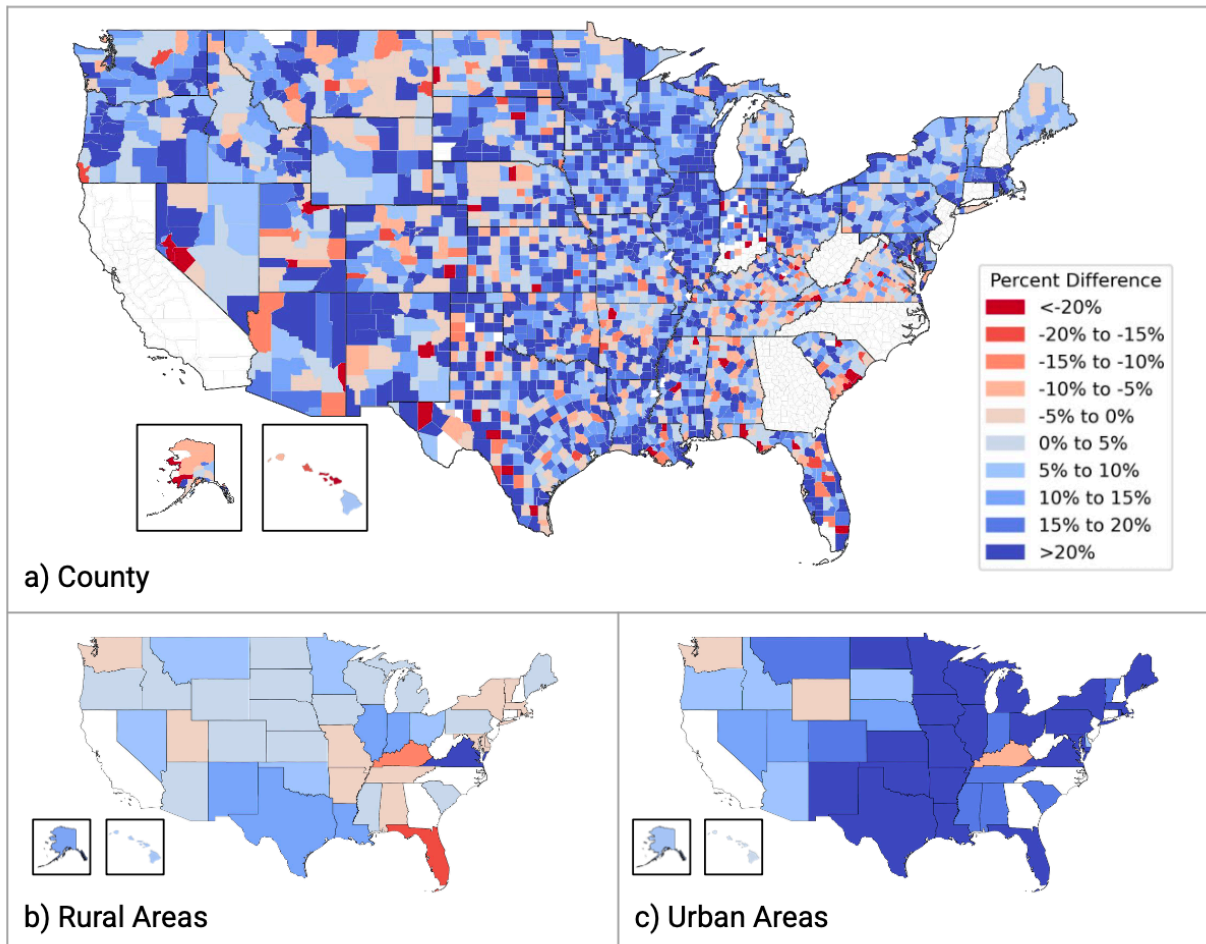
**Figure 2. Comparing post-secondary degree attainment of domestic well users to post-secondary degree attainment of the geographically corresponding population on public supplied water.** *The percent difference is aggregated a) by county, b) among all rural blocks within a state, and c) among all urban blocks within a state. A darker blue indicates higher levels of post-secondary degree attainment among well users, while a darker red indicates lower levels of post-secondary degree among well users. States and counties that are white contain no recorded domestic wells at the requisite level of detail; those with a hatched fill have insufficient wells to support a formal analysis, and those that are grey contain sufficient wells for analysis, but saw no significant difference in educational attainment between well users and public supplied water users.*

When aggregated to the state level, educational patterns are slightly different from those observed at the county level. When looking exclusively at rural areas, lower rates of postsecondary degree attainment are observed in 25 states, and higher rates are observed in 17 states (Fig. 2b). Similarly, in urban areas, lower rates of postsecondary degree attainment are

observed in 24 states, and higher rates are observed in 15 states (Fig. 2c); the difference in total state analyzes between rural and urban regions is due to fewer states having sufficient wells in urban areas to support formal analysis. However, similar patterns were observed at county level divisions, as differences in education between well users and public water users remained within  $\pm 5$  percentage points in rural areas of 29 states, and urban areas of 25 states.

### ***3.3 Income***

Domestic well users generally have higher household incomes than the populations in which they reside (Fig. 3a). Across all analyzed counties, median household income among well-using households is, on average, 13.9% higher than the county median. In 78.1% (n = 2,083) of counties, incomes of well users exceed the median, and in 37.8% (n = 1,009) of counties, well users' median incomes are more than 15% higher. Conversely, 77 counties across 26 states display the opposite pattern, with median incomes among well users at least 15% lower than the county median.



**Figure 3. Comparing the median household income of households that use domestic well water to the median household income of the geographically corresponding total population.** *The percent difference is aggregated a) by county, b) among all rural blocks within a state, and c) among all urban blocks within a state. A darker blue indicates higher household incomes among well users, while a darker red indicates lower household incomes among well users. States and counties that are white contain no recorded domestic wells with the level of detail required for this study.*

Income differences are more pronounced in urban areas (Fig. 3b–c). In 40 states (93% of analyzed states), incomes are higher among well users in urban areas than the overall urban population. In 22 states, the median household income of urban well users exceeds the state-level urban median by more than 20%. In rural areas, 67% (n = 29) of states indicated higher incomes among well users, and only one state (Virginia) suggests a >20% income advantage for rural well users relative to the rural population.

### ***3.4 Combined Statistics***

Race, educational attainment, and household income are interrelated, so we interpret these associations as descriptive patterns rather than independent effects.

As expected, higher educational attainment among well users is associated with larger income advantages. In counties where postsecondary attainment among well users exceeds the county rate by more than 5 percentage points, median household income among well users is 21.9% higher than the county median. Where postsecondary attainment among well users is similar to the county rate (within  $\pm 5$  percentage points), median income among well users remains 11.7% higher. Even in counties where well users have notably lower postsecondary attainment ( $\geq 5$  percentage points lower than the county rate), median incomes among well users are still 4.8% higher than the county median. Thus, while higher education corresponds to larger income advantages, lower education among well users does not correspond to lower incomes relative to the surrounding population. It is difficult to isolate interactions between education and income, as we see higher incomes among populations with higher degrees, but also a greater likelihood of continued education among wealthier populations (Card, 1999). The high incomes in areas of lower educational attainment may also be attributed to the rising popularity of some trade jobs, which are more common in rural areas and are seeing wage increases with a growing demand (Greenberg et al., 2024; Young, 2013).

A similar pattern emerges for race and income. In counties where well users are less likely to be white than the population on public water supply, median household incomes among well users are 2.8% higher than the county median. Where racial composition is similar between well users and the total population, income differences average 7.9% higher than county medians. In counties where the share of white well users exceeds the county share of white residents by more than 5 percentage points, median household incomes among well users are 16.2% higher than the county median. This observation is consistent with previous findings that illustrate significant income disparities and advanced job opportunities between races, even when controlled for education (Carnevale et al., 2019).

### 3.5 Counties Excluded by Power Analysis

Of the 2,666 counties with at least one identified well, 917 counties did not meet the minimum well threshold for the race analysis and were excluded from testing. Overall, counties below the power threshold exhibited descriptive patterns similar to those included in the significance testing: the estimated share of white well users exceeded that of public water users by 8.4 percentage points in unpowered counties and 7.2 percentage points in powered counties (Table 3). However, these counties below the power threshold as a whole are more demographically diverse overall. Only 5.0% of powered counties had public- or private- water using population estimates with a nonwhite population greater than 50%; this value more than triples to 16% among the excluded counties. This pattern is consistent with the possibility that areas with larger minority populations may be underrepresented in well records as collected for the USGWD.

**Table 3. Comparison of racial distribution patterns in counties above and below the power threshold.** Percentages reflect county-level statistics and are not weighted by county population or number of wells.

Power level	Counties (n)	Avg. % White (public supply)	Avg. % White (well users)	Avg. % White difference (pp)	Counties with > 50% non-White (public supply or well users)
Above threshold	1749	80.7%	88.0%	7.2 pp	5.0%
Below threshold	917	70.6%	79.1%	8.4 pp	16.1%

In analyzing educational attainment patterns, 1,455 counties did not meet the minimum well threshold and were excluded. As with race, the difference in educational attainment between well users and public water users was small in both the powered and unpowered counties (0.6 percentage points; Table 4). Unpowered counties, however, tended to have lower educational attainment overall. In 32.7% of unpowered counties, the share of adults with a post-secondary degree was below 25% in either public supply or private well populations, compared with only 20.1% of powered counties. This suggests that on average, counties excluded for limited well counts also tend to be counties with lower educational attainment, on average.

**Table 4. Comparison of educational attainment patterns in counties above and below the power threshold.** Percentages reflect county-level statistics and are not weighed by county population or number of wells.

Power level	Counties (n)	Avg. % with post-secondary degree (public supply)	Avg. % with post-secondary degree (well users)	Avg. % post-secondary degree difference (pp)	Counties with <25% postsecondary attainment (public supply or well users)
Above threshold	1211	35.0%	35.1%	0.6 pp	20.1%
Below threshold	1455	31.2%	31.8%	0.6 pp	32.7%

## 4. Discussion

### *4.1 Comparisons to Previous Work*

Our findings broadly align with prior research on domestic well users. Hernandez and Pierce (2023) concluded that households reliant on private wells are more likely to be non-Hispanic white, live in nonmetropolitan areas, and have higher incomes than households served by public water systems. These patterns mirror our results: well users are disproportionately white and higher income relative to the surrounding population.

However, while Hernandez and Pierce argue that the ratio of domestic well users to public water users is higher in nonmetropolitan areas (i.e., residents in nonmetropolitan areas are more likely to use well water than residents in metropolitan areas), a greater number of all households on well water are located in metropolitan regions. In contrast, more than 80% of wells in our dataset are located in rural census blocks. This difference likely reflects underlying data sources.

Hernandez and Pierce rely on the American Housing Survey, which, while aiming to represent the United States, oversamples metropolitan areas. The USGWD compiles state and local records without explicit urban oversampling. In addition, our rural–urban designation is based on housing and population density by census block, while metropolitan status is defined at the county level and captures economic and commuting patterns. Stratifying well user locations by metropolitan and nonmetropolitan misleadingly classifies many wells in rural areas as metropolitan, if they fall in a county that includes a large city or other urban areas. Our study improved upon this method by using block level classifications that more accurately depict a high-resolution population density of areas containing domestic wells. Table 5 identifies key methodological differences between this study and the research done by Hernandez and Pierce, and highlights how data availability and resolution contribute to the novelty of this study.

**Table 5. Key differences between Hernandez and Pierce (2023) and this study.** This research builds off of previous findings by addressing similar research questions with different datasets at a finer spatial resolution.

Feature	Hernandez and Pierce, 2023	This Study
Data Used	American Housing Survey (AHS); includes 50,000 households, with and without wells	Over 4.4 million households with wells from USGWD; over 100 million households total across 43 states
Area Classification	Metropolitan vs. Nonmetropolitan (county resolution)	Urban vs. Rural (block resolution)
Area Representation	AHS oversamples large metropolitan areas	Census data is exact counts; ACS estimates are spatially representative; USGWD provides all available well counts
Data Availability Resolution	Census Divisions (9 total)	Census block and block group (millions)
Summary Spatial Resolution	Region (West, Midwest, South, Northeast)	County

A state-wide health study conducted in Wisconsin from 2008-2013 also found that domestic well users were more likely to be white and of higher income than the general population, but with slightly lower levels of formal education (Niето et al., 2010; Malecki et al., 2017). Later surveys regarding well stewardship practices, however, showed that respondents had higher education than nonrespondents, highlighting a response bias: more educated and higher-income well owners were more likely to participate in surveys or proactively engage with testing programs (Malecki et al., 2017). Recent work from North Carolina further emphasizes disparities in well-testing records, finding that minority race and low-income well-using households are less likely to appear in testing datasets despite experiencing higher rates of contamination (Hayes et al., 2025). Thus, it is possible that individuals of certain demographic profiles who are less likely to appear in administrative or survey records may be underrepresented in both our dataset and others.

## ***4.2 Implications for Policy and Practice***

Our results have several implications for domestic well governance, especially for local health departments that often operate at the county level. Minority racial and ethnic groups have faced historical marginalization across several environmental health challenges, including unsafe drinking water, which has led to decreased trust in government protections and water quality (Pierce & González, 2017; Wilson et al., 2023; Nigra, 2020). In some areas, the use of private drinking supplies might be preferred due to a distrust in public water systems. Government organizations aimed at improving domestic water quality and testing practices in minority communities must acknowledge this added layer of trust when communicating with well owners.

Educational attainment, which is found to vary considerably across counties and between urban and rural areas, suggests that a “one-size-fits-all” outreach strategy is unlikely to be effective. Instead, health departments and extension programs may need different messaging and delivery modes across counties for urban and rural well users, even within the same state. Different levels of educational attainment may also be linked to careers with different demands and schedules. Knowledge of these patterns might guide outreach and testing programs; for example, adding weekend or evening hours to testing programs to accommodate careers that have less flexible hours.

Furthermore, we find that well users generally have higher median household incomes than their neighbors, particularly in urban areas. These patterns suggest that cost alone is unlikely to be the dominant barrier to well testing or maintenance for many well users. Prior studies similarly report that although low income is associated with lower stewardship in some contexts, knowledge, risk perception, and convenience often play stronger roles in whether households test or treat their wells (Flanagan et al. 2020; Kreutzwiser et al, 2011; Malecki et al., 2017). Thus, local health departments might prioritize addressing non-financial barriers (e.g., improving risk communication, simplifying testing logistics) while reserving targeted financial assistance for well users of lower income or who face high contamination risk.

Further research may link the demographic patterns we identify not only to well reliance, but also to stewardship practices (e.g., frequency of testing, type of treatment installed) and measured groundwater quality. Across the United States, minority communities are more likely

to face significant water quality and availability challenges in publicly supplied water (Nigra, 2020). Studies across smaller geographic regions also suggest that populations of color experience worse domestic well water quality (Pace, 2022). Coupling our demographic maps with state testing databases, such as those in North Carolina, could reveal where interventions are most needed and who current programs fail to reach (Eaves et al., 2022; Hayes et al., 2025). Our findings set the stage for researchers to further examine patterns of water quality and environmental justice across multiple demographic and socioeconomic characteristics.

### ***4.3 Limitations***

This study is constrained primarily by the availability and completeness of well location data. States vary widely in how they regulate, collect, and publish information about private wells; responsibilities often fall to local or county health departments with limited capacity.

While some states have relatively strong records of well locations and their use, others have more incomplete data. Several states, such as West Virginia and North Carolina, are known to have substantial domestic well-reliant, yet did not provide well locations to be included in our analysis. California released well locations at a coarse resolution (available at the centroids of square mile section), which was incompatible with our analysis at the census block and block group resolutions (Reade-Malagueño et al., 2025). According to the model by Murray et al., the seven states that were not analyzed due to missing data represent over 8 million well users, or 17.6% of the 45.8 million estimated well users. As a result, our analysis of over 4.4 million wells, representing nearly 11.8 million well users, covers only a subset of the well using population if 45.8 million people relied on private wells and each well served one household (Murray et al., 2025). The demographic patterns among users of unrecorded wells may differ systematically from those we observe, particularly if wells in more remote, lower-income, or minority communities are less likely to appear in administrative datasets. Furthermore, these unidentified well users are grouped into the public water using populations with which we use for comparisons. While this limits the interpretation of our results, it was nonetheless seen as preferred to the alternative of comparing well user demographics to demographic trends of the total population, since the proportion of well users to non-well users varies greatly across

counties (with some counties reporting little to no well users, and others reporting 100% domestic well use among residents).

Our analysis also excludes wells located on census blocks that report zero residents, as well as wells with identical coordinates. The former likely include wells situated on parcels separate from the homes they serve, wells in vacation or seasonal communities with few permanent residents, or misaligned locations resulting from geocoding or record errors. The latter may be the result of unidentified decommissioned wells or duplicate records due to property transfers; however, this may unintentionally exclude situations where multiple wells at a single property serve distinct households.

Finally, the demographic estimates themselves rely on census block and block-group summaries and on standard methods for protecting privacy, such as data swapping, which introduce noise at the smallest spatial scales. These processes preserve distributions at county or state scales but can shift demographic counts for individual blocks. As a result, our fine resolution estimates of well-user demographics should be interpreted as approximations that are most reliable when aggregated (e.g., by county or by urban/rural category) rather than as precise counts for any single block or block group.

## 5. Conclusion

This study provides a national, high-resolution portrait of the demographic characteristics of domestic well users in the United States by linking millions of wells to U.S. Census and ACS data at the finest scale available. Domestic well users are disproportionately white when compared to non-well users in the same geographic region, and households with wells generally have incomes higher than the median household income of the corresponding state or county. Educational attainment among well users is more mixed, but is often similar to what is seen among non-well users. Joint examination of race, education, and income shows that counties where well users are more likely to be white and hold postsecondary degrees also tend to exhibit the largest income advantages. As water quality is often worse among minority populations and in socioeconomically disadvantaged areas, county-level findings may inform further research into domestic well water contamination and vulnerability.

At the same time, substantial gaps in well records, the exclusion of some well types, and small-area census uncertainty mean our analysis likely underrepresents wells in more remote, lower-income, or minority communities. As such, the patterns we document should be interpreted as a partial but important view of the domestic well-using population. By moving beyond national survey averages to county-level and urban–rural comparisons, this work fills a key gap in the literature and offers a geospatial foundation for more targeted well stewardship, testing, and protection policies.

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