DOI:
10.1080/24694452.2018.1530587

Plumbing poverty: mapping hot spots of racial and geographic inequality in U.S. household water insecurity

Shiloh Deitz*
Katie Meehan*, +

* Department of Geography, King's College London
+ Department of Geography, University of Oregon

Author's Accepted Manuscript

To be published by:
Annals of the American Association of Geographers

Date of Acceptance: 22 August 2018

Abstract
Household water insecurity is a global threat to human health and development, yet existing metrics lack a systematic consideration of geographic inequality and spatial variation. In this paper, we introduce the notion of plumbing poverty as a conceptual and methodological heuristic to examine the intersectional nature of infrastructure, space, and social inequality. Plumbing poverty is understood in a dual sense: first, as a material and infrastructural condition produced by social relations that fundamentally vary through space, and second, as a methodology that operationalizes the spatial exploration of social inequality. Drawing on millions of census records, we strip household water security down to a single vital measure—the presence of complete household plumbing—to assess its spatial and sociodemographic trends. We identify distinct hot spots (geographic clusters of higher-than-average values) of plumbing poverty, track its social and spatial variance, and expose its fundamentally racialized nature. Our study finds that plumbing poverty is neither spatially nor socially random in the United States. Rather, plumbing incompleteness is spatially clustered in certain regions of the country and is clearly racialized: living in an American Indian or Alaskan Native, black, or Hispanic household increases the odds of being plumbing poor, and these predictors warp and woof through space. In considering who experiences the slow violence of infrastructural dysfunction, a geography that is simultaneously ignored and unevenly expressed in America, we argue that analyses of space and social difference are central to understanding household water insecurity and must be prioritized in the development of cross-comparable metrics and global measurement tools.

Key Words
Census microdata; hot spot analysis; infrastructural geographies; IPUMS

Introduction

In the high desert landscape of rocks and rivers, near the Arizona-Utah border, Verna Yazzie travels eighteen miles by car to fetch water in plastic tubs. "We've never had running water for as long as I remember," Yazzie recalls, "I usually haul water about three times a week for ourselves, for our livestock and for our planting."[1] Spread across parts of Arizona, Utah, and New Mexico, the Navajo Nation—Yazzie's home—is the largest American Indian reservation in the United States. Safe, potable, piped water is a perennial problem. Approximately 40 percent of families on the Navajo Nation lack running water in their homes. In just one neighborhood in Coconino County (northeast Arizona), a jurisdiction that includes five Native reservations, nearly 73 percent of households lack a plumbed connection.[2] George McGraw, a founder of the Navajo Water Project, describes this situation as unacceptable. "In one word, I'd say abysmal," McGraw says, "It's humiliating that it's this difficult to give people in this country access to what's an essential human right."[3]

Household water insecurity—the plight of people like Verna Yazzie in one of the world's wealthiest countries—is a global threat to human health and development. In the United States, a recorded 463,649 occupied households (an estimated 1,455,857 people[4]) lack a plumbed connection to potable water or sewerage (U.S. Census Bureau 2016). While this figure is small relative to the national population (0.39 percent) and scattered across the country, the aggregate number of the plumbing poor would be equivalent to the nation's *fifth largest city*—a population size just above Phoenix, Arizona.

Equally alarming is the lack of knowledge about who and where are the plumbing poor, a plight that helps keep the problem invisible in the United States. In recent years, the scholarly community—with notable contributions by geographers—has made huge strides in identifying the multiple dimensions of household water insecurity, including its drivers and effects (Wutich and Ragsdale 2008; Wutich 2009; Balazs and Ray 2014; Jepson 2014; Jepson and Vandewalle 2016; Jepson et al. 2017b; Wutich et al. 2017). Household water security is defined as the safe and reliable access to sufficient quantity and quality of water for household consumption, production, and cleanliness, a definition that puts social relations at the heart of how water provision is spatially produced and socially organized (Jepson et al. 2017a). Insecurity, then, is the *lack* of household water security—a state of being that is produced by social relations and uneven through space. The lack of secure household water is a major barrier to human health and development (Jepson et al. 2017a, 2017b; see also Bakker 2012). Previous studies have begun to identify sociodemographic factors that characterize household water insecurity: such as race, citizenship, poverty levels, and housing type (Wescoat, Headington and Theobald 2008; Wutich and Ragsdale 2008; Wutich 2009; Jepson 2014; Pierce and Jimenez 2015; Jepson and Vandewalle 2016; Eichelberger 2017). Still, few tools exist to *comprehensively* measure, elicit, and compare the sociodemographic landscape of household water insecurity at broader scales—a knowledge gap that limits international comparability and potentially contributes to institutional oversight of the problem (Jepson 2014; Jepson et al. 2017b). "Without robust, analytical tools," caution Wendy Jepson et al. (2017b, 2), "our knowledge of household water insecurity will remain anecdotal, precluding a comparative approach that will allow researchers to develop and validate generalizable models or causes of household water insecurity." Despite methodological advances and anecdotal evidence, the *geographic* nature of plumbing poverty remains poorly understood. Who and where are the plumbing poor in America?

This paper seeks to help close that knowledge gap. Our study makes two significant contributions. We introduce the notion of *plumbing poverty* as a heuristic to examine the intersectional nature of infrastructure, space, and social inequality. Plumbing poverty is understood in a dual sense: first, as a material and infrastructural condition produced by social relations that fundamentally vary through space, and second, as a methodology that operationalizes the spatial exploration of social inequality. In developing this heuristic, we draw inspiration from recent scholarship in geography on relational poverty and structural violence (Sharam and Hulse 2014; Elwood, Lawson, and Sheppard 2017; Laurie and Shaw 2018), critical approaches to urban infrastructure that transcend the 'North-South divide' (McFarlane 2010; Meehan 2012, 2014; Furlong 2014; Ranganathan and Balazs 2015; Furlong and Kooy 2017), and the exposition of racial-capitalist logics at work in perpetuating water marginalization and insecurity, particularly in the United States (Balazs and Ray 2014; Ranganathan 2016; Pulido 2016a, 2016b; Pulido, Kohl, and Cotton 2016). In considering *who* experiences the slow violence of infrastructural dysfunction, a geography that is simultaneously ignored and unevenly expressed in America, this paper injects important empirical insights about space and social difference into the heart of household water security.

Second, we advance a methodology to plumb poverty using 'small' units of analysis—the household—in the context of 'big' census data at the national scale. Our study is the first to systematically assess plumbing poverty across the entire United States. Previous research has identified key variables that explain a lack of complete household plumbing in select U.S. regions or housing types (Wescoat, Headington, and Theobold 2008; Jepson 2014; Vandewalle and Jepson 2015; Pierce and Jimenez 2015), but we advance a comprehensive and systematic approach. Drawing on millions of census records (IPUMS microdata), we strip household water security down to a single vital measure—the presence of complete household plumbing. We then couple innovations in spatial statistics and clustering methods to identify distinct hot spots and cold spots (geographic clusters of higher- or lower-than-average values, respectively) of plumbing poverty, track its social and spatial variance, and expose its fundamentally racialized nature. Without an explicitly spatial approach, plumbing poverty disappears as a racialized and spatially variegated problem, hidden by conventional choices in scale, scope, and data type. In helping to craft a methodological platform to support in-depth and comparative analysis (Jepson et al. 2017b), we argue that explicit considerations of space and geographic inequality must be prioritized in the development of cross-comparable metrics and global measurement tools.

There are some limitations to our analysis. For instance, we sacrifice breadth for depth. We examine just one aspect of household water security: plumbing completeness, defined by the U.S. Census Bureau as the presence of hot and cold running water, a flush toilet, and an indoor bathtub or shower. If a household lacks one or more of these infrastructural elements, the household is plumbing incomplete. Completeness of plumbing is only one element of household water security. Measuring other key ingredients—trust, quality, affordability, or reliability, for example—is important but beyond the scope of this paper. Nevertheless, we maintain that a plumbed connection to public water and sewerage is a central plank in human health and development. By narrowing analytical focus to a single variable, our approach elicits important methodological and empirical insights about the uneven geography of plumbing poverty.

The paper is organized as follows. In the next section, we identify key methodological gaps in the literature about household water insecurity and draw on geographic research to develop methodological principles for systematic analysis. Following a detailed description of our data and methods, we present results of the analysis, which reveals distinct hot spots of plumbing poverty, its sociodemographic and spatial variability, and its starkly racialized nature. In the penultimate section, we discuss who (and where) bears the brunt of plumbing poverty in

America, and what our insights imply for geographic methodology in a future of big data and entrenched social inequality. In tandem with Jepson et al. (2017a, 2017b), Wutich et al. (2017) and many others, this paper seeks to advance knowledge about household water insecurity to catalyze action toward more just and sustainable futures. But to achieve that goal, we argue, requires more robust methodological considerations of space in ways that also critically interrogate inequality. We must plumb poverty.

Measuring plumbing poverty

The United Nations recognizes safe, affordable, and reliable water supply and sanitation as essential to human life, health, and development. In the past decade, governments and global development agencies have enshrined the human right to water in constitutional law and policy, a product of struggles to recognize and mitigate persistent conditions of water poverty and insecurity in communities around the world (Sultana and Loftus 2015). In general, water security has no single definition (Cook and Bakker 2012), but within the domain of human development, household water insecurity is broadly understood as the insufficient supply of water to achieve a healthy and productive life (Jepson et al. 2017a, 2017b; see also Bakker 2012). Scholars argue that household water insecurity is not simply a technical problem of supply and engineering; rather, insecurity is *produced* by social relations and institutionalized in practice, therefore linking it to broader political, economic, and cultural systems of social inequality, marginalization, and exclusion (Wutich and Ragsdale 2008; Loftus 2015; Romero-Lankao and Gnatz 2016; Jepson et al. 2017a, 2017b).

Scholars recognize an urgent need to establish robust and comprehensive metrics to assess household water insecurity (Hadley and Wutich 2009; Jepson 2014; Jepson et al. 2017a; Wutich et al. 2017; see also Lankford et al. 2013; Garfin et al. 2016; Lemos et al. 2016). In one example, Wutich and Ragsdale (2008) identify at least three measurable aspects of household water insecurity: (1) a lack of adequate water quantity, defined by international health standards as 50 L per capita per day; (2) insufficient access to water distribution systems, such as piped water infrastructure; and (3) temporal and seasonal variability in water availability. As the first study to examine intra-community patterns of water insecurity, Wutich and Ragsdale (2008) use a mixed-methods approach—coupling household surveys (including closed and open-ended questions) with regression analysis—to explore the degree to which water-related emotional distress is associated with gender, seasonal variability, and socioeconomic assets and entitlements. They find that the sheer quantity of water did not cause stress, but that negotiating access through the market and reciprocal systems (which lack clear rules and predictability) is significantly associated with emotional distress, particularly for women. This work represents an important first step toward a systematic, comprehensive, and cross-cultural assessment of household water insecurity.

Wendy Jepson's (2014) research is a pioneering example of advancing both metrics and empirical knowledge. In a study of two low-income Texas neighborhoods near the U.S.-Mexico border, Jepson and Vandewalle (2016) find that immigration status of household members is the strongest predictor of water insecurity. They couple an experiential scalogram technique, tested in an earlier phase (Jepson 2014), with regression analysis of potential explanatory variables such as household size, income, and housing type. In the Texas borderlands, households with mixed immigration status were 4.2 times more likely to be water insecure than households with all citizen members (Jepson and Vandewalle 2016, 76). Other potential predictors—such as poverty, geographic isolation, or housing type (e.g. mobile homes)—increased the likelihood of household water insecurity, but not in a statistically significant way (Jepson and Vandewalle 2016). The authors note their surprise; indeed, they "would have expected relative poverty to increase the likelihood of water insecurity, but our results indicate that the degree to which a household lives in poverty might not strongly influence water insecurity among this population" (Jepson and Vandewalle 2016, 78). Their findings suggest that household water insecurity is not a straight reflection of class and poverty levels across space; rather, insecurity intersects with broader cultural-economic dynamics and institutionalized systems of exclusion that are locally particular.

Jepson's work confirms trends in other research in North America that establishes correlations between water insecurity and factors such as race, ethnicity, and housing type (Mascarenhas 2007; Patrick 2011; McDonald and Grineski 2012; Balazs and Ray 2014; Pulido 2016b; Eichelberger 2017). In California's San Joaquin Valley, for example, rural communities that are predominantly poor and Latino depend on arsenic-contaminated groundwater sources for drinking water, a product of historic marginalization underpinned by state and county regulatory failures (Balazas and Ray 2014, 604). This 'place-based' or case study approach is an in-depth way to measure insecurity; another approach is more extensive analysis of a particular feature, such as housing type. For example, across the United States, living in a mobile home unit (and especially in a mobile home park) is significantly and negatively correlated with water service reliability (Pierce and Jimenez 2015). In other words, trailer parks are more likely to be plumbing poor.

But does low income uniformly predict plumbing poverty across space? With a similar focus on the United States, Wescoat, Headington, and Theobold (2008) draw attention to the role of race, ethnicity, and class in household water provision. Over the 20th century, declining U.S. investment in water development programs has resulted in severe plumbing deficiencies and a lack of domestic awareness about low-income water issues. Focusing on Colorado, the authors use census data to map the spatial manifestation of incomplete plumbing rates, aggregated at the census tract level. Their analysis, which culminates in a series of adjacent, stand-alone maps, reports that incomplete plumbing and poverty are (in their words) "correlated" in tracts that have a majority of Native American residents. "The correlation between rural poverty and inadequate plumbing is strongest on economically distressed Indian reservations," they write (2008: 808), citing the Navajo Nation and the Four Corners region as specific examples.[5]

In reviewing these studies, we raise three methodological concerns. First, the analytical approach utilized by scholars, particularly at broader spatial extents, remain wedded to the census tract—a convenient and conventional spatial unit that raises serious problems for metric development and analysis at the *household* level. A well-known issue in geography is the problem of ecological fallacy: a source of statistical bias that occurs when inferences about one unit of analysis (such as households) are aggregated into 'bigger' spatial units (such as census blocks, tracts, MSAs, or regions), or vice versa. In a landmark paper, W.S. Robinson (1950) illustrates how factors that explain race and literacy vary significantly across the United States, leading him to caution against uniformly attributing causal factors across a continuous space. "The relation between ecological and individual correlations which is discussed in this paper provides a definite answer as to whether ecological correlations can validly be used as substitutes for individual correlations," he argues (1950: 357), "They cannot."

In other words, findings that are valid or true at one level of data aggregation may not hold true at a higher or lower level of aggregation. Studies have shown that by altering the unit of aggregation, or even modifying the boundaries of units, the prominence of influential variables and results can differ sharply (Openshaw 1984; Cutter, Mitchell, and Scott 2000; Maantay and McLafferty 2011). While studies such as Wescoat et al. (2008) reveal important broad-stroke dynamics, they cannot infer trends about *household* water insecurity based on aggregated *census tract* data.

Second, the studies collectively neglect a fundamental axiom of geography: social phenomena in fact *vary* through space and are more related in close proximity (Tobler 1970). For example, in a study of toxic air pollutants and human health, Gilbert and Chakraborty (2011) find that while race and ethnicity are significantly related to cancer risks in Florida, the significance of statistical associations vary across the state and are clustered in particular areas. New and emerging techniques, such as geographically weighted regression (GWR) or clustering techniques, offer fresh insights (Fotheringham, Brundson, and Charlton 2002). Gilbert and Chakraborty (2011) borrow "one of the more recent and fascinating developments in spatial statistics [GWR], the ability to explore how regression parameters and model performance vary across a study area, to demonstrate why statistical analysis of environmental justice should be more sensitive to local processes and effects." GWR has allowed for greater understanding of spatial heterogeneity in patterns of social inequality by environmental justice and health geographers, but this technique requires unique geographic identifiers so typically relies on aggregate data (Fotheringham, Brundson, and Charlton 2002). A more powerful mode of explanation for household water insecurity, in contrast, would utilize data sets (such as census microdata) that retain a spatial unit (such as the PUMA, or Public Use Microdata Area) but are collected at the *household* level. Such datasets allow for robust geographic comparison of the results of household level analyses—providing the opportunity to overcome the issue of ecological inference without sacrificing spatial analysis.

Third, the work on household insecurity in the United States is limited in its comparability and applicability. Studies that explore insecurity at the national level have often focused on only one correlation—mobile homes, for example (e.g., Pierce and Jimenez 2015). Other more thorough or intensive analyses have focused on a single geographic area, such as the Texas-Mexico border region (e.g., Jepson and Vandewalle 2016). Such scholarship has provided important insights, but provides just one cut of the problem and its socio-spatial characteristics. Recognizing these gaps, in this paper we develop a methodology that does not make inferences about households based on spatially aggregated data, that allows for geographic comparability, and that provides an extensive snapshot of plumbing poverty in the United States. Plumbing poverty needs to take a systematic and broad-scale spatial approach in order to compliment intensive place-based, ethnographic, and sectoral analyses. In the next section, we explain our data source, methods, and modelling techniques.

Data and methods

Our study utilizes census microdata to assess spatial and sociodemographic trends in household plumbing poverty at the national scale. Household data were sourced from the Integrated Public Use Microdata Series (IPUMS), taken from the year 2016. In contrast to summary or aggregate data, these data are composed of individual records collected about households—thus avoiding the ecological fallacy present in aggregated studies (e.g. Wescoat, Headington, and Theobold 2008).

Despite its micro prefix, census microdata are large in number. IPUMS includes almost a billion records from the U.S. Census dating from 1790 to the present, as well as over a billion records from international census of over one hundred countries. U.S. Census microdata permit spatial analysis of household-level characteristics using the Public Use Microdata Area (PUMA), a geographic unit that roughly follows county boundaries and contains between 100,000 to 200,000 residents. PUMAs are the smallest geographic units attached to household level census data. These data thus allow for a methodological approach that balances interpretation at the household level with national-scale geographic analyses and potential international comparability (Wutich et al. 2017).

The U.S. Census Bureau has collected data about household plumbing for the United States since 1960 and for Puerto Rico from 2000 to 2011. Our analysis utilized data from the 2016 American Community Survey (ACS) five-year estimates (Ruggles et al. 2017), though we note the potential for a longitudinal analysis.[6] The U.S. Census Bureau defines "complete plumbing facilities" as (1) piped hot and cold water, (2) a flush toilet, and (3) a bathtub or shower (3), all located within the housing unit and used only by occupants. Margin of error is an important consideration when working with census data. The 2016 ACS margin of error for the 463,649 households without complete plumbing is +/-5,058, which means we can be 90 percent confident that the actual plumbing incomplete population is between 458,591 and 468,707. The Census Bureau tends to undercount people of color (U.S. Census 2012). Our analysis suggests that certain communities of color (American Indian and Alaska Native, African-American, and Hispanic) are more likely to lack complete plumbing, therefore the actual number of plumbing poor in the United States is likely closer to the high end of the margin of error (468,707).

Analysis was conducted in three steps (Figure 1). In the first step, we use logistic regression to understand the relationship between incomplete plumbing and a range of sociodemographic and housing characteristics across the entire United States. The measures included in the model included: race, ethnicity, income, housing tenure, and housing type—factors identified as salient by the literature. The final model was selected based on a combination of factors including the strength of the univariate correlation with plumbing completeness, variable collinearity, and the water insecurity literature.

Second, we explored hot and cold spots (geographic clusters) of plumbing completeness. Specifically, we used Getis-Ord Gi* to identify spatial patterns of high and low clusters of plumbing incompleteness. The Getis-Ord Gi* method produces z-scores and p-values that identify statistically significant spatial clusters of high (hot spot) and low (cold spot) values. The calculation works by examining each feature in the context of neighboring features—the local sum for a feature is compared to the sum of all features. Significant hot spots and cold spots are those where the difference between the local sum and global sum is too large to be the result of random chance. This analysis drew on block group level rates of plumbing incompleteness. Block groups are the smallest geographic unit available for aggregate data.

Finally, to capture spatial patterns in relationships between plumbing completeness and the household characteristics identified in the first step, we examined univariate correlations and estimated 2,351 separate logistic regression equations for the households in each of the PUMAs across the United States. We then visualized the spatial patterns in the results—noting hot and cold spots of high and low correlations, coefficient deviation from the national model, and hot and cold spots of logistic regression odds ratios (Getis-Ord Gi*).

Plumbing poverty in the United States

In the United States, potable water infrastructure is broadly assumed to be 'universal' in its coverage, to the point where the U.S. Census Bureau has recently considered dropping its plumbing question from the ACS survey questionnaire (Cohn 2014). Before 1800, most U.S.

cities and towns depended on a precarious combination of private water carriers, tankers, wells, and cisterns to meet their household water needs (Melosi 2011). Disease outbreaks from contaminated water sources were common, leading to a push for municipal ownership of water infrastructure systems, a decision that "had as much to do with the desire to influence the growth of cities as to settle disputes with private companies over specific deficiencies" in local service delivery (Melosi 2011: 61). Technological innovations and federal funding allowed the extension of public water supply networks to reach new populations, particularly rural communities. For example, during the 1930s New Deal program, the Public Works Administration financed nearly three-quarters of its waterworks projects in communities with less than one thousand people (Melosi 2011: 64). Despite these advances, our findings suggest that universalized water infrastructure remains an incomplete promise for different populations in different places across the nation—and not just those in rural or hard-to-reach areas. As described below, the results of our inquiry reveal the racialized, classed, and variegated spatial nature of plumbing poverty.

Who are the plumbing poor?

In statistical terms, a greater proportion of specific kinds of households are plumbing poor than would be expected based on their representation in the population. For example, based solely on demographic ratios, a greater than expected number of households that lack complete plumbing are American Indian or Alaska Native (AIAN), black, Hispanic, have lower income relative to others in their local PUMA area, live in in mobile homes, and rent (see Table 1). Specifically, descriptive statistics revealed:

- Only **1.5 percent** of U.S. households are American Indian or Alaska Native, but among households that are plumbing incomplete, **6.2 percent** are AIAN households.
- Similarly, **12.8** percent of U.S. households are black, whereas **16.6 percent** of households with incomplete plumbing are black.
- Hispanic headed households make up 12.5 percent of all U.S. households and **16.7 percent** of those with incomplete plumbing.
- Households with incomplete plumbing have lower incomes on average than those with complete plumbing.
- While mobile homes are occupied by **5.8 percent** of households, that proportion is over twice as high among households with incomplete plumbing (**14.4 percent**);
- Considering housing tenure and ownership, a greater proportion of the plumbing incomplete rent **(51.1 percent)** than the national average **(36.6 percent).**

Table 1 suggests social inequality at work in household water insecurity. However, those results do not reveal how various household characteristics *interact* to *predict* plumbing poverty. Thus, we used logistic regression to elicit which sociodemographic factors, taken together, are significant. The results of multivariable logistic regression suggest that race, class, and housing characteristics intersect to increase the odds of plumbing completeness in the United States (Table 2).

Most strikingly, American Indian and Alaska Native households lack complete plumbing at orders of magnitude far greater than other racial and ethnic groups. After accounting for housing type and tenure, income, and Hispanic ethnicity, AIAN households are 3.7 times (95% CI: 3.66-3.74) and black households are 1.2 times (95% CI: 1.20-1.22) more likely to lack complete plumbing than households headed by someone who does not identify as black or AIAN. In line with Jepson and Vandewalle's (2016) work at the Texas-Mexico border, households with a Hispanic head are 1.2 times (95% CI: 1.23-1.25) more likely to lack complete plumbing than households not headed by a Hispanic.

Measures of economic insecurity were also found to increase the odds of plumbing poverty. Holding other variables in the model constant, households with incomes twice the PUMA median are 1.5 times more likely to have complete plumbing. Housing type, which is related to socioeconomic affluence, is also predictive of water insecurity. Those living in mobile homes are 2.5 times (95% CI: 2.45-2.50) more likely to be plumbing incomplete (c.f. Pierce and Jimenez 2015) compared to those living in other types of housing. Households that rent are 1.4 times (95% CI: 1.42-1.43) more likely to lack complete plumbing compared to those that own their homes.

These results point to the racialized nature of plumbing poverty across households in the United States. Moreover, these patterns are most striking in households headed by someone who identifies as American Indian or Alaska Native. An examination of Table 1 might lead someone to suggest that the high proportion of indigenous households that are plumbing incomplete is a function of other factors such as income or housing type. However, logistic regression results suggest that living in a Native American household increases the odds of incomplete plumbing even after accounting for these factors. Overall, the results of the analysis suggest distinct patterns of socioeconomic, ethnic, and racial inequality in plumbing completeness.

Where are the plumbing poor?

Results paint a variegated landscape of insecurity. Living in an American Indian or Alaskan Native, black, or Hispanic household increases the odds of being plumbing poor across the United States, but analysis also reveals spatial clusters at the local scale (Figure 2). At the census block group level (a neighborhood level of analysis) plumbing completeness ranges from 0-100 percent with an average rate of 2.2 percent (standard deviation, 4.9 percent). Communities with higher rates of plumbing poverty are clustered in the U.S. Southwest (especially the Four Corners and U.S.-Mexico border regions), the Upper Midwest, the Northeast (especially northern Maine and New Hampshire), and the Allegheny and Appalachian regions of Pennsylvania and West Virginia (Figure 2).[7] Rurality is not the sole or even best predictor of plumbing poverty. For example, in Figure 2, there are extensive rural areas in Montana and the Dakotas with almost no significant hot spots of plumbing poverty.

What surprised us more, however, is the degree to which sociodemographic predictors of plumbing poverty warp and woof through space. Figure 2 depicts the spatiality of plumbing completeness. The results of our PUMA analyses indicate clear geographic patterns to the relationships between plumbing completeness and household characteristics across the United States. Figure 3 maps the hot spots of correlation, or the univariate relationships between plumbing completeness and each of the household level characteristics.[8] Hot spots are areas where a higher rate of households with a given characteristic lack complete plumbing than would be expected through random variation across space. Results illustrate the hot spots of plumbing poverty—a geography that reveals how infrastructure is differently racialized across the United States. For example, a greater proportion of households headed by someone who is African-American lack complete plumbing in the Black Belt, a region that cuts across the U.S. South. AIAN households lack complete plumbing at higher rates than expected given their local representation in Alaska, Arizona, New Mexico, and the Great Plains—areas with large Native American reservations. Hispanics lack complete plumbing at higher rates in southwest Texas, areas of the Rust Belt, Utah, and the Northeast. The relationship between renting and plumbing incompleteness mostly follows state boundaries. Households that rent are less likely to lack complete plumbing in Montana but more likely in major swaths of California and the Northeast from New York to New Hampshire, for example. Given the national results (Table 1) we would expect negative relationships between income and plumbing incompleteness (cold spots)—income is particularly correlated with plumbing completeness in the expected direction in the Mississippi Delta region, the Four Corners, Maine, south Texas, the Pacific Northwest, and northern California. Those that live in mobile homes are more likely to lack complete plumbing in Colorado, New Mexico, and the upper Northeast surrounding New Jersey.

Logistic regression reveals socio-spatial patterns beyond individual correlations. Figure 4 maps the departure of local PUMA odds ratios from the national household multivariable model (Table 2) and Figure 5 synthesizes those multivariable results by mapping spatial clusters of high or low values (hot and cold spots).[9] Figure 4 should be used as a reference for understanding Figure 5. For example, living in a household headed by a Native American was found to increase the odds of lacking plumbing approximately 3.7 times across the United States (Table 1) but in Arizona, local PUMA results suggest that the odds are even higher for AIAN households, with the exception of one PUMA in the middle of the state where the odds ratio is both less than the national average and negative (Figure 4). The Getis-Ord Gi* methodology identified the state as a hot spot of AIAN coefficient values (Figure 5). Most of Washington state was identified as a hot spot, but a close look at local odds ratios suggests a more nuanced story: some PUMA-level models resulted in insignificant odds ratios, some odds ratios were higher than the national model, some were lower, and some even suggested that living in an AIAN household increased the odds of complete plumbing. Thus, while in general the Getis-Ord Gi* statistic suggests that neighboring odds ratios were higher on average than expected in comparison to the overall national average, that does not necessarily mean that each PUMA conformed to that pattern.

Race predicts plumbing poverty in different ways across the United States. In other words, place matters to explanation—a key geographic insight for understanding household water insecurity. In many PUMAs, race and ethnicity are insignificantly related to plumbing incompleteness (Figure 4). However, the hot spots in Figure 5 suggest particular spatial patterns of racial exclusion to water infrastructure access. As mentioned above, the national multivariable model suggests that across all households in the United States, living in an American Indian household increases the odds of incomplete plumbing. Regionally, the odds of incomplete plumbing for households with AIAN heads tend to be higher in PUMAs in Alaska, Arizona, New Mexico, Oklahoma, Kansas, Washington, Montana, and Oregon—all states with large tribal populations. The odds of lacking complete plumbing are generally higher for Hispanic households in PUMAs along the U.S.-Mexico border in the southwest and in southern Florida, where there are large Hispanic immigrant populations. In the Black Belt—an area with a history of racial segregation and institutionalized exclusion of African-Americans—a black household is more likely to lack complete plumbing than black households in other parts of the country.

Income and housing type are similarly variegated. Holding race and ethnicity constant, income and housing type exhibit spatial patterns in the suggested odds of lacking complete plumbing; however, these patterns are generally less obvious than those observed according to race (Figure 4). Income is a stronger predictor of plumbing poverty in Arizona and Michigan (Figure 5). Renters are more likely to lack plumbing on the West coast (especially California) but less likely in the Eastern U.S. (Figure 5)—again, there appears to be less of a coherent spatiality to the local PUMA odds ratios for renters.

Finally, and in contrast to popular opinion, living in a mobile home does not increase the odds of lacking complete plumbing uniformly or consistently across the United States (c.f. Pierce and Jimenez 2015). In fact, some PUMA results suggest that living in a mobile home increases the odds of complete plumbing (Figure 4). Regionally, the results suggest that the odds of lacking complete plumbing are higher for mobile home occupants in large parts of Arizona, Montana, North Dakota, and the Mississippi Delta region. Interestingly, univariate correlations suggest that in northern Maine, a hot spot of plumbing poverty (see Figure 2), mobile homes and households with lower incomes lack complete plumbing at higher rates than national averages. However, when these variables are taken together in logistic regression, the relationship is insignificant in the case of income and exhibits varied patterns in the case of mobile homes. Instead, race emerges as a significant factor.

Discussion

Plumbing poverty is racialized in America, but these infrastructural geographies are spatially nuanced. Castulo Estrada grew up on the east side of Coachella Valley (southeast of Los Angeles, near Palm Springs) where open sewage ditches and arsenic-contaminated drinking water are the daily living conditions for a community of mostly low-income, Hispanic farm-workers (Cereijido 2017). Lindsay Johnson, a mother living on the Navajo reservation in Arizona, lacks running water or electricity in her family home. Ms. Johnson stretches a water delivery of 400 gallons a month, compared with the average per capita American consumption of 100 gallons per day (McGraw 2016). In Lowndes, Alabama, one of the poorest counties in the country, Dorothy Rudolph runs a plastic pipe from her toilet to the woods behind her house. She is unable to afford a $6,000 septic tank and must plunge the toilet when it rains to prevent the system from overflowing (Tavernise 2016).

These stories are the human faces of plumbing poverty. In this paper, we adopt a sociodemographic and methodological approach to place these stories in the national context of household water insecurity. We plumb poverty in order to elicit its social geography and spatial nature. The experiences of Castulo, Lindsay, and Dorothy are not unique in their communities—our study finds that rates of plumbing incompleteness are spatially clustered. Our results also indicate clear racial and socioeconomic patterns to plumbing poverty. Logistic regression suggests that in the PUMA that covers eastern Riverside County (including Coachella) in California, living in a mobile home increases the odds of incomplete plumbing 18.5 times and living in a household headed by a Hispanic increases the odds 12.8 times. Meanwhile, in Arizona's Navajo and Apache counties, living in an American Indian household increases the odds of incomplete plumbing thirteen times. In central Alabama (Elmore, Autauga, outer Montgomery, and Lowndes Counties), black households are 4.9 times more likely to lack complete plumbing. Our findings place these stories in a larger national context of social inequality and marginalization.

Plumbing poverty is neither socially nor spatially random in the United States. Rather, our findings point to the intersection of household level characteristics, which vary spatially, to produce a landscape of household water insecurity. In line with other scholars, our work suggests that institutionalized and racial logics are at work in making certain groups of Americans, specifically communities of color, more likely to be plumbing poor (Jepson and Vandewalle 2016; Pulido 2016a, 2016b; Ranganathan 2016). Scholars have used place-based studies to understand how race, ethnicity, socioeconomic status, and housing type help *produce* household water insecurity (Cook and Bakker 2012; Lankford 2013; Zwarteveen and Boelens 2014; Jepson and Vandewalle 2016; see critique by Jepson et al. 2017a). Our study confirms previous empirical findings—for example, Jepson's (2014) geographic cluster in the Texas borderlands[10] and Wescoat et al.'s (2008) insights about American Indians in the Four Corners region—and goes farther to *systematically* plumb household water insecurity at the national scale.

This study has major implications for geographic methodology in the context of big data and entrenched social inequality. A spatial understanding of social inequality is vital if we are to abstract and contextualize anecdotal and place-based understandings of household water insecurity. To date, scholarly attempts at geostatistical understanding have relied on aggregate data and inferences about households—an approach that violates fundamental rules of geography. This paper is the first attempt to plumb poverty using household data (IPUMS data) as units of analysis. In terms of measuring inequality, this paper charts a path forward that avoids statistical bias introduced by the ecological fallacy, while also retaining the important insights that emerge from spatial analysis. We preserve the *household* as the unit of analysis, which is key to understanding the spatial nature of household water insecurity.

Of course, the presence of a piped connection—as measured in this study—is just one aspect of household water security. Plumbing poverty contributes to an understanding of household water insecurity, but it does not define it. Stripping household water insecurity down to one measure (plumbing completeness) enabled us to experiment with extensive census data and highlight geographic variability in hot spots. However, these data do not tell the unique human stories cited above; nor do census data tell us how plumbing poverty is produced, how living without secure water is experienced, or what can be done about the problem. We hope our work elicits future questions and avenues of investigation. For example, why is it that black households still lack plumbing at higher rates in the South, AIAN households lack plumbing in the Southwest, and Hispanic households along the southern border? Future research in this field must explore the multifaceted causes and effects of household water insecurity, including its interrelated physical, economic, political, and social domains. Future research must also interrogate how and why household water insecurity is produced in particular places and how it collectively impacts human health and development.

In our first blush at developing a heuristic—a tool for thought—this study provides important tools for mapping the intersectional nature of infrastructure, space, and social inequality. This mandate exceeds the study of household water. Recall that plumbing poverty is understood in a dual sense: first, as a material and infrastructural condition produced by social relations that fundamentally vary through space, and second, as a methodology that operationalizes the spatial exploration of social inequality. In this way, plumbing poverty provides a potential blueprint for exploring the social geographies of different kinds of networked infrastructures—such as transportation, housing, electricity, communication, or other vital public services. Inequalities are growing in America and elsewhere. A geographic perspective is urgent and necessary in order to locate and understand the spatial nuance of social inequality, including its sociodemographic and localized differences. Geographic approaches, too, must evolve to keep pace.

Conclusion

Plumbing poverty is produced through conditions of infrastructural violence: the slow burn of insecure water supply that negatively impacts human life and capacity for development (Laurie and Shaw 2018). In the United States, the plumbing poor have a distinct geography. Even more important, we showed how sociodemographic predictors *vary* through space. What it means to be plumbing poor in the Black Belt or the Four Corners or upper Maine is different compared to other regions, a finding that suggests varying racial, socioeconomic, and political logics at work in infrastructure provision. This work underscores the need to adopt a geographic perspective in the development of cross-comparable metrics and global measurement tools for household water insecurity.

We also exposed the racialized nature of plumbing poverty in America. At the national level, American Indians and Alaska Native households are nearly *four times more likely* to lack plumbing. African American households are 1.2 times more likely than households in similar conditions. Plumbing poverty is not a simple artifact of income, rurality, or housing type; infrastructure provision is clearly *racialized* and historically produced in America (Ranganathan 2016; Pulido 2016a, 2016b; Pulido, Kohl, and Cotton 2016). While our findings are perhaps unsurprising in a nation with a persistent history of institutionalized racism and settler colonialism, this evidence nonetheless puts the spotlight back on the state, the typical provider of municipal water provision and sewerage. More research is needed to elicit the *production* of plumbing poverty in specific locales; still, this paper begins to map the failure of public policy and local state institutions—what Karen Bakker (2010) calls 'governance failure' and what Laura Pulido et al. (2016) theorizes as the 'neoliberal racial state'—to provide equal life opportunity in the United States, a country in which public water provision is falsely assumed to be universal.

Geographic knowledge is essential to advance insights about social and spatial inequality. This paper is one step forward; much more work remains. Future research might explore the social production of plumbing poverty and infrastructure dysfunction in afflicted regions; examine how water insecurity intersects with other infrastructural geographies (e.g. food, transportation, electricity; housing); or utilize mixed methods approaches, especially with census, ethnographic, and public health data, to elicit comparable knowledge about the effects of plumbing poverty between places and nations (c.f. Jepson et al. 2017a; Wutich et al. 2017). Future work must include meaningful policy action at multiple scales of governance—municipal, state, federal—as measurement is only as good as the action it incites into practice. Nearly fifty-five years ago, the U.S. federal government declared war on poverty. That time of reckoning has come.

Notes

1. This story is adopted from a news article (Millman 2017), including direct quotes made by the reporter. Similar testimonies by the Diné (Navajo) people are available in other published media and policy briefs.
2. Source: U.S. Census Bureau (2016). The U.S. Census Bureau uses the term "American Indian and Alaska Native" to describe indigenous peoples in the United States. While problematic, we use this term for consistency and legibility (c.f. Pulido 2018). We also use "Native" and "Native American" in this article.
3. Quoted in Millman (2017).
4. This figure is a conservative estimate, calculated based on the average number of people per family household, which was 3.14 in 2016.
5. Wescoat, Headington, and Theobold (2008) provide no methodological explanation or evidence of data analysis in their paper, so it remains unclear how they arrived at these claims of correlation.
6. The definition of plumbing completeness has varied over time. In 1960 and 1970, the census defined "complete plumbing facilities" as piped hot and cold water (running hot and cold water in 1960), a flush toilet, and a bathtub or shower, all located within the structure and used only by occupants. The 1980 definition specified that all facilities must be located

within the same "housing" unit (prior definitions specified a "structure"); units with shared plumbing were identified separately. Definitions in subsequent census surveys utilized the same language as 1980, except the bureau dropped inquiry about shared facilities.

7. We are referring to vernacular regions rather than using definitions set by the Census Bureau or other state agency. Regional boundaries set by various agencies do not fully capture the patterns that we observe as their boundaries are somewhat arbitrary and not agreed upon.
8. These maps present spatial patterns in PUMA results. Table 1 can be referred to for the results of these same analyses across the entire US.
9. Note the hot and cold spots of Nagelkerke r-squared values. One of our findings is that the model does not actually perform well in all regions of the United States – in part due to the observed patterns. While race is highly significant in particular PUMAs there are others where it is not and perhaps other factors such as housing type explain most of the discrepancy in plumbing completeness.
10. Our results align with Jepson's more intensive work. We found that in the PUMA that covers southeast Hidalgo County Hispanic headed households are 7.1 times more likely to lack complete plumbing. In eastern El Paso County Hispanic households are 3.5 times more likely and in central El Paso Hispanic households are 4.7 times more likely to lack complete plumbing.

References

Bakker, K. 2010. *Privatizing Water: Governance Failure and the World's Water Crisis*. Ithaca, NY: Cornell University Press.

Bakker, K. 2012. Water security: research challenges and opportunities. *Science* 337 (6097): 914-915.

Balazs, C., and I. Ray. 2014. The drinking water disparities framework: on the origins and persistence of inequities in exposure. *American Journal of Public Health* 104(4): 603-611.

Cereijido, A. 2017. Valley of contrasts. *National Public Radio.* http://latinousa.org/episode/valley-of-contrasts/ (accessed May 15, 2017).

Cohn, D. 2014. Census may change some questions after pushback from public. *Pew Research Center*. http://www.pewresearch.org/fact-tank/2014/04/22/census-may-change-some-questions-after-pushback-from-public/ (accessed February 9, 2018).

Cook, C., and K. Bakker. 2012. Water security: debating an emerging paradigm. *Global Environmental Change* 22: 94-102.

Cutter, S.L., J.T. Mitchell, and M.S. Scott. 2000. Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers* 90 (4): 703-737.

Eichelberger, L. 2017. Household water insecurity and its cultural dimensions: preliminary results from Newtok, Alaska. *Environmental Science and Pollution Research* doi:10.1007/s11356-017-9432-4.

Elwood, S., V. Lawson, and E. Sheppard. 2017. Geographical relational poverty studies. *Progress in Human Geography* 41(6): 745-765.

Fotheringham, A., C. Brunsdon, and M. Charlton. 2002. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. New York, NY: Wiley.

Furlong, K. 2014. STS beyond the 'modern infrastructure ideal': extending theory by engaging with infrastructure challenges in the South. *Technology in Society* 38 (August): 139-147.

Furlong, K., and M. Kooy. 2017. Worlding water supply: thinking beyond the network in Jakarta. *International Journal of Urban and Regional Research* 41 (6): 888-903.
Garfin, G.M., C.A. Scott, M. Wilder, R.G. Varady, and R. Meredith. 2016. Metrics for assessing adaptive capacity and water security: common challenges, diverging contexts, emerging consensus. *Current Opinion in Environmental Sustainability* 21 (1): 86-89.
Gilbert, A., and J. Chakraborty. 2011. Using geographically weighted regression for environmental justice analysis: cumulative cancer risks from air toxics in Florida. *Social Science Research* 40: 273-286.
Hadley, C., and A. Wutich. 2009. Experience-based measures of food and water security: bicultural approaches to grounds measures of insecurity. *Human Organization* 68: 451-460.
Jepson, W. 2014. Measuring 'no-win' waterscapes: experience-based scales and classification approaches to assess household water security in colonias on the US-Mexico border. *Geoforum* 51 (1): 107-120.
Jepson, W., and E. 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.
Jepson, W., J. Budds, L. Eichelberger, L. Harris, E. Norman, K. O'Reilly, A. Pearson, S. Shah, J. Shinn, C. Staddon, J. Stoler, A. Wutich, and S. Young. 2017a. Advancing human capabilities for water security: A relational approach. *Water Security* 1(1): 46-52.
Jepson, W.E., A. Wutich, S.M. Collins, G.O. Boateng, and S.L. Young. 2017b. Progress in household water insecurity metrics: a cross-disciplinary approach. *WIREs Water* 4 (3): doi: 10.1002/wat2.1214
Lankford, B., K. Bakker, M. Zeitoun, and D. Conway (eds). 2013. *Water security: principles, perspectives and practices*. New York, NY: Routledge.
Laurie, E.W., and I.G.R. Shaw. 2018. Violent conditions. *Political Geography* 65(1): 8-16.
Lemos, M.C., C. Manuel-Navarrete, B.L. Willems, R.D. Caravantes, and R.G. Varady. 2016. Advancing metrics: models for understanding adaptation capacity and water security. *Current Opinion in Environmental Sustainability* 21(1): 52-57.
Loftus, A. 2015. Water (in)security: securing the right to water. *Geographical Journal* 181(4): 350-356.
Maantay, J., and S. McLafferty. 2011. *Geospatial analysis of environmental health.* New York, NY: Springer.
Mascarenhas, M. 2007. Where the waters divide: First Nations, tainted water and environmental justice in Canada. *Local Environment* 12 (6): 565-577.
McFarlane, C. 2010. The comparative city: knowledge, learning, urbanism. *International Journal of Urban and Regional Research* 34(4): 725-742.
McGraw, G. 2016. For these Americans, clean water is a luxury. https://www.nytimes.com/2016/10/20/opinion/for-these-americans-clean-water-is-a-luxury.html (accessed May 15, 2017).
McDonald, Y.J., and S.E. Grineski. 2012. Disparities in access to residential plumbing: a binational comparison of environmental injustice in El Paso and Ciudad Juárez. *Population and Environment* 34 (2): 194-246.
Meehan, K. 2012. Water rights and wrongs: illegality and informal use in Mexico and the U.S. In *The Right to Water: Politics, Governance and Social Struggles*, ed. F. Sultana and A. Loftus, 159-173. Abingdon, UK: Routledge.

----. 2014. Tool-power: water infrastructure as wellsprings of state power. *Geoforum* 57: 215-224.

Melosi, M.V. 2011. *Precious Commodity: Providing Water for America's Cities*. Pittsburgh: University of Pittsburgh Press.

Millman, E. 2017. Navajo Nation reservation in need of running water. https://www.usnews.com/news/best-states/arizona/articles/2017-05-20/navajo-nation-reservation-in-need-of-running-water (accessed February 9, 2018).

Openshaw, S. 1984. *The Modifiable Areal Unit Problem.* Norwich, England: Geobooks.

Patrick, R.J. 2011. Uneven access to safe drinking water for First Nations in Canada: connecting health and place through source water protection. *Health & Place* 17 (1): 386-389.

Pierce, G., and S. Jimenez. 2015. Unreliable water access in U.S. mobile homes: Evidence from the American Housing Survey. *Housing Policy Debate* 25 (4): 739-753.

Pulido, L. 2016a. Geographies of race and ethnicity II: Environmental racism, racial capitalism and state-sanctioned violence. *Progress in Human Geography* 41 (4): 524-533.

-----. 2016b. Flint, environmental racism, and racial capitalism. *Capitalism Nature Socialism* 27 (3): 1-16.

Pulido, L., E. Kohl, and N-M Cotton. 2016b. State regulation and environmental justice: The need for strategy reassessment. *Capitalism Nature Socialism* 27 (2): 12-31.

Ranganathan, M. 2016. Thinking with Flint: racial liberalism and the roots of an American water tragedy. *Capitalism Nature Socialism* 27(3): 17-33.

Ranganathan, M., and C. Balazs. 2015. Water marginalization at the urban fringe: environmental justice and urban political ecology across the North–South divide. *Urban Geography* 36 (3): 403-423.

Robinson, W.S. 1950. Ecological correlations and the behavior of individuals. *American Sociological Review* 15 (3): 351-357.

Romero-Lankao, P., and D. Gnatz. 2016. Conceptualizing urban water security in an urbanizing world. *Current Opinion in Environmental Sustainability* 21: 45-51.

Ruggles. S. K. Genadek, R. Goeken, J. Grover, and M. Sobek. 2017. Integrated Public Used Microdata Series: version 7.0 [dataset]. Minneapolis, MN: University of Minnesota. https://doi.org/10.18128/D010.V7.0.

Sharam, A., and K. Hulse. 2014. Understanding the nexus between poverty and homelessness: relational poverty analysis of families experiencing homelessness in Australia. *Housing, Theory and Society* 31 (3): 294-309.

Sultana, F., and A. Loftus. 2015. The human right to water: critiques and condition of possibility. *WIREs:Water* 2 (2): 97-105.

Tavernise, S. 2016. A toilet, but no proper plumbing: a reality in 500,000 U.S. homes. https://www.nytimes.com/2016/09/27/health/plumbing-united-states-poverty.html (accessed May 15, 2017).

Tobler, W. 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography* 46: 234-40.

Vandewalle, E., and W. Jepson. 2015. Mediating water governance: Point-of-use water filtration devices for low-income communities on the US-Mexico border. *GEO: Geography and Environment* 2 (2): 107-121.

U.S. Census Bureau. 2012. Census bureau releases estimates of undercount and overcount in the 2010 Census. https://www.census.gov/newsroom/releases/archives/2010_census/cb12-95.html (accessed August 9, 2018).

U.S. Census Bureau. 2016. Five-year estimates. *American Community Survey*. Washington, DC: U.S. Census Bureau's American Community Survey Office.
Wescoat Jr, J.L., L. Headington, and R. Theobald. 2008. Water and poverty in the United States. *Geoforum* 38 (5): 801-814.
Wutich, A. 2009. Intrahousehold disparities in women and men's experiences of water insecurity and emotional distress in urban Bolivia. *Human Organization* 68: 451-460.
Wutich, A., and K. Ragsdale. 2008. Water insecurity and emotional distress: Coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. *Social Science & Medicine* 67 (12): 2116-2125.
Wutich, A., J. Budds, L. Eichelberger, J. Geere, L.M. Harris, J.A. Horney, W.E. Jepson, E. Norman, K. O'Reilly, A.L. Pearson, S.H. Shah, J. Shinn, K. Simpson, C. Staddon, J. Stoler, M.P. Teodoro, and S.L. Young. 2017. Advancing methods for research on household water insecurity: studying entitlements and capabilities, socio-cultural dynamics, and political processes, institutions and governance. *Water Security* (2): 1-10 doi:10.1016/j.wasec.2017.09.001
Zwarteveen, M.Z., and R. Boelens. 2014. Defining, researching and struggling for water justice: some conceptual building blocks for research and action. *Water International* 39 (2): 143-158.

Acknowledgements
We are grateful to Jason Jurjevich, Amy Lobben, Kate Shields, Olivia Molden, Lourdes Ginart, and Fiona De Los Ríos for constructive comments on previous drafts of this article. Katie Meehan would like to thank the Agnese Nelms Haury Program in Environment and Social Justice at the University of Arizona, where ideas for this article germinated during a 2016-2017 visiting fellowship. All statements, findings, and conclusions are our own.

Author Information
SHILOH DEITZ is a doctoral student in the Department of Geography at King's College London, Strand, London WC2R 2LS, United Kingdom. Email: shiloh.deitz@kcl.ac.uk. Her research interests include development geography, infrastructure, and spatial analysis of social inequality.

KATIE MEEHAN is an Associate Professor in the Department of Geography at the University of Oregon, Eugene, OR 97403-1251. Email: meehan@uoregon.edu, katharine.meehan@kcl.ac.uk. In 2019 she will be a Senior Lecturer in the Department of Geography at King's College London. Her research interests include urban political ecology, household water insecurity, and grassroots infrastructure in Latin American cities.

Figure Captions

FIGURE 1. Methods and data in plumbing poverty

FIGURE 2. Clusters of incomplete household plumbing
Data source: U.S. Census Bureau (2016)

FIGURE 3. Correlations with plumbing poverty
Data source: U.S. Census Bureau (2016)

FIGURE 4. Significant local coefficients departure from U.S. household model
Data source: U.S. Census Bureau (2016)

FIGURE 5. PUMA results: hot and cold spots of local coefficients and Nagelkerke r-square
Data source: U.S. Census Bureau (2016)

FIGURE 1. Methods and data in plumbing poverty

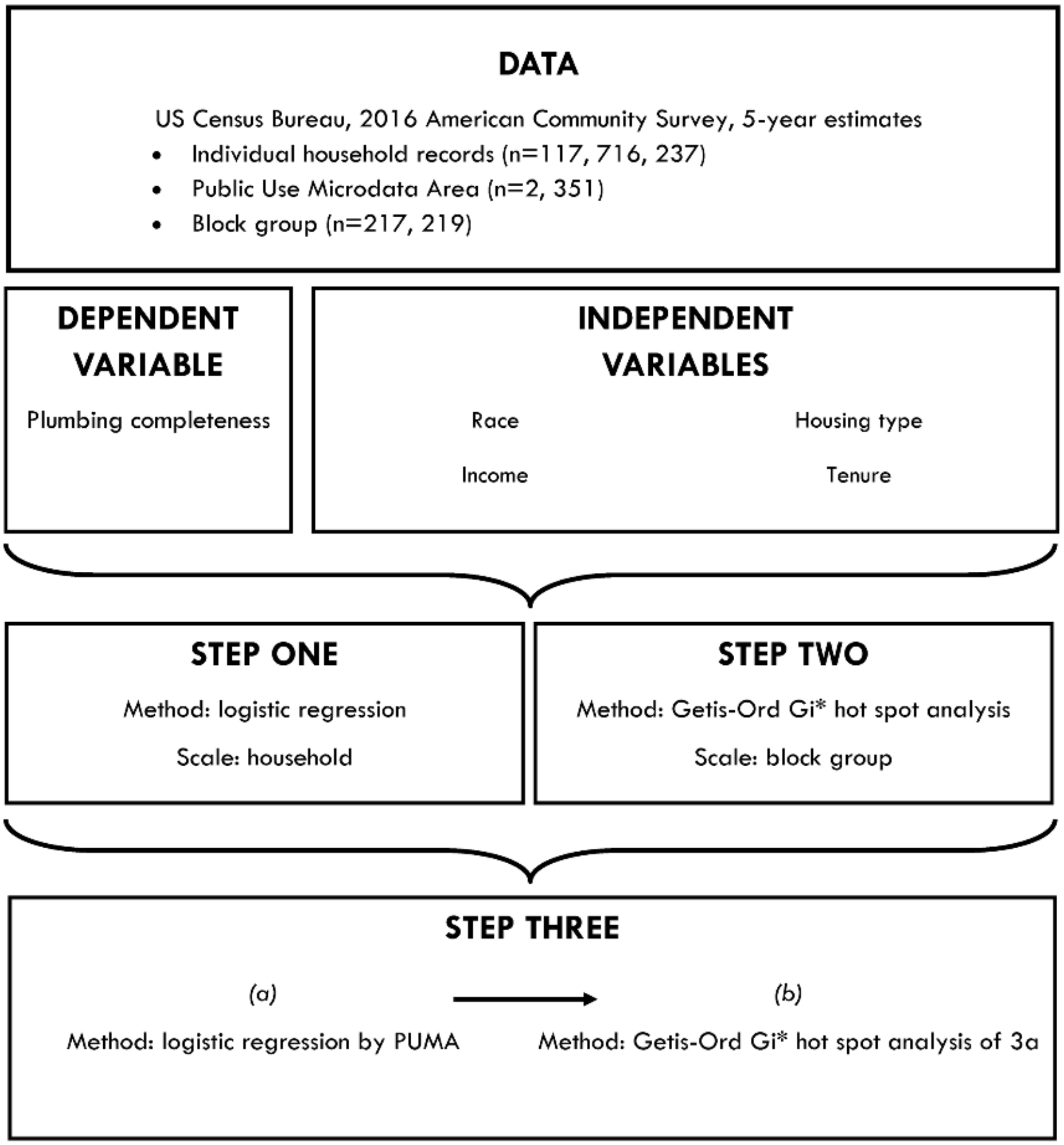

FIGURE 2. Clusters of incomplete household plumbing
Data source: U.S. Census Bureau (2016)

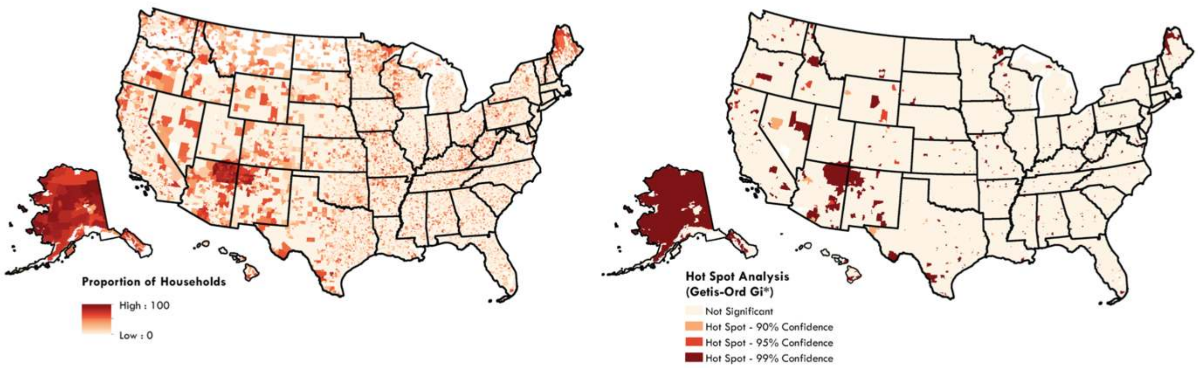

FIGURE 3. Correlations with plumbing poverty
Data source: U.S. Census Bureau (2016)

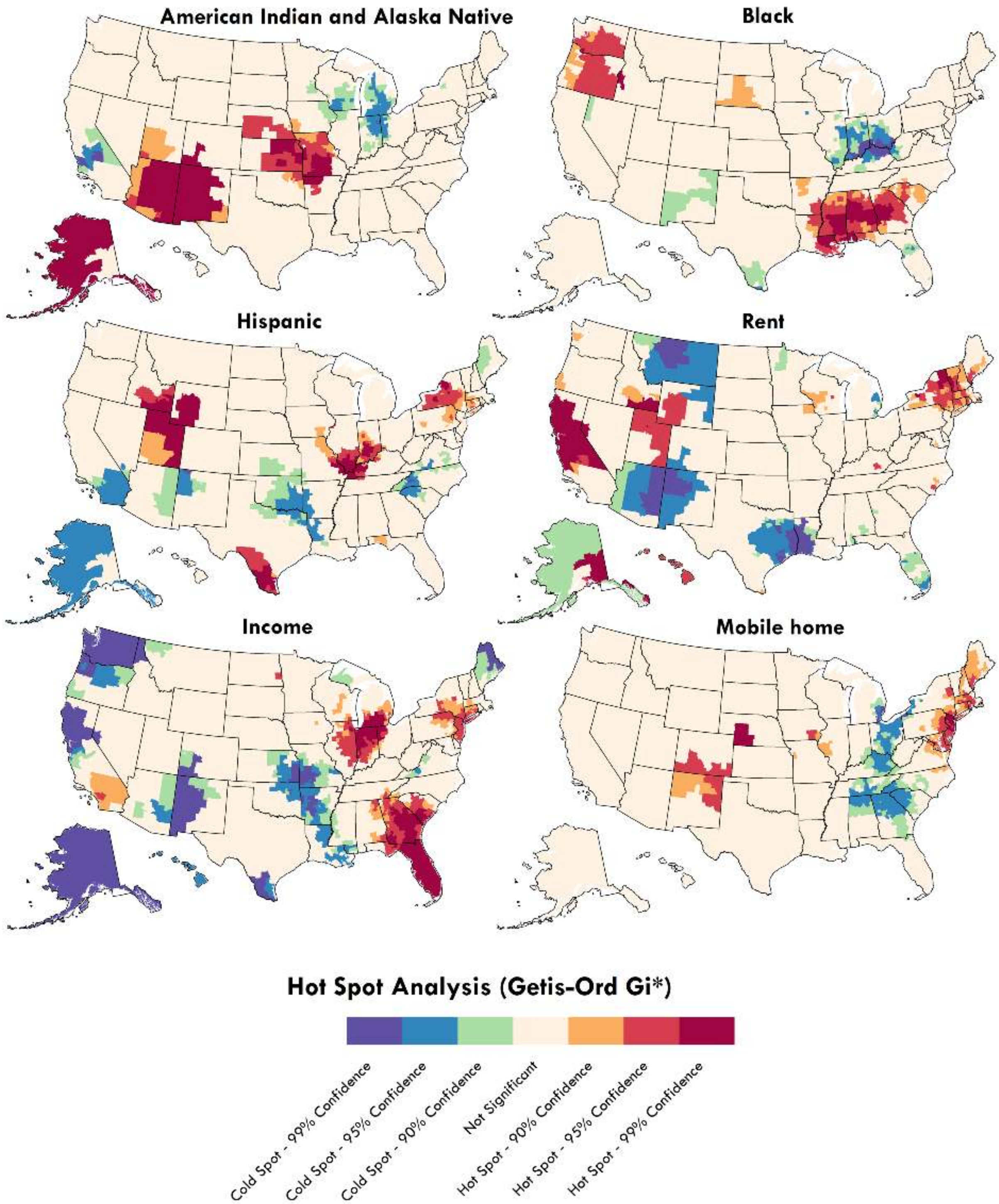

FIGURE 4. Significant local coefficients departure from U.S. household model
Data source: U.S. Census Bureau (2016)

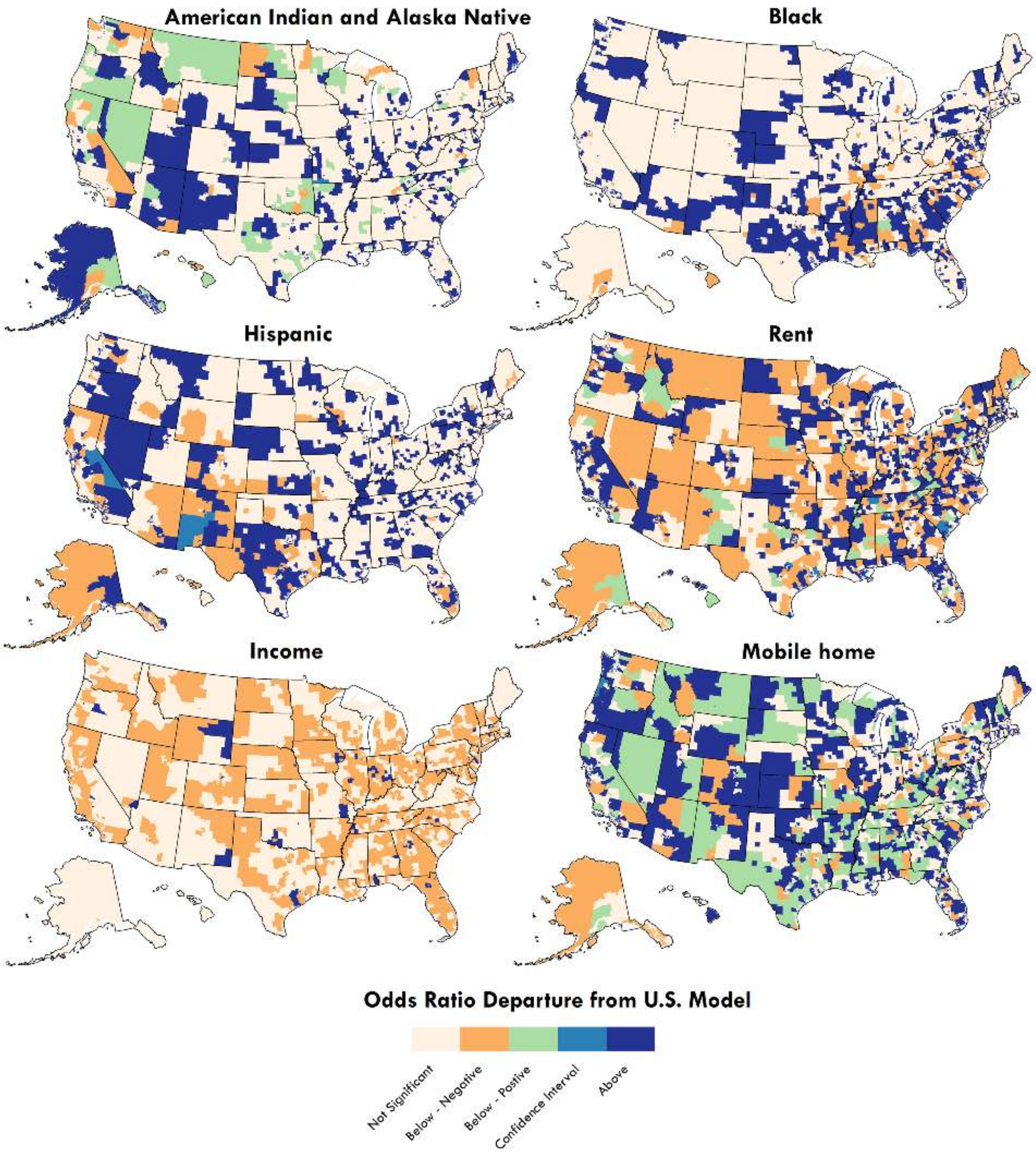

FIGURE 5. PUMA results: hot and cold spots of local coefficients and Nagelkerke r-square
Data source: U.S. Census Bureau (2016)