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The inequitable exposure of socially vulnerable groups to water shortages across the United States

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Abstract

Socially vulnerable populations in the United States are bearing the highest costs of water scarcity, which is likely to worsen with climate change, population growth, and growing disparities between areas with high water demand and the location of available supplies. Prior research showing that socially vulnerable groups are inequitably exposed to water shortages has focused on singular dimensions of social vulnerability, typically in relatively localized geographies, leaving us with an incomplete understanding of the national scope of the shortage risks. This study combines data on surface water shortages with the U.S. Center for Disease Control's Social Vulnerability Index (SVI) to spatially identify clusters of high-shortage, high-vulnerability hotspots from 71 195 census tracts across the conterminous United States. We estimate that 5 percent of the population of the lower 48 states—nearly 15 million people—lives in high-SVI, high-shortage hotspot areas. We examine the relationship between exposure to water shortage and (a) SVI, (b) SVI themes, and (c) 15 indicators used to construct SVI across the U.S. and within hotspots. We find evidence that water shortages constitute an environmental injustice, as multiple dimensions of social vulnerability are disproportionately exposed to water shortages. However, the distinct dimensions of vulnerability that are correlated with a higher probability of exposure to water shortage vary across regions and within hotspots, indicating that adaptation strategies will have to be tailored to their specific contexts. This statement is to certify that all Authors have seen and approved the manuscript being submitted. We confirm that the article is the Authors' original work and that we have no conflicts of interest.

1. Introduction

The western United States is currently experiencing a megadrought unlike any experienced in over 1200 years [1]. By most estimates, water shortages even beyond the U.S. West will become more common due to warmer temperatures, more variable precipitation patterns, and increased demands [2–6]. As with many environmental hazards, the burden of water shortage will likely fall more heavily on the most vulnerable members of society [7, 8]. Reducing risks of future shortages, therefore, requires a clear understanding of the spatial patterns of where social vulnerability and occurrence of water shortage intersect and socioeconomic and demographic factors that amplify vulnerability to shortages.

Water shortage risk (i.e. the potential for harm) is a function of physical water scarcity and a population's capacity to anticipate, adapt to, and recover from water supply shocks and stresses [9, 10]. The same shortage scenario poses a higher risk to socially vulnerable communities with less capacity to cope than to their less vulnerable counterparts. Resilience literature increasingly considers complex dynamics between human vulnerability and the intensity, frequency, scale, and duration of environmental hazards, emphasizing the importance of adapting to long-term, uncertain environmental risks [10–14].

Adaptation is especially important as climate change intensifies and prolongs shortages across much of the U.S., and mitigation efforts are unlikely to moderate the effects of climate change on the hydrological cycle [3, 15]. Yet, high upfront costs of adaptation [16–19] suggest that without interventions, shortage risks will increase for vulnerable groups.

The growing policy focus, in the U.S[3]. and abroad[4], on addressing environmental injustices[5] requires defining vulnerability, understanding where and how vulnerable groups are inequitably exposed to environmental hazards, and acting to mitigate risks. A common approach is to use social vulnerability indices, which combine spatial data with socioeconomic and demographic factors that predict a community's relative vulnerability to natural hazards [10, 24–27]. Collated indices have been used to identify communities most in need of assistance during hurricanes [28], floods [29], wildfires [30], and heatwaves [31], but their application to longer-term stressors such as water scarcity has been limited.

Research on water shortage risks in the U.S. has focused on singular elements of vulnerability, such as race [32–34], poverty [35], rurality [36], housing [37, 38], and livelihoods [8, 39, 40], often at state and county levels [41–43], demonstrating that water scarcity disproportionately impacts the health and livelihoods of distinct types of vulnerable groups. Few studies, however, explore the multidimensionality of social vulnerability to drought, leaving us with an incomplete understanding of the scope, variability, and spatial distribution of vulnerability to water shortage on a national scale.

To address this gap, we combine spatial data on surface water shortage volumes with the Center for Disease Control's (CDC) Social Vulnerability Index (SVI) data to identify census tracts characterized by high water shortage and high SVI across the conterminous U.S. (CONUS). Next, we estimate the relationship between the probability of exposure to surface water shortage and (a) SVI, (b) four SVI themes, and (c) the 15 indicators used to construct SVI. By deconstructing SVI into its root components, we find substantial spatial variation in the different dimensions of social vulnerability that are correlated with water shortage exposure. A positive and statistically significant relationship between shortage and measures of social vulnerability indicates an environmental injustice. Finally, we restrict our analysis to census tracts in high-SVI, high-shortage hotspots to understand the varying dimensions of social vulnerability *within* the highest risk areas. We provide one of the few fine-scale, national assessments of water shortage risks to socially vulnerable communities. In doing so, we aim to inform equitable, actionable adaptation strategies tailored to their specific contexts.

2. Background

The frequency and intensity of surface water shortages across the U.S. are increasing with climate change and population growth [2, 3, 44], raising risks of water insecurity for already vulnerable populations [45–47]. Concomitant declines in water quality [48] and affordability [49] disproportionately impact low-income and minority households, further exacerbating their water insecurity risks [32][6]. Hence, the growing policy focus on addressing inequitable exposure to environmental shocks and stressors includes ensuring that vulnerable communities—those with the fewest resources to prepare for, adapt to, and recover from environmental shocks and stressors—can adapt to water shortages [20, 51].

State and federal agencies increasingly use social vulnerability indices like the CDC's SVI to locate communities most in need of assistance and allocate resources accordingly[7]. Federal Emergency Management Agency grant programs require vulnerability assessments as part of their funding applications and use SVI as a measure of vulnerability [57, 58]. Likewise, the U.S. Climate Resilience Toolkit has used SVI as a measure of community resilience to climate change impacts [51]. Similar indices are being used internationally to allocate resources from national governments and non-governmental organizations to local communities to mitigate the water shortage risks [59, 60]. The SVI's potential impact on policy and funding outcomes warrants an analysis of what it reveals about the spatial distribution of vulnerability to water shortage on a national scale, but to our knowledge, no such analysis exists.

The SVI aggregates 15 socioeconomic and demographic variables that predict a community's susceptibility to a range of natural hazards (see table A1). While its application to drought has been limited, a rich body of work identifies mechanisms through which singular elements of vulnerability embedded in SVI increase a community's water

[3] For example, the 2021 US Executive Order 14 008, Tackling the Climate Crisis at Home and Abroad, directs federal agencies to make environmental justice part of their missions [20]. To meet this order, the 2022 Justice40 Initiative aims for 40 percent of benefits from certain Federal investments to be directed to disadvantaged communities [21].

[4] The United Nations is adopting a Multidimensional Vulnerability Index to account for climate injustices experienced by small island nations [22].

[5] Defined by the U.S. Environmental Protection Agency as the 'fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies' [23].

[6] Key aspects of human rights to water, and important measures of overall water security, include (a) availability, (b) accessibility, which includes affordability, and (c) water quality [50].

[7] For example, Hawai'i [52], California [53], Florida [54], Nevada [55], and the U.S. EPA [56] use social vulnerability indices to assess vulnerability to climate change.

shortage risk. Economic diversification away from water-intensive agriculture [61], storage and conveyance infrastructure [62], multiple water sourcing options [63], and water right institutions [64] can mitigate shortage risk even in areas facing recurring, multiyear drought. However, heterogeneous and often inequitable resource distribution undermine the adaptive capacity of vulnerable populations, even within relatively affluent areas.

Wealth predicts vulnerability to water shortage through several pathways [65]. Poorer households, those with proportionally fewer working-age adults contributing to household income, and those in multi-unit housing tend to use only enough water to meet their basic needs and have few options for decreasing consumption [66, 67]. Rising infrastructure and water acquisition costs, render basic water services unaffordable [68, 69], with the poorest tenth of U.S. households paying as much as 8 percent of their income for basic water services [70, 71]. Affordability concerns are positively correlated with minority status [72]. Water shortages exacerbate water quality impairments[8] [48], which are already more prevalent in minority communities relative to predominantly white communities [74, 75]. Minorities tend to be under-represented in political processes [76, 77] and therefore see less investment in infrastructure necessary to remedy water such quality and accessibility inequities [78, 79].

Rural households and, in particular, mobile homes disproportionately rely on unregulated, private wells, leaving them vulnerable to groundwater depletion during drought [38, 80]. Rural drinking water providers with small customer bases often lack the financial capacity to access alternative water sources [81]. Where rural economies rely on water-intensive agriculture, community members with limited financial resources and education may be less able to adapt to changes in income and employment should water shortages erode agricultural production [82]. These socioeconomic and demographic factors underlying measures of vulnerability often occur in tandem, and can exponentially intensify shortage risk [24].

3. Methods and data

This study proceeds in three steps. First, by mapping high-vulnerability, high-shortage areas across CONUS, we identify high-risk areas. Mapping provides insight into the scope and distribution of high-risk communities. Next, we use regression analysis to assess whether vulnerable groups are disproportionately exposed to water shortage. Finally, we examine the different dimensions of social vulnerability in high-risk hotspot areas. Following the IPCC's Special Report on Managing the Risks of Extreme Events [7], we conceptualize water shortage risk as a function of the environmental hazard, exposure (i.e. potential for harm), and a population's vulnerability, which can exacerbate potential harm. In this context, a hazard is water shortage, exposure is the population across 71 196 census tracts, and vulnerability is assessed using the CDC's SVI.

3.1. Defining water shortage

We assess water shortage as occurring when demand exceeds supply. We use estimates from Heidari *et al* [2] to measure shortages as million cubic meters per month difference between water demand and renewable freshwater supply. Shortages are estimated for each of the 204 four-digit hydrologic units (HUC4s) – referred to hereafter as *basins*—which delineate large river basins[9] in the CONUS [83]. Water supply in a given basin includes the basin's water yield plus inflow from upstream basins, within-basin reservoir storage, and its net water imports via transbasin diversions minus instream flow requirements. Note that our measure of water supply excludes groundwater mining, which depletes a confined aquifer in the long term. Instead, it includes only renewable freshwater sources, which are primarily surface water [3]. Total annual water demand includes domestic and public; irrigation; thermoelectric; industrial, commercial, and mining; livestock; and aquacultural water use.

We define shortage events as those lasting at least 12 months over the 1985-2015 time period, and use estimates for a 50-year drought to coincide with the planning horizons of many water utilities. Our models assess water shortage as (a) the probability that a census tract in a given basin experiences any water shortage, and (b) the water shortage volume experienced by a census tract.

3.2. Defining vulnerability

We use CDC's SVI as a measure of social vulnerability. The SVI is comprised of 15 indicators grouped into four themes. Theme 1, socioeconomic status, includes income, poverty, unemployment, and education. Theme 2, household composition, includes measures of age, disability, and single-parent households. Theme 3, minority status, includes individuals identifying as a racial or ethnic minority, and English language proficiency. Theme 4, housing and transportation, includes measures of housing structure, crowding, transportation access, and group quarters. Indicators (table A1) are assessed at the census tract level using 2018 SVI data derived from the 2014-2018 American Community Survey (ACS) [84].

Our independent variables of interest are (a) overall SVI, (b) SVI themes, and, (c) 15 SVI indicators.

[8] For example, lead contamination in Flint, Michigan, or uranium contamination on Navajo Nation [73].

[9] Given that surface water supplies are frequently transferred throughout and across large river basins, HUC4 is a useful unit of analysis for assessing water availability for water users with the area.

Each is assessed as a percentile rank, which is calculated for each tract over each variable [25]. Each theme's percentile rank is calculated by summing the percentile ranks of the variables comprising that theme. SVI is the sum of the percentile rankings of the four SVI themes. A higher percentile rank indicates greater vulnerability.

3.3. Covariates

We control for covariates that potentially shape water use and adaptive capacity. Agricultural communities are particularly susceptible to water shortages [36, 39, 40, 85, 86]. Using geospatial data from the National Land Cover Database, we control the percentage of 2019 agricultural land use (defined as the sum of crops and hay/pasture land use) at the census tract level. We use 2018 ACS data to control for a census tract's 2018 population density per square mile as a measure of water demand [87]. Bureau of Economic Analysis provides county-level data on 2018 GDP (adj. $;2012), which we include as a measure of a county's overall economic vitality. We use data from Deiter *et al* [88] to estimate average census tract-level surface water water use for irrigation, commercial and industrial, domestic, thermoelectric, and livestock. All models include state-level fixed effects to account for differing state water policies.

3.4. Mapping risk

We partition census tracts into high, medium, and low social vulnerability categories based on their SVI score terciles. High social vulnerability includes tracts in the ⩾66th percentile, medium social vulnerability includes those in the ⩾33rd to <66th percentile, and low social vulnerability tracts are those ranking in the <33rd percentile. The large number of census tracts with water shortage values of zero necessitates a different method of categorizing water shortages. We define high-shortage tracts as those falling in the ⩾90th shortage percentile, medium-shortage tracts fall in the 0 < 90th shortage percentile, and low-shortage tracts have a shortage value equal to zero.

By overlaying categorical measures of water shortage and social vulnerability on a map, we spatially identify high-risk areas characterized by the coincidence of high-shortage and high-SVI. We aggregate results by climate regions defined in the US Forest Service's Resource Planning Act (RPA) Assessment (e.g. see U.S. Department of Agriculture, Forest Service [89]). These regions were chosen to align with research efforts of federal agencies, but also because they divide the country across state boundaries into four distinct climate zones useful for this analysis (figure A1).

3.5. Spatial analysis

We use multilinear regression (MLR) to assess whether socially vulnerable populations are disproportionately exposed to water shortages. Because collated measures of social vulnerability potentially mask the significance of any single variable, we examine the relationship between water shortage and (a) SVI, (b) SVI themes and (c) 15 SVI variables across CONUS and separately in each RPA region. Selecting water shortage as our dependent variable does not imply causality between SVI and shortage. Rather, it enables us to test whether socially vulnerable populations and various dimensions of social vulnerability are predisposed to experiencing worse shortages. Our primary regression estimates the probability of census tract, *i*, experiencing water shortage, as a function of social vulnerability:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1 \text{SVI}_i + \beta_2 \gamma_i + \beta_3 \delta_c + \xi_{\text{state}} + u_i. \quad (1)$$

$\Pr(\text{Shortage}_i)$ is a dummy variable equal to one if census tract, *i*, experiences any water shortage (i.e. if it falls into medium or high shortage categories), and equal to zero if its water shortage volume is equal to zero. SVI_i is the SVI percentile rank for census tract, *i*, γ_i is a vector of census tract-level covariates, δ_c is a vector of county-level covariates, ξ_{state} depicts state-level fixed effects, and u_i is the error term. Standard errors are clustered at the county level. Separate regressions are run for CONUS as a whole and for subsets of data within each RPA region. We then adapt equation (1) to examine how different dimensions of vulnerability are potentially exposed to water shortage. In a second model, we replace SVI_i with a vector of SVI's four themes. In a third model, we replace SVI_i with a vector of the SVI's 15 indicators. We assess all full models for multicollinearity using VIF values and consider a VIF < 10 as an acceptable threshold for non-collinearity.

3.6. High-shortage, high-vulnerability hotspots

Finally, we identify a subset of high-shortage, high-SVI *hotspots* with the highest water shortage risks and examine how various dimensions of vulnerability shape shortage risk within those areas. To identify hotspots, we use the Stata `getisord` package to calculate the Getis-Ord Gi* statistics with a binary spatial weight matrix and a 10 km threshold [90]. The Getis-Ord Gi* method compares SVI scores and, separately, water shortage volumes in census tracts relative to neighboring tracts to identify clusters of tracts with local[10] patterns of SVI and shortage that differ significantly from the full sample of tracts. It produces *p*-values and *z*-scores that identify spatially clustered hotspots. We define hotspots as census tracts where both water shortage and SVI have z-scores of > 1.65 and critical values of $p < .1$. We adapt equation (1) to

[10] Here we define 'local' those census tracts within a 10 km radius of each census tract's centroid.

regress water shortage volume on (a) SVI themes, and (b) SVI indicators, restricting our sample to hotspots:

$$\text{Shortage}_i = \beta_0 + \beta_1 \text{SVI}_i + \beta_2 \gamma_i + \beta_3 \delta_c + \xi_{\text{state}} + u_i. \quad (2)$$

Here, Shortage_i is the water shortage volume in census tract, *i*. Because census tracts within hotspots are likely spatially correlated at a sub-county level, we use the `reg2hdfespatial` Stata package developed by Thiermo Fetzer, based on Hsiang [91] and Conley [92] to compute standard errors that allow for spatial correlation across 10 km.

4. Results

4.1. The Intersection of Water Shortage and Social Vulnerability

Figure 1 depicts high, medium, and low classifications of water shortage. High and medium shortage areas in Minnesota and surrounding Lake Michigan (the Northern RPA region) are densely populated relative to those in other regions, where shortages are expansive, but impact similar numbers of people (table A3). The Pacific Coast's water shortages are in the ⩾90th shortage percentile and occur almost exclusively in California.

Notably, high-shortage areas are clustered in areas that the literature has identified as being reliant on groundwater to offset surface water shortages [88]. Those in California overlie the Central and Imperial Valleys where irrigators offset surface water with groundwater in dry years [93, 94]. Across the Great Plains and Southern Texas, irrigators draw from the Ogallala and Gulf aquifers, respectively [88, 95], while Navajo Nation in northeastern Arizona lacks surface water rights and largely relies on unregulated groundwater withdrawals [34, 73]. High-shortage areas in Florida and along Lake Michigan overlie the Floridan and Deep Sandstone aquifers, respectively, which support rapid urban development [96].

Figure 2 depicts spatial overlays of water shortage and SVI score categories. While clusters of high social vulnerability, more so than water shortage, are distributed across the U.S. (see figures A2 and A3), social vulnerability and water shortages converge in areas across the Southwest, the Great Plains, along Lake Michigan, Central Florida, and along the Gulf Coast. The Pacific Coast region, due to the situation in California, has the most severe shortages, and the highest SVI score (table A2). Nearly 9 percent of the region's population resides in high-risk areas (figure A5).

High-risk areas across the South (tables A3 and A4) are concentrated in Texas, in the relatively densely populated Tampa Bay in Florida, and along the Louisiana Coast. The Rocky Mountain region is characterized by extensive water shortages (table A3), but has a relatively low SVI score (table A2) and a relatively small share of its population categorized as highly vulnerable (table A4). That high-risk areas in the region tend to coincide with Native American reservations in Arizona, Colorado, and New Mexico corroborates existing work showing that tribes are especially vulnerable to water shortages [34]. High-risk areas along Lake Michigan in the Northern RPA are a function of rapid municipal and industrial demand growth, which has relied heavily on unsustainable groundwater withdrawals [97], and the Great Lakes Compact, which limits surface water withdrawals from Lake Michigan [98].

4.2. Dimensions of social vulnerability exposed to water shortage vary by region

Maps in figures 1 and 2 provide insight into the scope and spatial distribution of water shortage risks, which are highly clustered across the U.S. They do not, however, reveal whether vulnerable populations are inequitably exposed to water shortages. Here, we present regression estimates that clarify the relationship between water shortage exposure and multiple dimensions of social vulnerability. Coefficient plot estimates in figure 3 are from three separate MLRs that estimate the probability of a census tract experiencing water shortage as a function of (a) SVI (table A8); (b) SVI themes (table A11), and (c) SVI indicators (table A14).

We find a positive and significant relationship between SVI and the probability of water shortage across the U.S. (table A8, col. 1). U.S.-level estimates likely stem from the strong relationship between shortage and SVI on the Pacific Coast, and in particular, California, where inequities are most pronounced and water shortages are most severe (table A2). Thus, socioeconomic and household composition vulnerabilities in California likely drive the positive correlation between water shortage and social vulnerability reflected in U.S.-level estimates.

Overall SVI is not significantly correlated with the probability of water shortage in regions outside of the Pacific Coast. But by deconstructing SVI into its root components, we find positive and significant correlations between exposure to water shortage and distinct dimensions of social vulnerability. The types of vulnerability that are correlated with shortage vary across regions. Minority status and household youth are positively correlated with the shortage exposure in the North, most likely driven by areas along the Great Lakes (see figure 2). Socioeconomic vulnerability stemming from poverty and household youth are positively correlated with the occurrence of water shortage in the South. While water shortage is pervasive across the Rocky Mountain region, only the number of people in group quarters is positively correlated with shortage exposure. This may be because widespread shortages across the region impact vulnerable and non-vulnerable groups alike. Robustness checks in figure A6 reveal that minority status and limited education in the region are positively correlated with

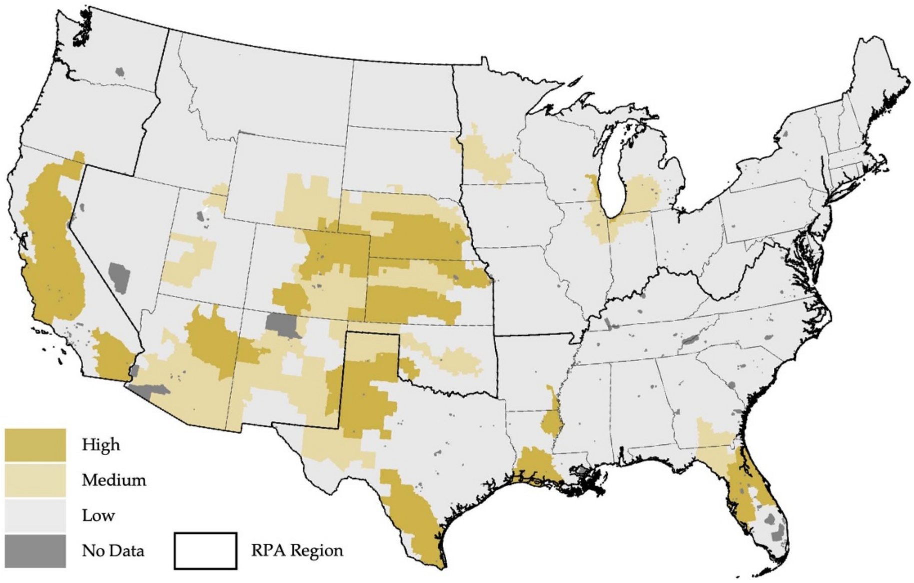

Figure 1. Current water shortage.
Notes: figure depicts high, medium, and low categories of current water shortages across the U.S., with water shortage defined as having a ≥12-month duration and a 50-year return period.

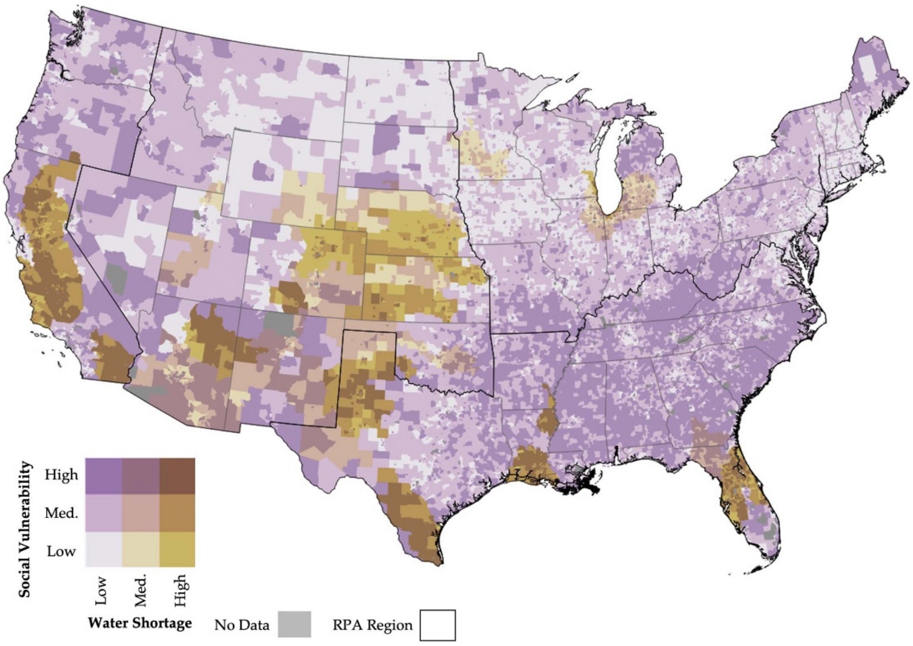

Figure 2. Current Water shortage and SVI categories.
Notes: figure overlays high, medium, and low categories of water shortage with high, medium, and low categories of SVI scores. Maps overlaying categories of water shortage and individual SVI themes are depicted in figure A4.

exposure to high levels of water shortage (⩾90th percentile), which extend across Native American reservations in Arizona, Colorado, and New Mexico.

4.3. High-shortage, high-vulnerability hotspots

Next, we use the Gi* Statistic to identify areas of extreme water shortage and social vulnerability (See table A17 for summary statistics). Figure 4 maps high-shortage, high-SVI hotspots. While we continue to reference RPA regions as we present our results, note that hotspots with a Gi* statistic of $p < .1$ are located in 13 states (table A15). Four states—California, Texas, Florida, and Illinois—account for nearly 80 percent of the high-shortage, high-SVI hotspot population (figure A7). See figures A8 thru A13 for region-specific hotspot maps.

Water use differs significantly between hotspots and non-hotspots (table A16). Hotspots use larger shares of water supplies for irrigation and have larger

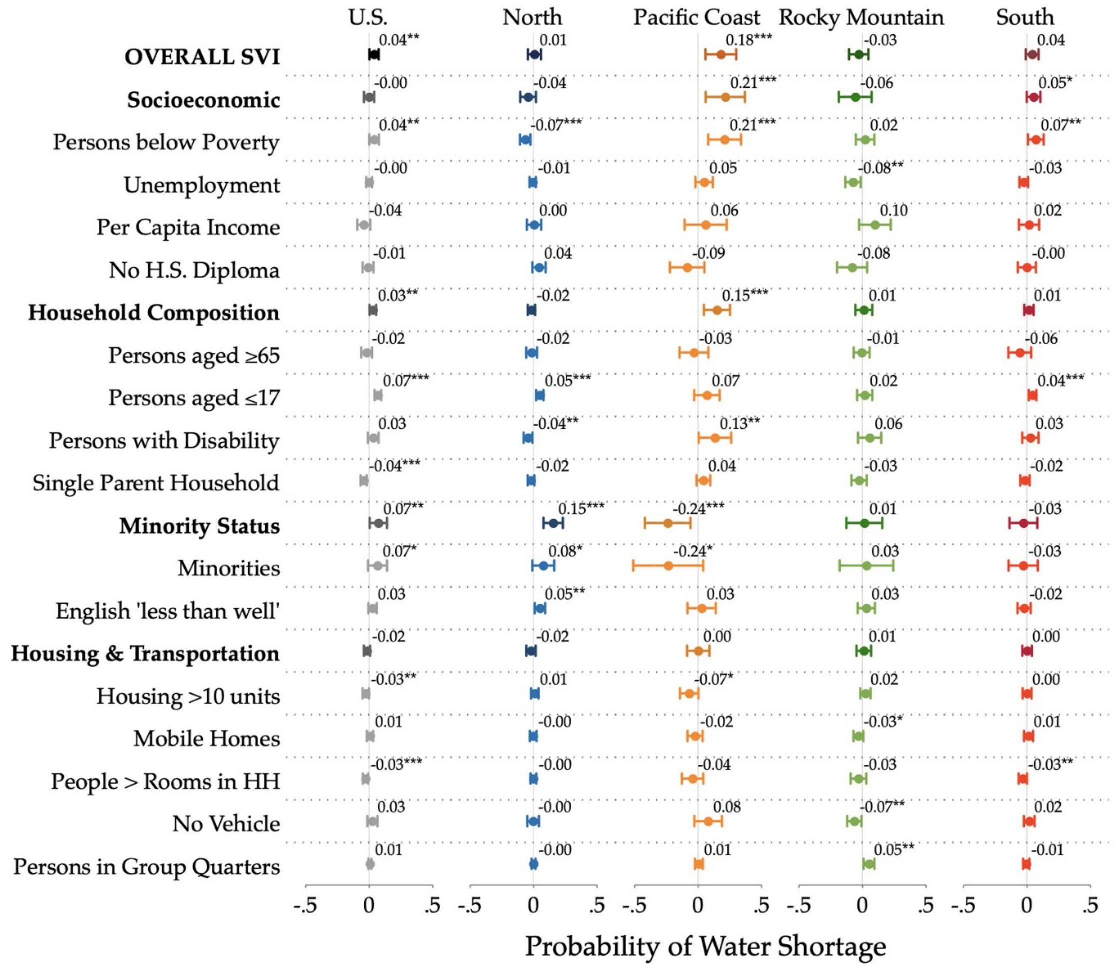

Figure 3. Coefficient plot estimates of probability of exposure to water shortage.
Notes: figure depicts coefficients on the relationship between the probability of census tract, *i*, experiencing water shortage as a function of social vulnerability from three separate MLRs. Coefficients on overall SVI are from table A8. Coefficients on SVI themes (in bold font) are from MLRs in table A11 and coefficients on the 15 U.S. Census variables (non-boldface font) used to construct SVI are from table A14. Lines depict 95% confidence intervals. Coefficient values and stars depicting statistical significance (***$p < .01$, **$p < .05$, *$p < .1$) are shown at the top right of each marker. All models include state FE and controls for agricultural land use and population density at the tract level, and county-level GDP. All VIF values are < 10. Robustness checks are presented in tables A6 through A13. The unit of measurement for all independent variables is percentile rank.

shares of agricultural land use, while non-hotspots use larger portions of water for domestic and commercial water use. Moreover, hotspots overlie aquifers with some of the highest abstraction rates [99]. Where surface water scarcity is offset by nonrenewable groundwater use, vulnerable communities may face long-term shortage risks as aquifers are depleted.

Spatially heterogeneous water use patterns within hotspots and across regions suggest a need for context-specific adaptation strategies. Adaptation strageties in Rocky Mountain region hotspots (in Kansas, Nebraska, and Native American reservations in Arizona, Colorado, and New Mexico), where water use is primarily agricultural, will likely differ from those along the Great Lakes, where water is primarily domestic and industrial. Likewise, the marginal costs and benefits of adaptation through, for example, demand management versus supply augmentation will likely differ by region.

4.4. Drivers of social vulnerability in hotspots

Here, we examine potential water shortage inequities *within* hotspots. Figure 5 plots the coefficients from two separate MLRs: (a) coefficients on SVI themes are from regressions estimated in table A20 and (b) coefficients on census variables are from regressions estimated in table A23.

Within hotspots across the U.S., socioeconomically vulnerable populations are disproportionately exposed to the worst shortages. The relationship is driven by high poverty rates in California (table A23). The Pacific Coast's large minority population even outside of water-short areas likely explains the negative correlation between the occurrence of water shortage and minority status in the region across the full sample of census tracts (figure 3). However, minorities are disproportionately exposed to the worst shortages *within* hotspots in California. Results corroborate literature documenting the inequitable exposure

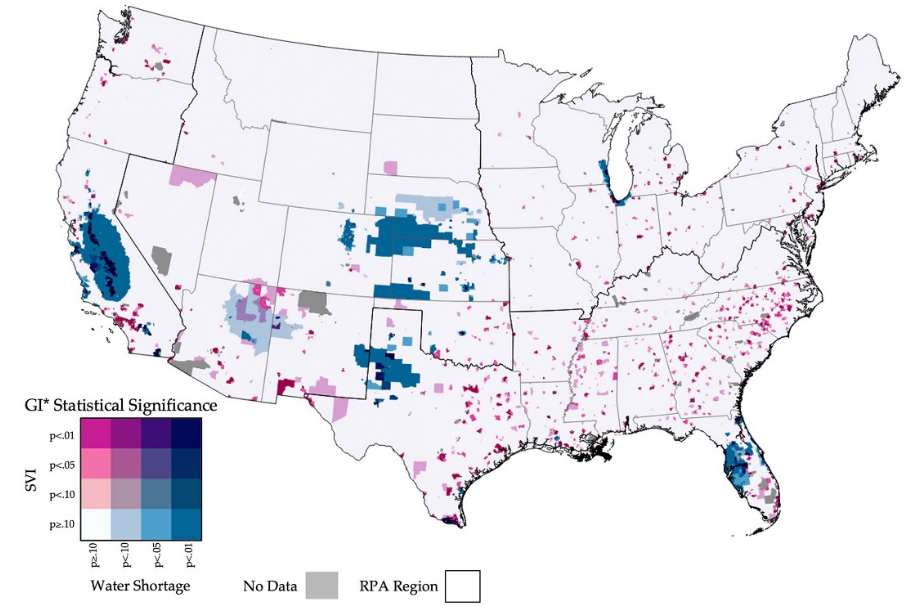

Figure 4. High-Shortage, High-Vulnerability Hotspots.
Notes: This figure overlays water shortage and SVI hotspots with Gi* statistics of $p < .1$, $p < .05$, and $p < .01$. The darkest blue areas are census tracts facing the most severe drought ($p < .01$); the darkest pink have the highest SVI scores ($p < .01$), and the darkest purple have Gi* statistics exceeding $p < .01$ for both shortage and SVI. While the water shortage hotspots, such as those across the Great Plains in Kansas and Nebraska, and in Northern Texas, Florida, and California, are relatively expansive, high-SVI hotspots tend to be concentrated in population centers. As such, the co-occurrence of high-shortage, high-SVI hotspots appear relatively small, but impact relatively large populations. Figures A8 through A13 provide relatively detailed maps of hotspots within RPA regions.

of California's migrant farm workers and minority populations to drought [100–102].

The severity of water shortage is increasing with social vulnerability stemming from poverty, household youth, and persons in group quarters in the North, where hotspots are located in major cities along Lake Michigan (figure A11). Surface water shortage risks in these areas have been attributed to population growth, groundwater depletion, and laws limiting freshwater withdrawals from Lake Michigan [98]. Low-income, single-parent households, and persons in group quarters are disproportionately exposed to worse shortages within Rocky Mountain region hotspots (figures A8 and A13). Exposure to shortage is increasing with limited educational attainment and population in group quarters in Southern hotspots in Texas and Florida (figures A10 and A13)[11].

5. Discussion

We estimate that 14 869 749 people – 5 percent of the CONUS population—live in high-shortage, high-SVI hotspots. This figure will likely increase as climate change and population growth exacerbate shortages [2, 3]. Without interventions, the negative impacts of shortages on these populations will likely worsen. We demonstrate that water shortage constitutes an environmental injustice, with multiple dimensions of social vulnerability being inequitably exposed to water shortages across the U.S. However, the types of vulnerability that are correlated with water shortage exposure vary substantially across the U.S. and within hotspots.

Our results highlight the diversity of water shortage risks across the U.S. For instance, risk in hotspots along the Great Lakes is characterized by high surface water demand in densely populated cities and social vulnerability stemming from poverty and household youth. The poorest communities are already paying disproportionately higher drinking water rates [104, 105] while costs of proposed infrastructure to import water from Lake Michigan are expected to exacerbate inequities [106]. Thus, risk mitigation efforts may consider a drinking water affordability program [107].

Conversely, high-risk and hotspot areas in California, Texas, and across the Plains are concentrated in agricultural hubs, underscoring concurrent water shortage risks associated with agricultural water use and vulnerability in agricultural communities. The scope and severity of water shortage in these areas have prompted state and federal interventions aimed at reducing risk via reductions to agricultural water use. For example, a 2022 Bureau of Reclamation

[11] While we can only hypothesize, the positive and significant correlation between group quarters and water shortage across hotspots in three of the four RPA regions may be related to the limited influence that people in institutionalized and non-institutionalized group quarters have over environmental decisions, and limited social and economic capital that leave them vulnerable to environmental hazards [103].

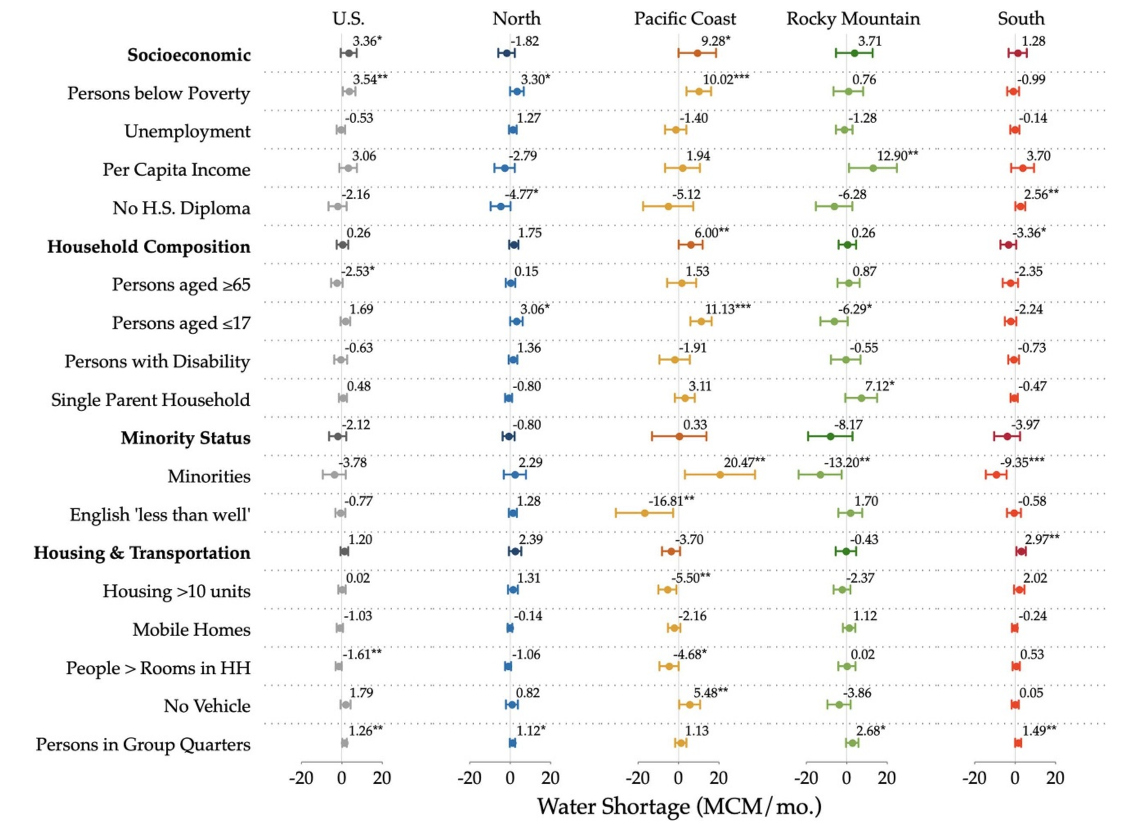

Figure 5. Coefficient plot estimates of social vulnerability exposure to water shortage in high-shortage, high-SVI hotspots (Gi* $p < .10$).
Notes: figure depicts coefficients on the relationship between water shortage and SVI in hotspot areas ($p < .1$) from two separate MLRs. Coefficients on SVI themes (in bold font) are from MLRs in table A20 and coefficients on the 15 U.S. Census variables (non-boldface font) used to construct SVI are from table A23. Lines depict 95% confidence intervals. Coefficient values and stars depicting statistical significance ($^{***}p < .01$, $^{**}p < .05$, $^{*}p < .1$) are shown at the top right of each marker. All models include state FE and controls for agricultural land use and population density at the tract level, and county-level GDP. All VIF values are < 10. We include robustness checks that phase out census tract and county-level controls in tables A18 and A19 which regress shortage on SVI themes, and tables A21 and A22 which regress shortage on SVI variables. The unit of measurement for all independent variables is percentile rank.

program aims to reduce shortage risk in the Colorado River Basin by paying farmers to reduce agricultural water use [108]. While it is beyond the scope of this study to explain the nuances of relatively localized water shortage risks, our results indicate that such broad conservation efforts may be made more equitable if they consider their potential impacts on the diverse types of vulnerable groups within their target areas. For instance, where reducing agricultural water use translates to job losses and economic hardship in rural communities [109], then interventions may also consider strategies that identify and insulate those most at risk of harm.

One limitation of this study is that our measure of water shortage omits groundwater. Groundwater is a strategic reserve during drought, but its inadequate management and overuse [110–113] inequitably harm vulnerable communities [38, 114]. That hotspots are located almost exclusively in areas with high groundwater extraction rates highlights the need to integrate groundwater into future risk assessments. Further, our measure of water shortage does not consider the distribution of water rights within basins. Because water rights shape adaptive capacity to water shortages [64], future research may consider the relationship between water rights and shortage risk.

By showing the heterogeneity of water shortage risks across multiple dimensions of social vulnerability, our results caution against relying exclusively on collated social vulnerability indices to identify environmental injustices. While the relationship between overall SVI and water shortage exposure across the U.S. is largely due to the situation in California, deconstructiong SVI reveals other correlates between vulnerability and shortage within regions. Heterogeneity across regions and within hotspots likely reflects institutional path dependencies that shape water use decisions and perpetuate inequities. Thus, meaningful policy design, and an area for future research, may require examining *why* various dimensions of vulnerability are correlated with shortage risks in different contexts.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Appendix

Table A1. Social vulnerability index themes and indicator definitions.

Theme	Variable	Definition
Socioeconomic Status	Poverty (%)	Percent of persons in a census tract below the federally defined poverty line (a threshold that varies by the size and age composition of a household). The denominator is the total population of the census tract.
	Unemployed (%)	Percent of civilians (age $\geqslant$ 16) unemployed divided by the total civilian population. Unemployed persons are those actively seeking work.
	Per capita income ($)	Mean income calculated for every person in a census tract.
	No HS Diploma (%)	Percent of persons (age $\geqslant$ 25) with less than a 12th grade education (including individuals with 12 grades but no diploma).
Household composition & disability	Age $\geqslant$ 65 (%)	Percent of population aged 65 or older.
	Age $\leqslant$ 17 (%)	Percent of persons aged 17 or younger.
	Disability (%)	Percent of non-institutionalized, civilian population (age $\geqslant$ 5) with a disability.
	Single-Parent HH	Percent of households with no spouse present and with children under the age of 18.
Minority status & language	Minority Status	Percent minority (all persons except white, non-Hispanic) population
	Limited english	Percent of persons (age $\geqslant$ 5) who speaks English 'less than well'.
Housing type & transportation	Multi-Unit Housing (%)	Percent of housing units with $\geqslant$ 10 units in structure.
	Mobile home %)	Percent of housing units that are mobile homes.
	Crowding	Percent of households with more people than rooms.
	No vehicle	Percent of households with no vehicle available.
	Group quarters	Percent of persons in institutionalized group quarters (e.g., correctional institutions, nursing homes) and non-institutionalized group quarters (e.g., college dormitories, military quarters).

Notes: Definitions of SVI themes and individual variables provided in this table are provided by CDC/ATSDR [84]. SVI variables have been validated for convergence, robustness, and construct [115]. Convergence validation assesses agreement between SVI and other models using the same construct. Robustness validation evaluates a model's statistical and analytical soundness. Construct validation evaluates whether the SVI measures what it intends to measure. (Return to section 3.2).

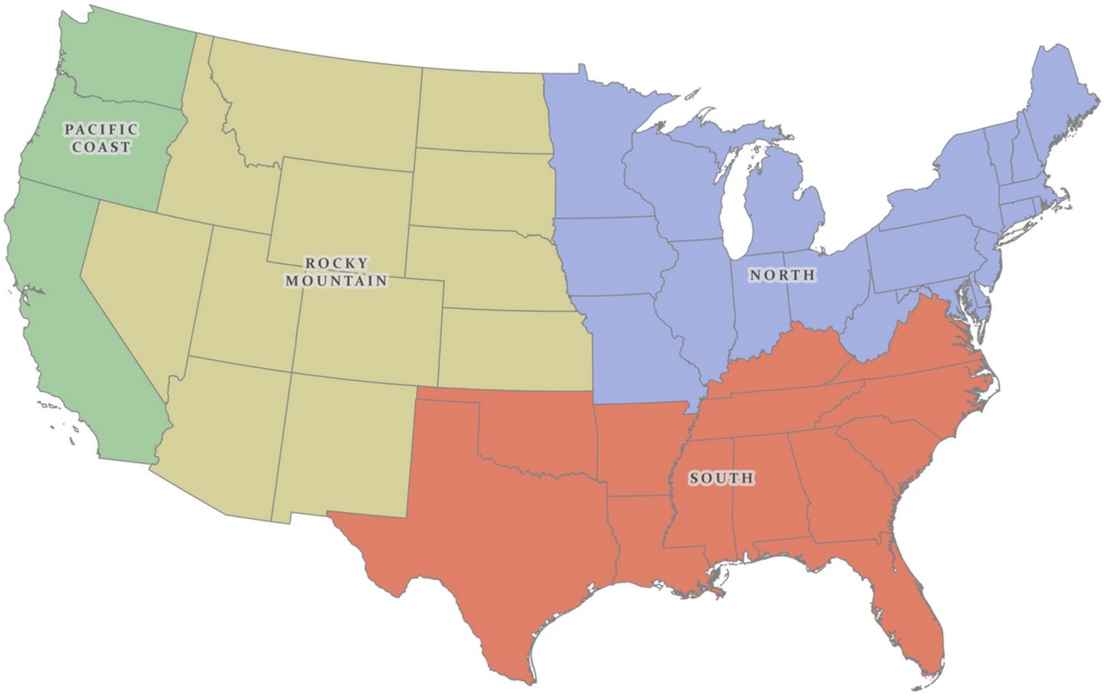

Figure A1. RPA regions.
Notes: This figure depicts four Resources Planning Act Assessment (RPA) regions, as defined by the U.S. Forest Service. Regions are divided across state boundaries into four distinct climate zones, which are useful for assessing differences in social vulnerability as it pertains to patterns of water use, supply, and demand. Return to section 3.3.

Table A2. Summary statistics.

	U.S.		North		Pacific		Rocky Mt.		South	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Current Water Shortage (MCM/mo.)	1.177	4.310	0.438	2.268	2.730	7.893	2.412	4.170	1.097	3.897
Overall SVI	0.501	0.289	0.452	0.283	0.559	0.286	0.463	0.294	0.549	0.283
Socioeconomic Rank	0.502	0.289	0.462	0.286	0.508	0.292	0.456	0.280	0.563	0.282
Below Poverty (%)	0.500	0.289	0.464	0.295	0.484	0.275	0.477	0.280	0.558	0.281
Unemployed (%)	0.496	0.290	0.483	0.291	0.545	0.268	0.424	0.292	0.513	0.291
Income ($)	0.501	0.288	0.465	0.278	0.456	0.311	0.508	0.270	0.565	0.284
No HS Diploma (%)	0.500	0.289	0.454	0.271	0.536	0.319	0.433	0.288	0.564	0.283
HH Composition	0.502	0.289	0.490	0.289	0.419	0.271	0.494	0.273	0.555	0.290
Pop. Age ⩾ 65 (%)	0.498	0.287	0.528	0.273	0.437	0.292	0.474	0.311	0.492	0.291
Pop. Age ⩽ 17 (%)	0.501	0.287	0.470	0.271	0.505	0.298	0.559	0.308	0.522	0.292
Pop. Age ⩾ 5 with Disability (%)	0.498	0.289	0.492	0.283	0.402	0.266	0.474	0.278	0.554	0.297
Single-Parent HH (%)	0.500	0.288	0.486	0.290	0.488	0.294	0.480	0.281	0.529	0.284
Minority Status	0.499	0.289	0.422	0.288	0.697	0.243	0.476	0.272	0.520	0.269
Minority (%)	0.498	0.289	0.411	0.301	0.657	0.227	0.463	0.252	0.551	0.264
English 'Less than Well' (%)	0.479	0.313	0.421	0.306	0.692	0.256	0.471	0.294	0.464	0.312
Housing & Transportation	0.500	0.288	0.478	0.283	0.577	0.285	0.480	0.303	0.500	0.287
Multi-Unit Structures (%)	0.477	0.319	0.489	0.310	0.544	0.312	0.452	0.319	0.438	0.327
Mobile Homes (%)	0.411	0.373	0.314	0.349	0.361	0.362	0.475	0.366	0.538	0.369
Crowding (%)	0.480	0.311	0.407	0.300	0.678	0.290	0.489	0.304	0.485	0.297
No Vehicle (%)	0.497	0.291	0.556	0.297	0.462	0.275	0.399	0.274	0.463	0.278
Group Quarters (%)	0.419	0.360	0.453	0.354	0.461	0.325	0.400	0.368	0.363	0.373
Agriculture (%)	12.062	20.983	13.939	23.441	5.718	16.047	12.843	23.273	12.152	18.079
Pop. Density (pp./mi2)	5410	11 935	7419	16 678	7590	9088	3008	3315	2585	3870
County GDP (adj. $2012)	76 479 895	140 300 000	55 114 291	92 247 777	230 200 000	258 100 000	51 608 540	73 216 769	45 013 396	78 316 316
Observations	71 196		30 454		10 193		6909		23 643	

(Return to section 4.1).

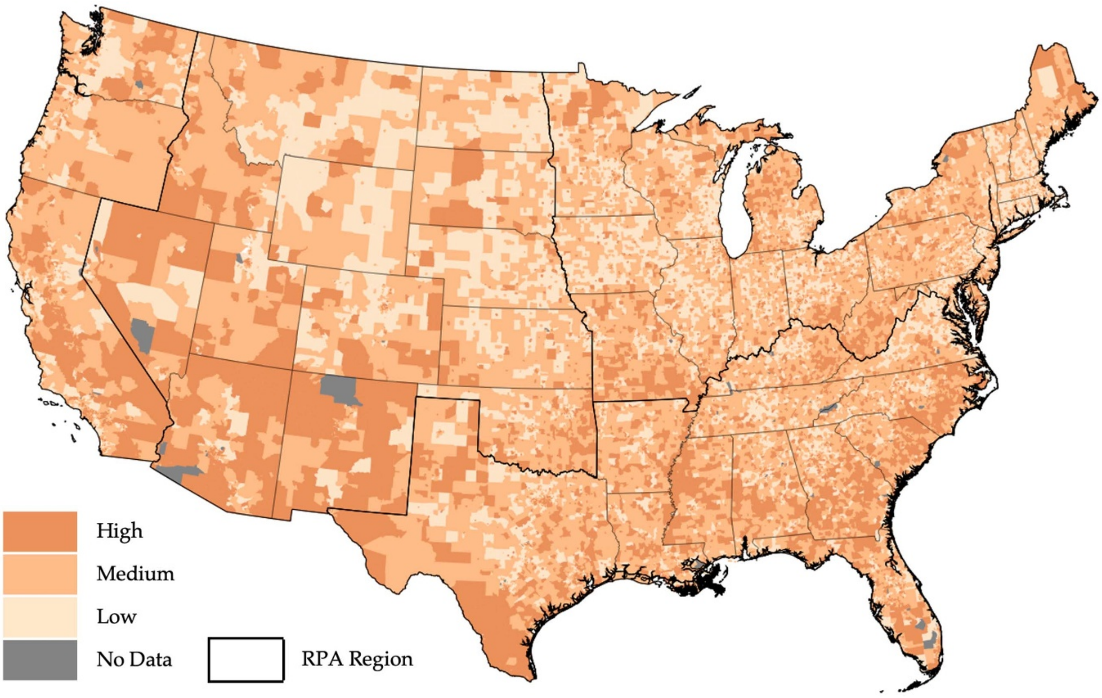

Figure A2. Social vulnerability index categories.
Notes: figure depicts high, medium, and low categories of SVI. Return to section 4.1.

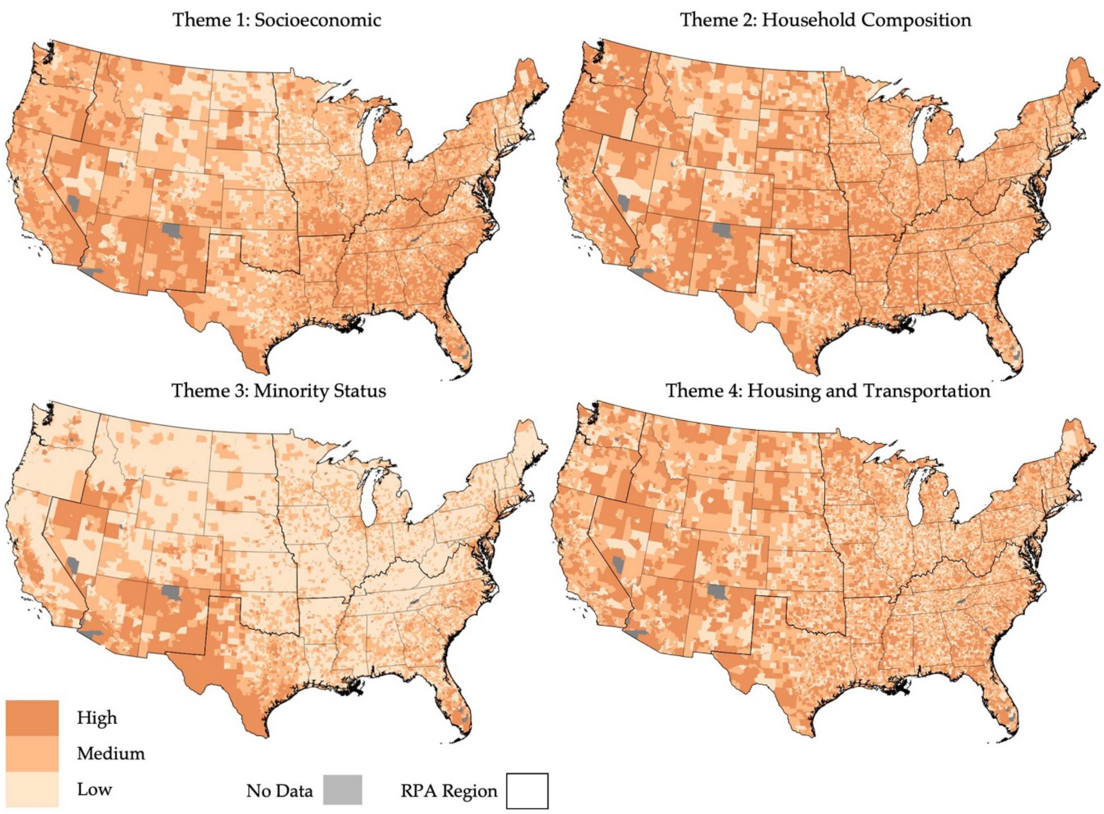

Figure A3. Socioeconomic vulnerability index theme categories.
Notes: figure depicts high, medium, and low categories of SVI Themes. Return to section 4.1.

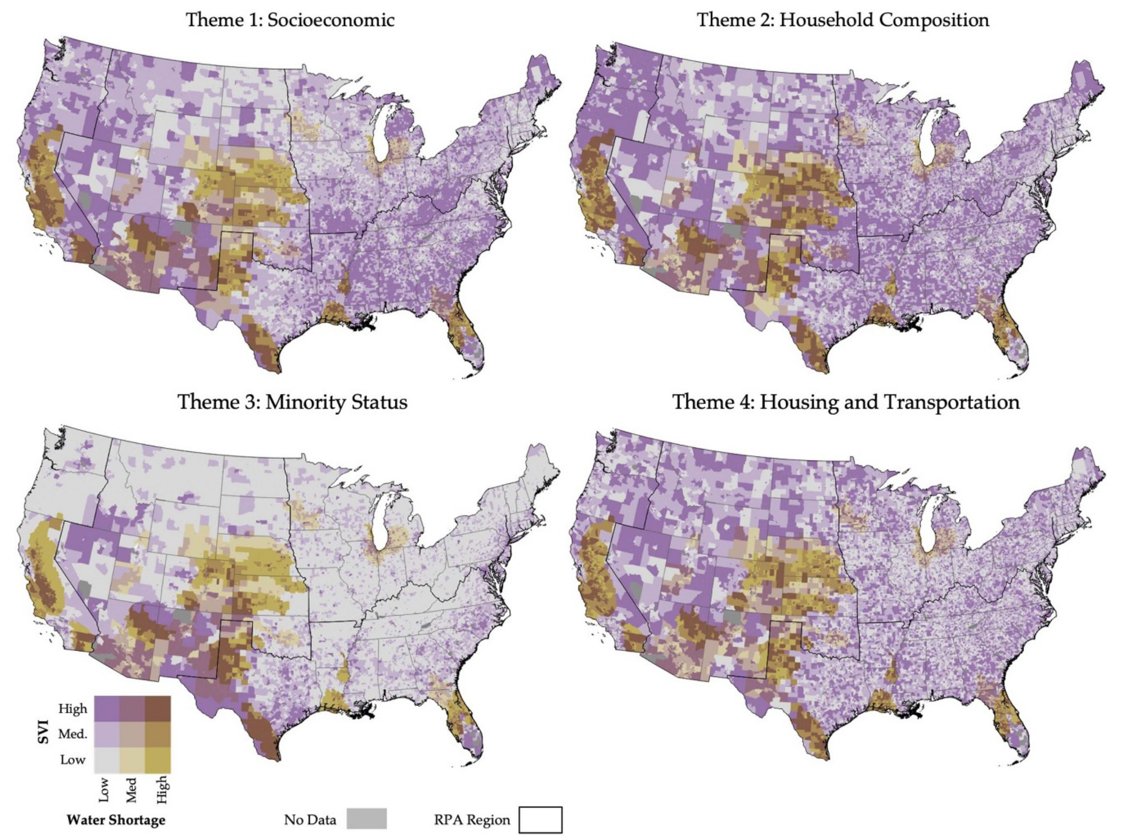

Figure A4. Current water shortage and SVI theme categories.
Notes: figure depicts high, medium, and low categories of SVI Themes overlaid with high, medium, and low categories of water scarcity. Return to section 4.1.

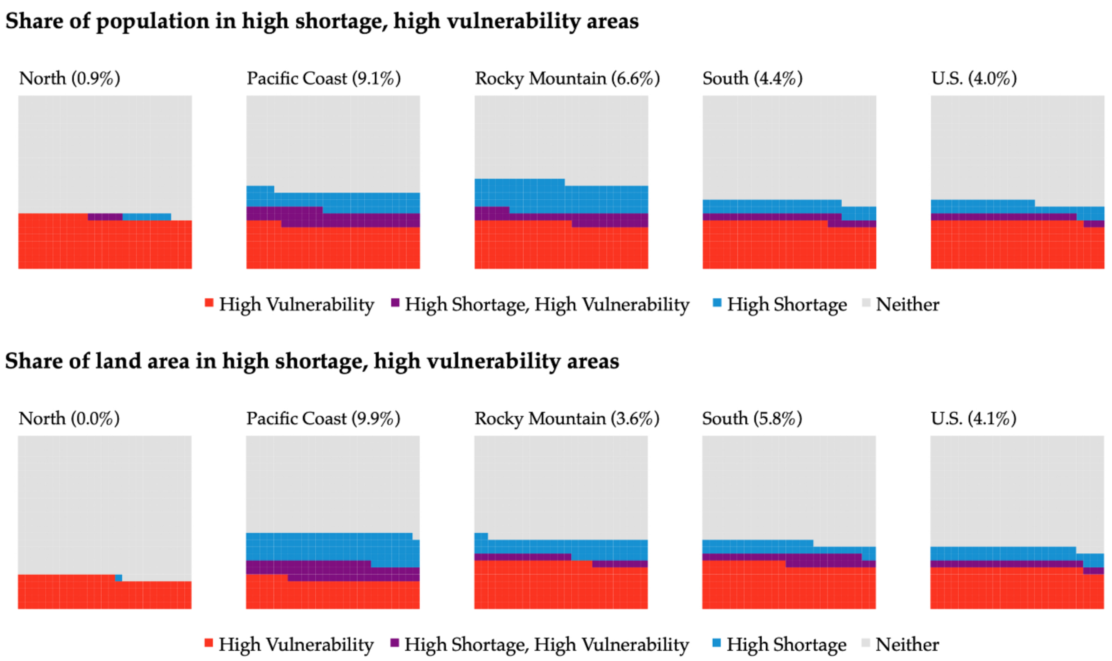

Figure A5. Share of population and land area in high shortage, high vulnerability areas.
Notes: figure depicts the prevalence of high social vulnerability and high shortage, by RPA region. Panel a (b) depicts the share of each region's population (land area) that falls into the category of high water shortage (blue squares), high social vulnerability (red squares), or both high shortage and high vulnerability (purple squares). Each square represents .25 percent of a region's population (land area). Figures in parentheses adjacent to the region names are the percentages of each region's population (land area) that fall into a high shortage, high vulnerability category. Summary statistics used to construct this figure are depicted in tables A3 and A4. Return to section 4.1.

Table A3. Prevalence of water shortage, by category.

		Low shortage		Medium shortage		High shortage	
RPA region	Variables	Total	%	Total	%	Total	%
North	Tracts (n)	26 706	87.69	3035	9.97	713	2.34
	Population	109 804 846	87.46	13 099 009	10.43	2 647 265	2.11
	Sq. Miles	602 026	93.67	38 609	6.01	2064	0.32
Pacific Coast	Tracts (n)	8220	80.64	0	0	1973	19.36
	Population	40 176 343	80.02	0	0	10 034 316	19.98
	Sq. Miles	231 460	73.03	0	0	85 465	26.97
Rocky Mountain	Tracts (n)	3,066	44.4	2145	31.06	1695	24.54
	Population	13 489 332	44.73	9 473 193	31.41	7 196 685	23.86
	Sq. Miles	745 901	65.19	240 159	20.99	158 117	13.82
South	Tracts (n)	20 169	85.31	606	2.56	2868	12.13
	Population	96 269 354	85.53	2 270 627	2.02	14 019 450	12.46
	Sq. Miles	655 591	79.36	66 058	8	104 473	12.65
U.S. Total	Tracts (n)	58 161	81.69	5786	8.13	7249	10.18
	Population	259 739 875	81.56	24 842 829	7.8	33 897 716	10.64
	Sq. Miles	2 234 979	76.28	344 825	11.77	350 120	11.95

Return to figure A5.

Table A4. Prevalence of social vulnerability index score, by category.

		Low SVI		Medium SVI		High SVI	
RPA Region	Variables	Total	%	Total	%	Total	%
North	Tracts (n)	12 093	39.71	10 242	33.63	8119	26.66
	Population	52 972 053	42.19	42 288 032	33.68	30 291 035	24.13
	Sq. Miles	271 033	42.17	306 979	47.76	64 688	10.07
Pacific Coast	Tracts (n)	2745	26.93	3272	32.1	4176	40.97
	Population	12 964 226	25.82	16 264,195	32.39	20 982 238	41.79
	Sq. Miles	41 156	12.99	152 237	48.04	123 532	38.98
Rocky Mountain	Tracts (n)	2683	38.85	2236	32.38	1987	28.77
	Population	11 865 802	39.34	9 794 757	32.48	8 498 651	28.18
	Sq. Miles	398 419	34.82	444 751	38.87	301 006	26.31
South	Tracts (n)	6216	26.29	7977	33.74	9,450	39.97
	Population	31 270 484	27.78	38 657 287	34.34	42 631 660	37.87
	Sq. Miles	106 974	12.95	365 060	44.19	354 089	42.86
U.S. Total	Tracts (n)	23 737	33.34	23 727	33.33	23 732	33.33
	Population	109 072 565	34.25	107 004 271	33.6	102 403 584	32.15
	Sq. Miles	817 582	27.9	1 269 027	43.31	843 315	28.78

Return to figure A5.

Table A5. Difference in mean water shortage volume, by SVI category.

	Water Shortage (MCM/mo.)			Low SVI—Med SVI		Med SVI—High SVI	
RPA Region	Low SVI	Med SVI	High SVI	Diff.	t-stat.	Diff.	t-stat.
North	0.373	0.346	0.651	0.027	1.00	-0.305^{***}	−8.56
Pacific Coast	1.291	1.967	4.274	-0.675^{***}	4.69	-2.307^{***}	−11.52
Rocky Mountain	2.598	2.302	2.287	0.296^{**}	2.68	0.015^{**}	0.10
South	0.955	1.121	1.171	-0.166^{**}	2.67	−0.049	−0.80
U.S. Total	0.883	1.014	1.632	-0.118^{**}	3.23	−0.443	(−8.73)

Return to figure A5.

Table A6. MLR estimates probability of exposure to water shortage, as a function of SVI score.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
SVI	0.0392**	0.0131	0.153	−0.0405	0.0461
	(0.0195)	(0.0262)	(0.0941)	(0.0390)	(0.0316)
Constant	0.163***	0.117***	0.108**	0.575***	0.122***
	(0.0135)	(0.0156)	(0.0503)	(0.0286)	(0.0226)
Observations	71 196	30 454	10 193	6906	23 643
R-Squared	0.411	0.396	0.080	0.593	0.286
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR estimates are from model specified in equation (1) and include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A7. MLR estimates probability of exposure to water shortage, as a function of SVI score; census tract controls.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
SVI	0.0475***	−0.0202	0.184**	−0.0567	0.0489*
	(0.0183)	(0.0211)	(0.0722)	(0.0443)	(0.0265)
Agriculture (%)	0.0003 96	−0.001 67***	0.006 30***	0.001 10	0.0009 77*
	(0.0004 40)	(0.0006 42)	(0.001 20)	(0.0009 81)	(0.0005 35)
Pop. Density (pp./mi2)	-9.35×10^{-07}	6.40×10^{-07}*	-1.07×10^{-05}***	9.24×10^{-06}**	-1.28×10^{-05}***
	(6.18×10^{-07})	(3.83×10^{-07})	(2.90×10^{-06})	(4.01×10^{-06})	(4.71×10^{-06})
Constant	0.160***	0.151***	0.136**	0.540***	0.141***
	(0.0167)	(0.0243)	(0.0603)	(0.0364)	(0.0284)
Observations	71 195	30 453	10 193	6,906	23 643
R-squared	0.412	0.409	0.228	0.596	0.308
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR estimates are from model specified in equation (1) and include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A8. MLR estimates probability of exposure to water shortage, as a function of SVI score; census tract and county-level controls.

	$Y = \Pr(\text{Water shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
SVI	0.0384**	0.006 25	0.179***	−0.0307	0.0401
	(0.0185)	(0.0261)	(0.0613)	(0.0388)	(0.0256)
Agriculture (%)	-2.62×10^{-05}	−0.0008 40	0.004 77***	0.001 07	0.0005 19
	(0.0004 05)	(0.0005 64)	(0.0009 17)	(0.0009 92)	(0.0005 44)
Pop. Density (pp./mi2)	4.97×10^{-07}	-1.45×10^{-06}*	-4.67×10^{-06}**	4.51×10^{-06}	-8.09×10^{-06}*
	(5.67×10^{-07})	(7.53×10^{-07})	(1.92×10^{-06})	(3.82×10^{-06})	(4.19×10^{-06})
County GDP (adj. $2012)	-4.40×10^{-10}**	8.75×10^{-10}**	-6.55×10^{-10}***	6.49×10^{-10}	-7.56×10^{-10}***
	(1.72×10^{-10})	(3.97×10^{-10})	(1.40×10^{-10})	(4.84×10^{-10})	(2.78×10^{-10})
Constant	0.195***	0.0945***	0.253***	0.509***	0.174***
	(0.0194)	(0.0301)	(0.0698)	(0.0425)	(0.0315)
Observations	71 195	30 453	10 193	6906	23 643
R-squared	0.427	0.443	0.364	0.600	0.326
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR estimates are from model specified in equation (1) and include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A9. MLR estimates of the probability of exposure to water shortage as a function of SVI theme score.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	0.00516	-0.0803^{***}	0.205^{**}	-0.0784	0.0601^{**}
	(0.0222)	(0.0252)	(0.0853)	(0.0680)	(0.0282)
Household composition	0.0605^{***}	-0.0363^{**}	0.365^{***}	-0.0128	0.0762^{***}
	(0.0198)	(0.0157)	(0.0691)	(0.0382)	(0.0263)
Minority status/language	0.0206	0.225^{***}	-0.449^{***}	0.0588	-0.137^{*}
	(0.0403)	(0.0488)	(0.102)	(0.0827)	(0.0740)
Housing type & transportation	-0.0169	-0.0237	-0.0394	0.005 03	0.005 53
	(0.0124)	(0.0174)	(0.0465)	(0.0286)	(0.0191)
Constant	0.148^{***}	0.0942^{***}	0.272^{***}	0.568^{***}	0.139^{***}
	(0.0151)	(0.0143)	(0.0674)	(0.0317)	(0.0304)
Observations	71 196	30 454	10 193	6906	23 643
R-squared	0.412	0.422	0.190	0.594	0.298
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1\text{Theme1}_i + \beta_2\text{Theme2}_i + \beta_3\text{Theme3}_i + \beta_4\text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, Theme3_i is minority status, and Theme4_i is housing and transportation vulnerability. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A10. MLR estimates of the probability of exposure to water shortage as a function of SVI Theme Score; Census Tract Controls.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	0.00664	-0.0832^{***}	0.207^{***}	-0.0864	0.0547^{**}
	(0.0218)	(0.0250)	(0.0673)	(0.0691)	(0.0276)
Household composition	0.0518^{***}	-0.0311^{**}	0.238^{***}	$-0.002\,12$	0.0371^{*}
	(0.0168)	(0.0140)	(0.0588)	(0.0344)	(0.0207)
Minority status/language	0.0403	0.195^{***}	-0.393^{***}	0.0339	-0.0703
	(0.0362)	(0.0335)	(0.0954)	(0.0731)	(0.0611)
Housing type & transportation	-0.0138	-0.0179	0.0353	0.003 15	0.0122
	(0.0120)	(0.0160)	(0.0406)	(0.0287)	(0.0189)
Agriculture (%)	0.0004 24	$-0.0009\,45^{*}$	$0.006\,17^{***}$	0.001 12	0.0008 16
	(0.0004 11)	(0.0005 44)	(0.001 08)	(0.0009 75)	(0.0005 69)
Pop. density (pp./mi2)	-8.46×10^{-07}	-1.36×10^{-07}	$-7.09 \times 10^{-06***}$	$8.95 \times 10^{-06**}$	$-1.08 \times 10^{-05***}$
	(5.27×10^{-07})	(2.57×10^{-07})	(1.93×10^{-06})	(3.59×10^{-06})	(4.02×10^{-06})
Constant	0.140^{***}	0.117^{***}	0.261^{***}	0.538^{***}	0.144^{***}
	(0.0185)	(0.0209)	(0.0670)	(0.0397)	(0.0367)
Observations	71 195	30 453	10 193	6906	23 643
R-squared	0.413	0.425	0.284	0.597	0.311
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1\text{Theme1}_i + \beta_2\text{Theme2}_i + \beta_3\text{Theme3}_i + \beta_4\text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, Theme3_i is minority status, and Theme4_i is housing and transportation vulnerability. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A11. MLR estimates of the probability of exposure to water shortage as a function of SVI theme score; census tract and county-level controls.

	$Y = \Pr(\text{Water shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	−0.0009 47	−0.0437	0.214***	−0.0579	0.0512*
	(0.0205)	(0.0315)	(0.0782)	(0.0657)	(0.0273)
Household	0.0287**	−0.0177	0.148***	0.00974	0.0148
composition	(0.0133)	(0.0146)	(0.0519)	(0.0338)	(0.0187)
Minority	0.0722**	0.154***	−0.239***	0.0138	−0.0286
status/language	(0.0348)	(0.0387)	(0.0907)	(0.0719)	(0.0559)
Housing type &	−0.0172	−0.0208	0.0009 03	0.009 55	0.0004 06
transportation	(0.0124)	(0.0186)	(0.0445)	(0.0293)	(0.0193)
Agriculture (%)	0.0001 07	−0.0003 48	0.004 78***	0.001 07	0.0004 57
	(0.0003 91)	(0.0004 44)	(0.0009 08)	(0.0009 85)	(0.0005 70)
Pop. density	3.91×10^{-07}	$-1.83 \times 10^{-06**}$	$-2.97 \times 10^{-06**}$	4.69×10^{-06}	$-7.40 \times 10^{-06*}$
(pp./mi2)	(5.93×10^{-07})	(7.26×10^{-07})	(1.29×10^{-06})	(3.57×10^{-06})	(3.78×10^{-06})
County GDP	$-4.52 \times 10^{-10***}$	$7.94 \times 10^{-10**}$	$-5.92 \times 10^{-10***}$	6.39×10^{-10}	$-7.30 \times 10^{-10***}$
(adj. $2012)	(1.70×10^{-10})	(3.87×10^{-10})	(1.33×10^{-10})	(4.86×10^{-10})	(2.69×10^{-10})
Constant	0.173***	0.0717***	0.320***	0.506***	0.171***
	(0.0208)	(0.0264)	(0.0706)	(0.0451)	(0.0380)
Observations	71 195	30 453	10 193	6906	23 643
R-squared	0.428	0.452	0.387	0.600	0.327
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1 \text{Theme1}_i + \beta_2 \text{Theme2}_i + \beta_3 \text{Theme3}_i + \beta_4 \text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, Theme3_i is minority status, and Theme4_i is housing and transportation vulnerability. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A12. MLR estimates of the probability of exposure to water shortage as a function of SVI variable scores.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below Poverty	0.0488**	−0.0686***	0.254***	0.005 96	0.0777**
	(0.0205)	(0.0208)	(0.0751)	(0.0349)	(0.0342)
Unemployment	−0.002 53	0.00390	0.0557	−0.0888***	−0.0330*
	(0.0123)	(0.0138)	(0.0410)	(0.0339)	(0.0197)
Per capita income	−0.0271	−0.0645**	−0.0102	0.0822	0.0390
	(0.0284)	(0.0276)	(0.0687)	(0.0654)	(0.0409)
No H.S. diploma	−0.0332	0.0377	−0.102	−0.0468	−0.0394
	(0.0262)	(0.0264)	(0.0840)	(0.0574)	(0.0412)
Persons aged ⩾ 65	−0.0251	−0.0173	−0.104*	−0.0348	−0.0447
	(0.0228)	(0.0224)	(0.0619)	(0.0380)	(0.0466)
Persons aged ⩽ 17	0.0834***	0.0405***	0.230***	0.0247	0.0706***
	(0.0167)	(0.0135)	(0.0666)	(0.0305)	(0.0214)
Persons with disability	0.0656**	−0.0509**	0.295***	0.0346	0.0822*
	(0.0287)	(0.0225)	(0.0794)	(0.0464)	(0.0457)
Single parent household	−0.0359***	−0.0354**	0.0452	−0.0263	−0.0132
	(0.0125)	(0.0153)	(0.0291)	(0.0301)	(0.0192)
Minorities	0.0305	0.148***	−0.528***	−0.00308	−0.0700
	(0.0418)	(0.0549)	(0.133)	(0.117)	(0.0677)
English ‘less than well’	0.0266	0.0496**	0.0795	0.0390	−0.0390
	(0.0165)	(0.0204)	(0.0555)	(0.0343)	(0.0287)
Housing > 10 units	−0.0377***	0.00481	−0.144***	0.0338	−0.0299*
	(0.0115)	(0.0141)	(0.0381)	(0.0207)	(0.0173)
Mobile homes	0.0244*	−0.0234	0.0931***	−0.0506*	0.0614***
	(0.0128)	(0.0153)	(0.0336)	(0.0272)	(0.0202)
People > rooms in HH)	−0.0326***	−0.008 02	−0.0711	−0.0358	−0.0435**
	(0.0113)	(0.0126)	(0.0548)	(0.0321)	(0.0217)
No vehicle	0.0109	0.0255	−0.0127	−0.0545*	−0.00563
	(0.0215)	(0.0342)	(0.0500)	(0.0302)	(0.0201)
Persons in group quarters	0.0154*	−0.002 01	0.0630**	0.0482**	0.0165*
	(0.008 12)	(0.008 03)	(0.0248)	(0.0230)	(0.009 94)
Constant	0.130***	0.111***	0.250***	0.580***	0.122***
	(0.0225)	(0.0229)	(0.0876)	(0.0478)	(0.0470)
Observations	71 196	30 454	10 193	6,906	23 643
R-Squared	0.416	0.428	0.242	0.599	0.308
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2\gamma_i + \beta 3\delta_c + \xi_{\text{state}} + u_i$$

Where SVI Indicators is a vector of the 15 ACS indicators used to construct SVI. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI variables is percentile rank. Partitions in the table separate variables into SVI themes. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A13. MLR estimates of the probability of exposure to water shortage as a function of SVI variable scores; census tract controls.

	$Y = \Pr(\text{Water Shortage})$				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below poverty	0.0509**	−0.0722***	0.226***	0.0105	0.0803**
	(0.0211)	(0.0213)	(0.0683)	(0.0358)	(0.0337)
Unemployment	−0.001 63	−0.003 06	0.0389	−0.0801**	−0.0352*
	(0.0120)	(0.0128)	(0.0370)	(0.0315)	(0.0183)
Per capita income	−0.0298	−0.0588**	0.0327	0.0633	0.0435
	(0.0279)	(0.0258)	(0.0660)	(0.0644)	(0.0412)
No H.S. Diploma	−0.0350	0.0504*	−0.126	−0.0645	−0.0433
	(0.0270)	(0.0273)	(0.0785)	(0.0576)	(0.0402)
Persons aged $\geqslant 65$	−0.0278	−0.0135	−0.123**	−0.0224	−0.0596
	(0.0231)	(0.0227)	(0.0601)	(0.0371)	(0.0462)
Persons aged $\leqslant 17$	0.0786***	0.0475***	0.128**	0.0187	0.0451***
	(0.0149)	(0.0137)	(0.0521)	(0.0311)	(0.0157)
Persons with disability	0.0637**	−0.0577***	0.252***	0.0458	0.0613*
	(0.0279)	(0.0218)	(0.0720)	(0.0465)	(0.0362)
Single parent household	−0.0368***	−0.0389**	0.0590**	−0.0239	−0.0135
	(0.0127)	(0.0157)	(0.0283)	(0.0305)	(0.0187)
Minorities	0.0391	0.129***	−0.435***	0.0285	−0.0551
	(0.0391)	(0.0474)	(0.133)	(0.108)	(0.0618)
English 'less than well'	0.0287*	0.0444**	0.0363	0.0305	−0.0257
	(0.0169)	(0.0208)	(0.0554)	(0.0342)	(0.0270)
Housing > 10 units	−0.0346***	0.002 74	−0.0959***	0.0253	−0.0116
	(0.0118)	(0.0149)	(0.0305)	(0.0204)	(0.0175)
Mobile homes	0.0179	−0.006 73	0.0119	−0.0439**	0.0269
	(0.0123)	(0.0128)	(0.0364)	(0.0191)	(0.0180)
People > rooms in HH)	−0.0306***	−0.00122	−0.0455	−0.0363	−0.0339**
	(0.0108)	(0.0116)	(0.0485)	(0.0313)	(0.0170)
No Vehicle	0.0177	0.0243	0.0792*	−0.0645**	0.0175
	(0.0191)	(0.0314)	(0.0459)	(0.0289)	(0.0214)
Persons in group quarters	0.0126*	−0.0005 94	0.0458**	0.0525**	0.003 09
	(0.00728)	(0.007 31)	(0.0216)	(0.0223)	(0.0116)
Agriculture (%)	0.0003 12	−0.0009 71**	0.006 01***	0.00118	0.000728
	(0.0004 10)	(0.0004 84)	(0.0009 01)	(0.0009 31)	(0.0005 29)
Pop. density (pp/mi2)	-6.51×10^{-07}	-3.37×10^{-07}	$-6.92 \times 10^{-06***}$	$7.50 \times 10^{-06**}$	$-1.01 \times 10^{-05**}$
	(4.43×10^{-07})	(2.07×10^{-07})	(2.06×10^{-06})	(3.24×10^{-06})	(4.03×10^{-06})
Constant	0.128***	0.127***	0.274***	0.537***	0.156***
	(0.0243)	(0.0260)	(0.0913)	(0.0548)	(0.0554)
Observations	71 195	30 453	10 193	6906	23 643
R-Squared	0.416	0.431	0.314	0.601	0.316
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\Pr(\text{Shortage}_i) = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2 \gamma_i + \beta 3 \delta_c + \xi_{\text{state}} + u_i$$

Where SVI Indicators is a vector of the 15 ACS indicators used to construct SVI. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. Partitions in the table separate variables into SVI themes. The unit of measurement for SVI variables is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

Table A14. MLR estimates of the probability of exposure to water shortage as a function of SVI variable scores; census trace and county-level controls.

	Y = Pr(Water Shortage)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below poverty	0.0387**	−0.0666***	0.208***	0.0194	0.0690**
	(0.0193)	(0.0209)	(0.0653)	(0.0371)	(0.0314)
Unemployment	−0.000632	−0.00746	0.0475	−0.0757**	−0.0257
	(0.0117)	(0.0126)	(0.0346)	(0.0308)	(0.0173)
Per capita income	−0.0425	0.00313	0.0590	0.0970	0.0154
	(0.0261)	(0.0287)	(0.0837)	(0.0634)	(0.0405)
No H.S. diploma	−0.00885	0.0423	−0.0863	−0.0826	−0.00140
	(0.0218)	(0.0265)	(0.0686)	(0.0602)	(0.0364)
Persons aged $\geqslant$ 65	−0.0202	−0.0157	−0.0325	−0.00740	−0.0574
	(0.0217)	(0.0217)	(0.0573)	(0.0319)	(0.0456)
Persons aged $\leqslant$ 17	0.0687***	0.0484***	0.0690	0.0167	0.0434***
	(0.0131)	(0.0148)	(0.0507)	(0.0302)	(0.0152)
Persons with disability	0.0314	−0.0442**	0.132**	0.0554	0.0261
	(0.0213)	(0.0177)	(0.0647)	(0.0465)	(0.0326)
Single parent household	−0.0431***	−0.0208	0.0414	−0.0277	−0.0164
	(0.0125)	(0.0133)	(0.0272)	(0.0306)	(0.0187)
Minorities	0.0657*	0.0755*	−0.235*	0.0305	−0.0304
	(0.0381)	(0.0438)	(0.139)	(0.107)	(0.0586)
English 'less than well'	0.0266	0.0494**	0.0278	0.0294	−0.0232
	(0.0165)	(0.0209)	(0.0562)	(0.0346)	(0.0264)
Housing > 10 units	−0.0272**	0.00925	−0.0702*	0.0223	0.000128
	(0.0128)	(0.0147)	(0.0366)	(0.0207)	(0.0179)
Mobile Homes	0.00638	−0.00358	−0.0243	−0.0329*	0.0114
	(0.0127)	(0.0133)	(0.0299)	(0.0197)	(0.0181)
People > rooms in HH)	−0.0287***	−0.00156	−0.0436	−0.0324	−0.0336**
	(0.0106)	(0.0115)	(0.0426)	(0.0313)	(0.0166)
No Vehicle	0.0253	−0.00415	0.0788	−0.0651**	0.0171
	(0.0202)	(0.0233)	(0.0549)	(0.0287)	(0.0213)
Persons in group quarters	0.00615	−0.000554	0.00600	0.0505**	−0.00638
	(0.00594)	(0.00800)	(0.0153)	(0.0214)	(0.0124)
Agriculture (%)	7.73×10^{-05}	−0.000527	0.00496***	0.00113	0.000448
	(0.000394)	(0.000417)	(0.000831)	(0.000935)	(0.000521)
Pop. Density (pp/mi2)	3.86×10^{-07}	-1.88×10^{-06}***	-3.85×10^{-06}***	3.76×10^{-06}	-7.62×10^{-06}**
	(5.95×10^{-07})	(7.25×10^{-07})	(1.38×10^{-06})	(3.22×10^{-06})	(3.81×10^{-06})
County GDP (adj. $2012)	-4.47×10^{-10}***	7.97×10^{-10}**	-5.63×10^{-10}***	6.71×10^{-10}	-7.16×10^{-10}***
	(1.68×10^{-10})	(3.79×10^{-10})	(1.25×10^{-10})	(4.77×10^{-10})	(2.70×10^{-10})
Constant	0.166***	0.0797**	0.295***	0.485***	0.192***
	(0.0277)	(0.0336)	(0.0912)	(0.0591)	(0.0564)
Observations	71 195	30 453	10 193	6,906	23 643
R-Squared	0.430	0.457	0.401	0.605	0.331
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (1) and are specified as:

$$\text{Pr}(\text{Shortage}_i) = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2\gamma_i + \beta 3\delta_c + \xi_{\text{state}} + u_i$$

Where SVI Indicators is a vector of the 15 ACS indicators used to construct SVI. Models include the full sample of census tracts. Models include state FE to account for state-level social, economic, and water policies. Partitions in the table separate variables into SVI themes. The unit of measurement for SVI variables is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 3.

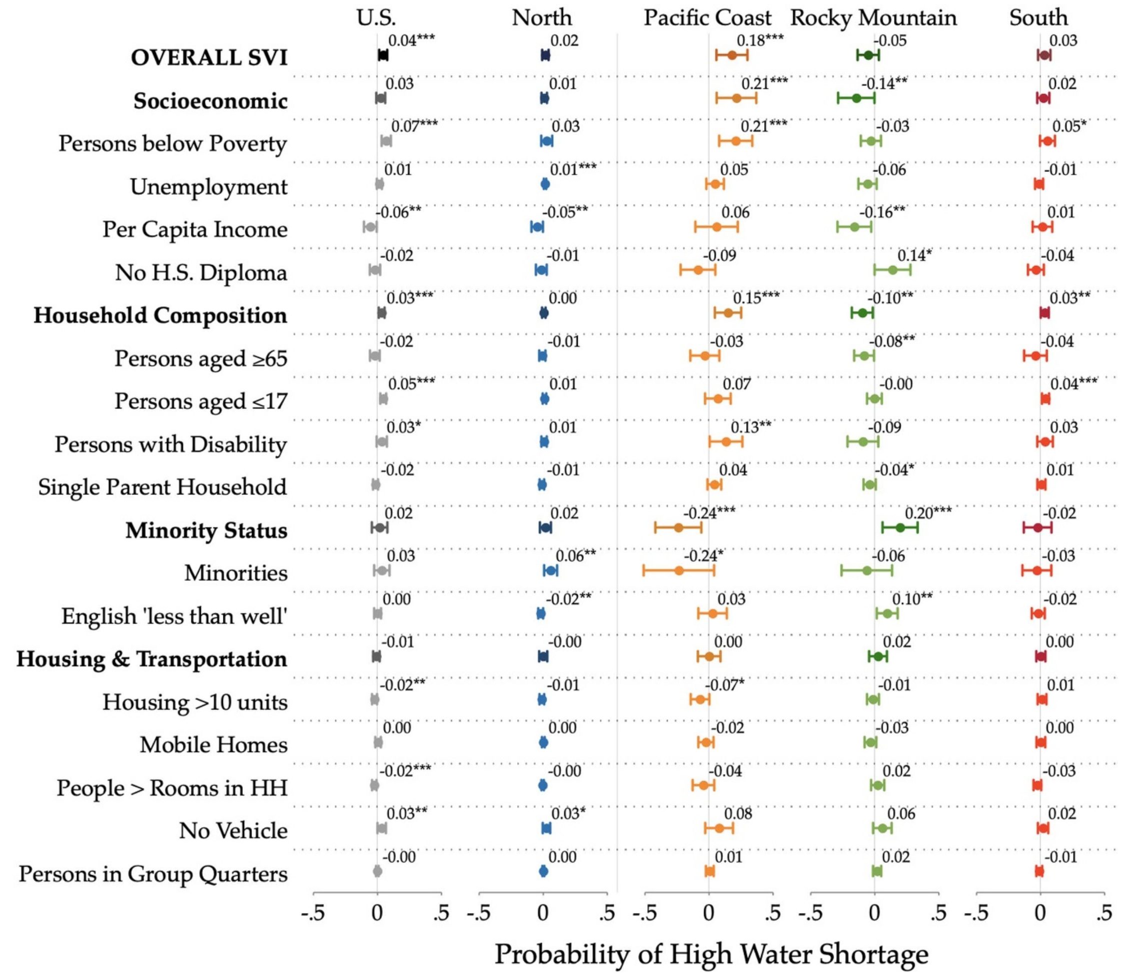

Figure A6. Coefficient Plot Estimates of Probability of Exposure to High Water Shortage.
Notes: figure depicts coefficients on the relationship between the probability of census tract, i, experiencing high water shortage (defined as the ⩾90th shortage percentile) as a function of social vulnerability from three separate MLRs. We adapt MLRs in tables A8, A11 and A14 by replacing $\Pr(\mathrm{Shortage}_i)$ with the probability of census tract, i, experiencing high shortage, $\Pr(\mathrm{HighShortage}_i)$ to get coefficients on coefficients on overall SVI, SVI themes, and SVI variables, respectively. Lines depict 95% confidence intervals. Coefficient values and stars depicting statistical significance ($***p < .01$, $**p < .05$, $*p < .1$) are shown at the top right of each marker. All models include state FE and controls for agricultural land use and population density at the tract level, and county-level GDP. All VIF values are < 10. The unit of measurement for all independent variables is percentile rank. Return to figure 3.

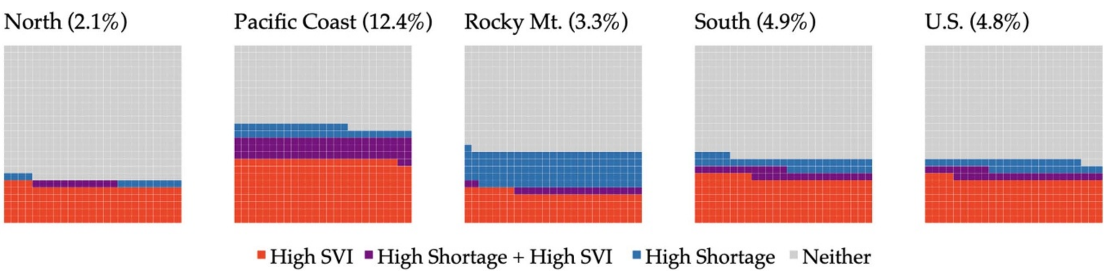

Figure A7. Share of population in high-shortage, high-SVI hotspots.
Notes: figure depicts the percentage of each region's population in (a) high-SVI hotspots with a Gi* statistic of $p < .10$ (red squares), (b) high-shortage hotspots with a Gi* statistic of $p < .10$ (blue squares), and (c) hotspots with both SVI and water shortages with Gi* statistics of $p < .10$ (purple squares). Each square represents .25 percent of a region's population. Numbers in parentheses adjacent to the region names are the percentages of each region's population in high-SVI, high-shortage hotspots. Note that in the North, hotspots are located only in Illinois and Wisconsin along Lake Michigan. Rocky Mountain hotspots are overly the Ogallala Aquifer in Kansas and Nebraska. While in the different RPA regions, these areas may have more in common with hotspots in Oklahoma and Texas, which are technically in the South, than they do with those in New Mexico, Arizona, and Colorado. Return to section 3.6.

Table A15. Shares of population and land area in high shortage, high SVI hotspots ($p < .10$).

		Hotspot population			Hotspot land area		
RPA Region	State	Hotspot Pop.	Pct. (%)	Cumulative (%)	Square-Miles	Pct. (%)	Cumulative Pct.(%)
Pacific Coast	California	6,117,992	41.14	41.14	8,862.89	38.42	38.42
South	Florida	2,964,060	19.93	61.08	2,047.15	8.87	47.29
North	Illinois	1,354,751	9.11	70.19	168.82	0.73	48.02
South	Texas	1,765,546	11.87	82.06	4,776.02	20.70	68.72
North	Wisconsin	837,867	5.63	87.7	195.03	0.85	69.57
Rocky Mt.	Kansas	472,111	3.17	90.87	444.10	1.92	71.50
South	Oklahoma	340,237	2.29	93.16	140.17	0.61	72.10
North	Indiana	282,581	1.9	95.06	138.82	0.60	72.70
South	Louisiana	301,880	2.03	97.09	409.65	1.78	74.48
Rocky Mt.	New Mexico	143,986	0.97	98.06	762.37	3.30	77.78
Rocky Mt.	Colorado	157,191	1.06	99.12	318.10	1.38	79.16
Rocky Mt.	Arizona	73,001	0.49	99.61	4,749.55	20.59	99.75
Rocky Mt.	Nebraska	58,537	0.39	100	57.44	0.25	100.00
Total		14 869 740	100		23,070.10	100.00	

Return to section 3.6.

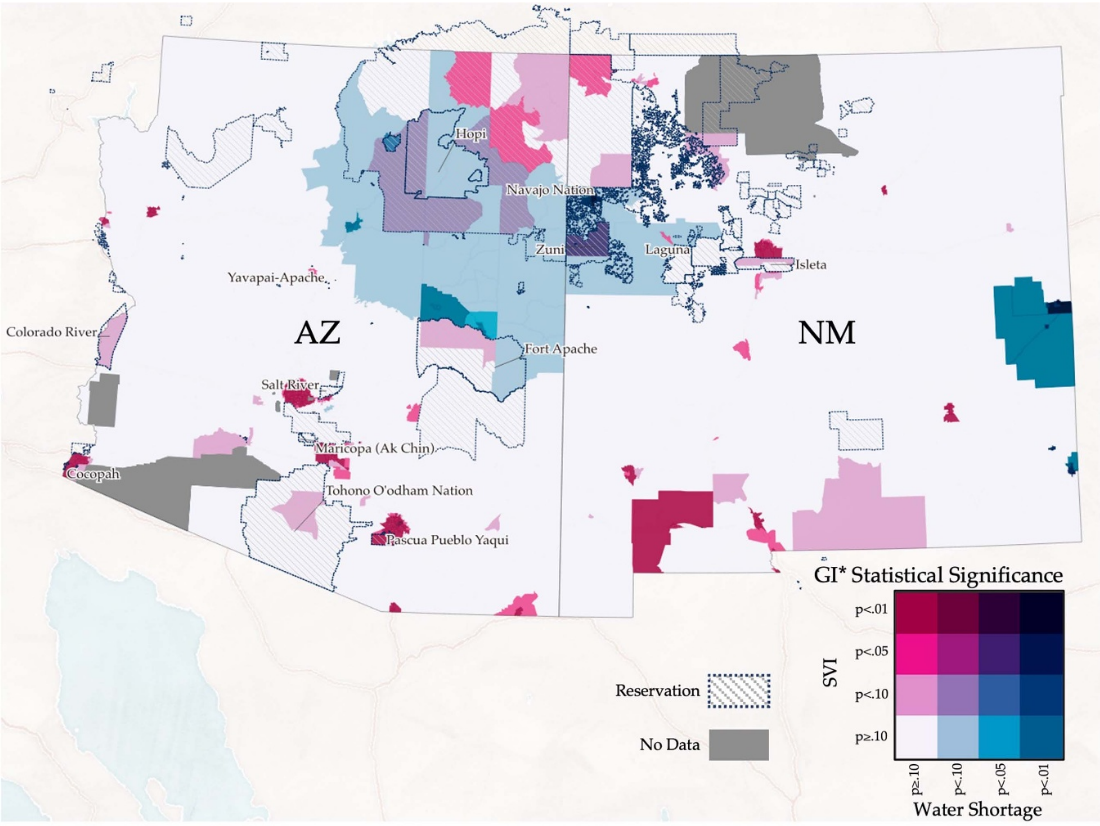

Figure A8. High-shortage, high-SVI hotspots: Arizona and New Mexico.
Notes: figure depicts high-shortage, high-SVI hotspots in Arizona and New Mexico in the Rocky Mountain RPA region. Native American Reservation boundaries, publicly available from the Bureau of Indian Affairs, are included to highlight hotspots on reservations. Those reservations that are labeled contain shortage risk hotspots. Return to section 3.6.

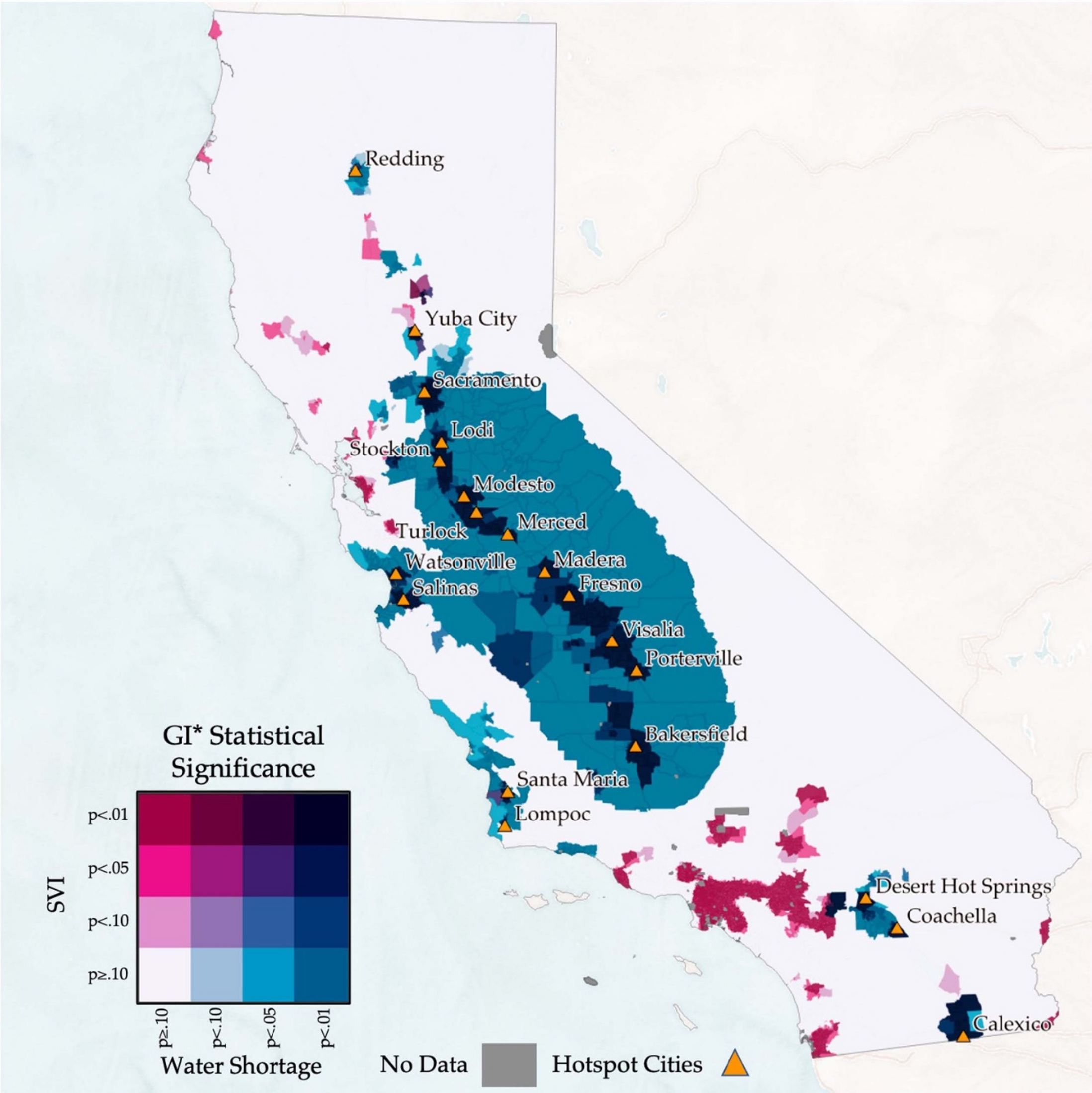

Figure A9. High-shortage, high-SVI hotspots: California.
Notes: figure depicts high-shortage, high-SVI hotspots in California in the Pacific Coast RPA region. Major cities (located primarily in agricultural areas) within hotspots areas are depicted with orange triangles. Return to section 3.6.

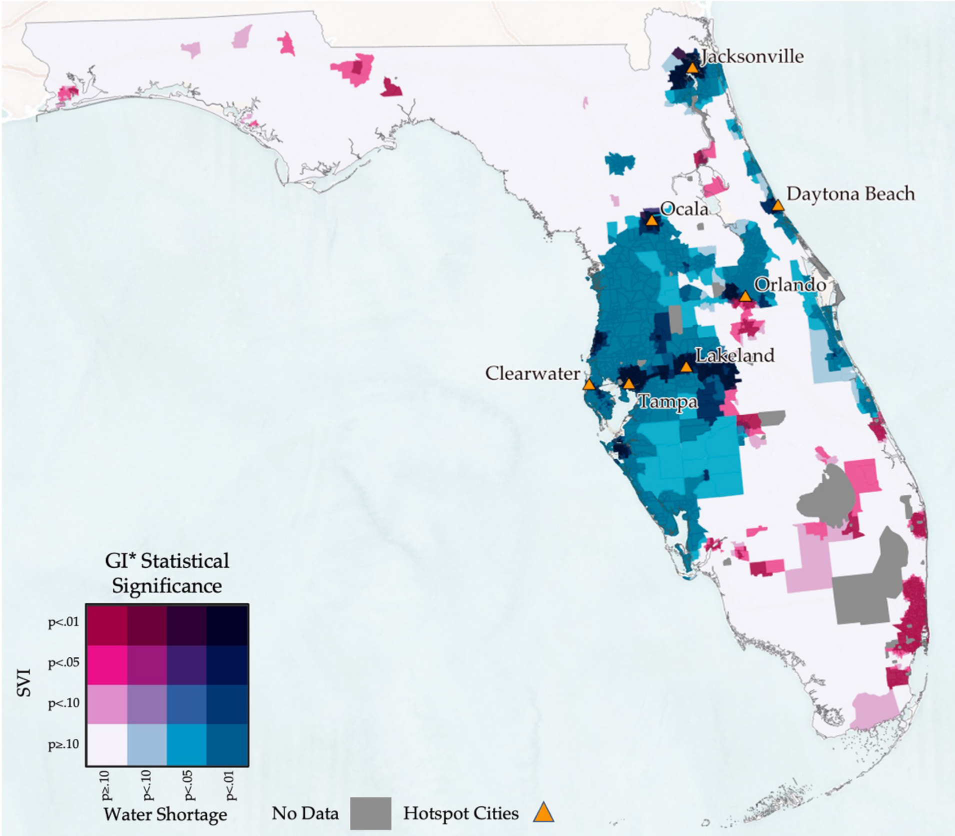

Figure A10. High-shortage, High-SVI hotspots: Florida.
Notes: figure depicts high-shortage, high-SVI hotspots in Florida in the Southern RPA region. Major cities within hotspots areas are depicted with orange triangles. Return to section 3.6.

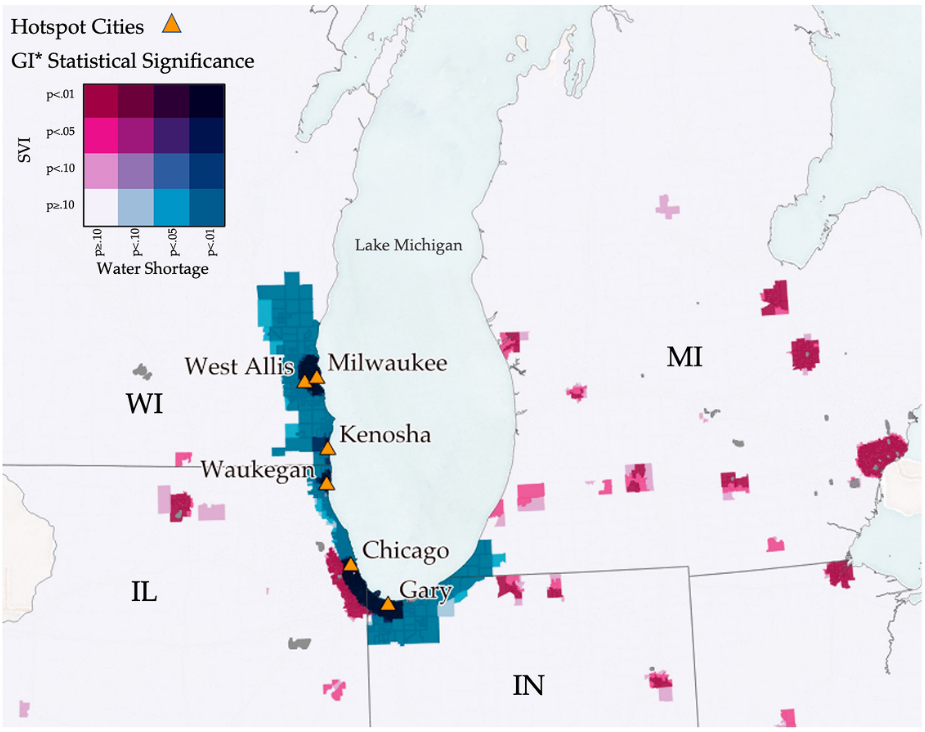

Figure A11. High-shortage, High-SVI hotspots: Great Lakes.
Notes: figure depicts high-shortage, high-SVI hotspots along Lake Michigan in the Northern RPA region. Major cities within hotspots areas are depicted with orange triangles. Return to section 3.6.

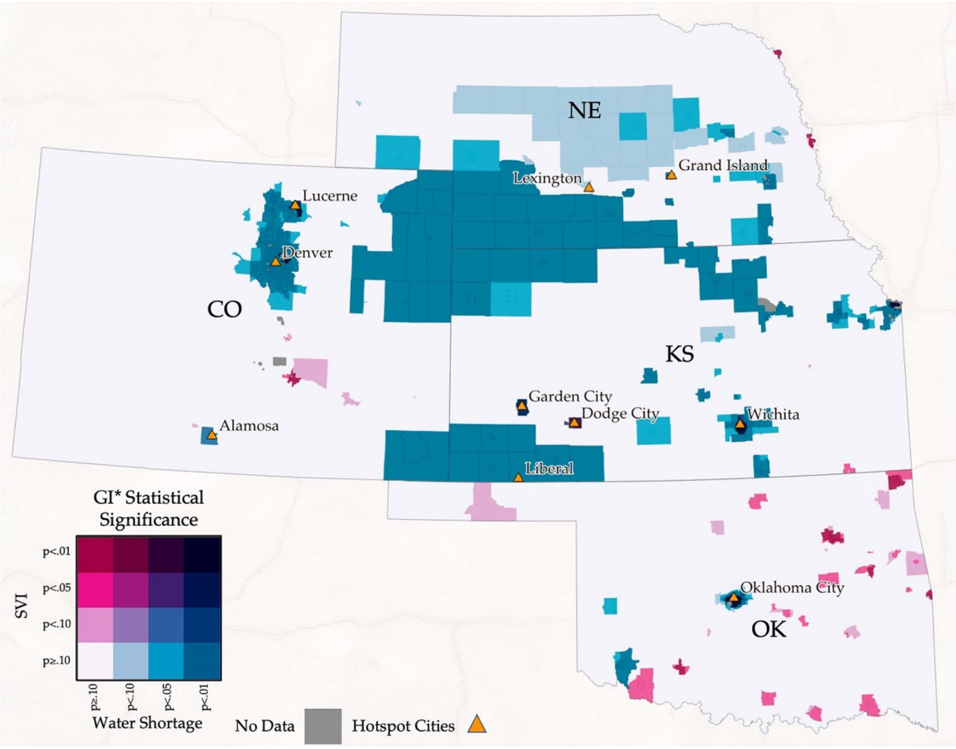

Figure A12. High-shortage, High-SVI hotspots: great plains.
Notes: figure depicts high-shortage, high-SVI hotspots across the Great Plains in the Rocky Mountain RPA region. Major cities within hotspots areas are depicted with orange triangles. Return to section 3.6.

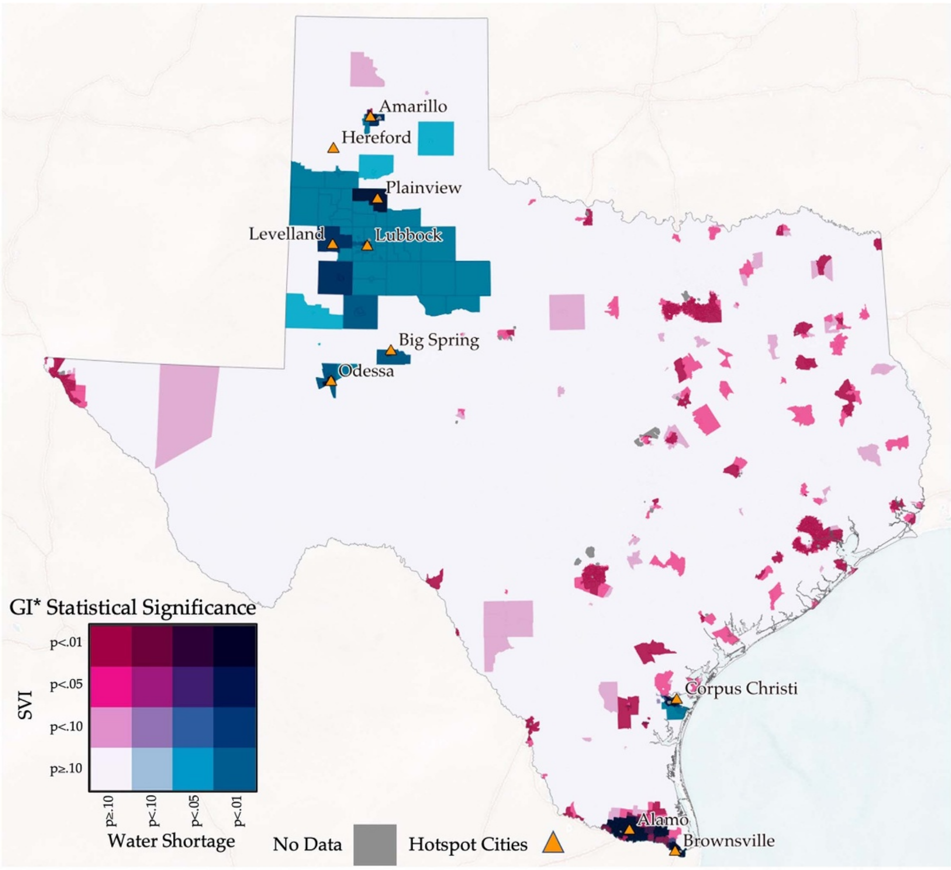

Figure A13. High-Shortage, High-SVI Hotspots: Texas.
Notes: figure depicts high-shortage, high-SVI hotspots across in Texas in the Southern RPA region. Major cities within hotspots areas are depicted with orange triangles. Return to section 3.6.

Table A16. Balance table showing differences in means between non-hotspot and hotspot census tracts. Difference in means equals non-hotspot average minus hotspot average.

	US		North		Pacific Coast		Rocky Mountain		South	
	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat
Agriculture (%)	2.53***	(6.83)	13.74***	(16.33)	−12.07***	(−24.83)	4.39**	(2.83)	2.99***	(5.57)
Pop. Density pp./mi2	−159.02	(−0.76)	−3,375.84***	(−5.62)	2,966.26***	(10.52)	5.05	(0.02)	−681.16***	(−5.92)
County GDP adj. $2012	−2,461,221	(−0.99)	−158,358,399***	(−49.50)	209,775,852***	(26.98)	33,738,774***	(6.94)	7,829,891***	(3.36)
Water Use 2015	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat
Domestic (%)	28.98***	(44.15)	59.89***	(31.49)	47.26***	(53.14)	7.82*	(2.27)	−3.31**	(−3.19)
Irrigation (%)	−30.02***	(−51.09)	5.07***	(7.44)	−52.59***	(−57.38)	−3.15	(−0.88)	−3.80***	(−4.51)
Commercial (%)	5.89***	(18.98)	14.47***	(12.46)	5.93***	(20.71)	0.77	(0.75)	−1.10**	(−2.61)
Thermoelectric (%)	−5.10***	(−11.50)	−82.95***	(−55.04)	0.39***	(6.68)	−4.61***	(−5.09)	5.99***	(7.34)
Livestock (%)	0.26	(1.44)	3.52***	(6.53)	−1.00**	(−3.23)	−0.83	(−1.51)	2.22***	(7.53)
Water Use 1985	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat
Domestic (%)	22.58***	(40.13)	24.37***	(21.50)	48.20***	(52.59)	5.61***	(3.38)	9.08***	(9.45)
Irrigation (%)	−30.78***	(−61.32)	2.93***	(8.94)	−54.17***	(−58.82)	12.99***	(5.86)	−25.52***	(−34.24)
Commercial (%)	6.00***	(16.10)	3.81***	(4.55)	5.89***	(15.20)	−2.41**	(−3.27)	2.10***	(3.32)
Thermoelectric (%)	−0.06	(−0.10)	−34.44***	(−25.85)	0.13	(0.40)	−17.78***	(−14.80)	11.86***	(12.28)
Livestock (%)	2.26***	(15.74)	3.34***	(11.22)	−0.05	(−1.33)	1.60***	(3.92)	2.49***	(8.51)

(Continued.)

Table A16. (Continued.)

Water Use 1985−2015 (%Δ)	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat	Diff. in Means	t-stat
Domestic (%Δ)	−14.11***	(−10.32)	−14.20***	(−5.89)	11.47***	(11.26)	−54.36***	(−10.54)	−26.93***	(−9.45)
Irrigation (%Δ)	−632.65***	(−13.52)	−635.09***	(−8.36)	−28.77***	(−5.94)	−51.96	(−0.63)	−1038.48***	(−9.12)
Commercial (%Δ)	−279.12***	(−5.65)	−459.93***	(−3.84)	−75.27***	(−3.71)	−248.43	(−1.82)	−186.05*	(−2.22)
Thermoelectric (%Δ)	1,238.91	(1.69)	−7,656.75**	(−2.65)	12 112.21***	(30.34)	−669.88	(−1.60)	−541.29***	(−4.75)
Livestock (%Δ)	−65.28	(−0.57)	−329.29***	(−3.70)	−246.51	(−1.82)	−204.45**	(−2.84)	−464.59	(−1.51)
Social Vulnerability	**Diff. in Means**	**t-stat**	**Diff. in Means**	**t-stat**	**Diff. in Means**	**t-stat**	**Diff. in Means**	**t-stat**	**Diff. in Means**	**t-stat**
Socioeconomic	−0.22***	(−44.09)	−0.26***	(−25.90)	−0.24***	(−26.90)	−0.26***	(−14.38)	−0.15***	(−17.74)
Household Comp.	−0.14***	(−27.47)	−0.11***	(−10.77)	−0.24***	(−29.93)	−0.18***	(−9.80)	−0.10***	(−11.94)
Minority Status	−0.24***	(−47.73)	−0.25***	(−24.22)	−0.13***	(−17.27)	−0.27***	(−14.96)	−0.17***	(−22.07)
Housing & Transport	−0.10***	(−20.46)	−0.07***	(−6.50)	−0.07***	(−7.58)	−0.11***	(−5.53)	−0.11***	(−12.52)
Overall SVI	−0.23***	(−46.08)	−0.24***	(−23.39)	−0.22***	(−25.31)	−0.27***	(−14.03)	−0.17***	(−20.91)
Observations	71 196		30 454		10 193		6906		23 643	

Notes: Table presents differences in water use, social vulnerability, and economic characteristics between hotspot and non-hotspot census tracts. We define hotspots as census tracts with a Gi* statistical significance of $p < .10$ for both water shortage and SVI. The difference in means is the average value in non-hotspots minus the average value in hotspot areas. So, a value of -30 percent on 2015 Irrigation (%) in the U.S. (col. 1) signifies that average census tracts in non-hotspots used 30 percent less of their total 2015 freshwater water supplies for irrigation than census tracts in hotspots. The percent change in water use between 1984-2010 is estimated for census tracts with non-zero water use values in 1985. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to section 3.6.

Table A17. Hotspot summary statistics.

	U.S.		North		Pacific		Rocky Mt.		South	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Current water shortage (MCM/mo.)	11.287	11.131	8.301	7.054	17.784	13.996	8.777	10.347	7.428	6.576
Overall SVI	0.721	0.245	0.683	0.263	0.753	0.231	0.726	0.239	0.715	0.242
Socioeconomic rank	0.713	0.250	0.720	0.272	0.718	0.247	0.711	0.234	0.703	0.239
Below poverty (%)	0.691	0.247	0.735	0.242	0.656	0.252	0.674	0.248	0.698	0.241
Unemployed (%)	0.666	0.281	0.722	0.302	0.711	0.245	0.588	0.287	0.601	0.281
Income ($)	0.688	0.268	0.687	0.289	0.660	0.278	0.735	0.229	0.705	0.249
No HS diploma (%)	0.685	0.268	0.619	0.285	0.726	0.261	0.717	0.243	0.683	0.259
HH Composition	0.634	0.273	0.599	0.319	0.634	0.240	0.665	0.253	0.652	0.271
Pop. Aged $\geqslant$ 65	0.388	0.282	0.354	0.276	0.352	0.260	0.317	0.236	0.460	0.300
Pop. Aged $\leqslant$ 17	0.633	0.314	0.583	0.335	0.708	0.269	0.745	0.253	0.569	0.329
$\geqslant$ Age 5 with Disability (%)	0.549	0.263	0.508	0.291	0.504	0.246	0.557	0.264	0.617	0.245
Single-Parent HH (%)	0.670	0.274	0.697	0.302	0.681	0.255	0.693	0.242	0.638	0.275
Minority status	0.727	0.209	0.665	0.213	0.811	0.157	0.734	0.200	0.686	0.226
Minority (%)	0.743	0.199	0.800	0.220	0.762	0.145	0.710	0.181	0.693	0.218
English 'Less than Well' (%)	0.661	0.290	0.484	0.336	0.800	0.180	0.703	0.238	0.634	0.282
Housing & transportation	0.599	0.267	0.543	0.250	0.636	0.261	0.588	0.294	0.601	0.272
Multi-unit structures (%)	0.507	0.291	0.552	0.302	0.496	0.267	0.463	0.289	0.497	0.304
Mobile homes (%)	0.392	0.369	0.132	0.242	0.403	0.355	0.448	0.365	0.541	0.361
Crowding (%)	0.655	0.291	0.538	0.299	0.777	0.237	0.641	0.293	0.616	0.291
No vehicle (%)	0.606	0.276	0.808	0.212	0.517	0.259	0.559	0.269	0.568	0.265
Group quarters (%)	0.415	0.354	0.382	0.355	0.485	0.308	0.419	0.377	0.367	0.378
Agriculture (%)	9.654	20.737	0.555	3.179	16.414	27.018	8.605	17.931	9.310	18.400
Pop. density (pp./mi2)	5562	5477	10 707	7884	4962	3640	3003	2437	3232	2257
County GDP (adj. $2012)	78 824 513	108 900 000	209 400 000	159 300 000	44 250 608	31 813 591	19 008 071	16 402 552	37 577 599	29 300 337
Observations	3,373		790		1,160		233		1,190	

Notes: Return to section 3.6.

Table A18. MLR estimates of exposure to water shortage as a function of SVI theme scores in high shortage, high SVI hotspots (Gi* statistic $p < .10$).

	$Y =$ Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	3.470*	−3.221	9.681**	0.661	1.632
	(2.055)	(2.122)	(4.693)	(5.139)	(2.255)
Household	0.714	1.858	7.739**	0.348	−2.906
Composition	(1.545)	(1.362)	(3.464)	(2.501)	(2.092)
Minority	−1.524	1.495	2.56	−1.978	−5.241*
Status/Language	(2.293)	(2.122)	(7.308)	(5.769)	(3.049)
Housing Type &	1.342	3.161*	−4.607**	0.245	3.069***
Transportation	(1.035)	(1.785)	(2.329)	(2.861)	(1.187)
Observations	3,373	790	1,160	233	1,190
R-squared	0.263	0.51	0.06	0.313	0.112
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1\text{Theme1}_i + \beta_2\text{Theme2}_i + \beta_3\text{Theme3}_i + \beta_4\text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, $Theme3_i$ is minority status, and Theme4_i is housing and transportation vulnerability. Models include hotspot census tracts with a GI* Statistic of $p < .10$ for both SVI and water shortage volume. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 5.

Table A19. MLR Estimates of Exposure to Water Shortage as a Function of SVI Theme Scores in High Shortage, High SVI Hotspots (Gi* statistic $p < .10$); Census Tract Controls.

	Y = Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	3.342	−3.154	10.48**	3.652	1.582
	(2.086)	(2.209)	(4.607)	(4.582)	(2.277)
Household	0.882	1.743	8.177**	0.581	−2.883
Composition	(1.526)	(1.439)	(3.232)	(2.287)	(2.003)
Minority	−2.233	1.692	−0.810	−5.929	−5.354*
Status/Language	(2.250)	(2.360)	(6.871)	(5.342)	(3.201)
Housing Type &	1.550	3.165*	−4.003*	0.008 97	3.090***
Transportation	(0.994)	(1.635)	(2.276)	(2.465)	(1.183)
Agriculture (%)	8.524***	7.980	9.350***	19.47***	1.004
	(2.389)	(7.148)	(3.286)	(6.791)	(1.821)
Pop. Density	-1.46×10^{-05}	-1.75×10^{-05}	−0.0002 15	0.0005 16*	4.24×10^{-05}
(pp./mi2)	(7.68×10^{-05})	(8.89×10^{-05})	(0.0001 68)	(0.0003 03)	(0.0001 54)
Observations	3,373	790	1,160	233	1,190
R-squared	0.285	0.512	0.106	0.393	0.113
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1\text{Theme1}_i + \beta_2\text{Theme2}_i + \beta_3\text{Theme3}_i + \beta_4\text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, Theme3_i is minority status, and Theme4_i is housing and transportation vulnerability. Models include hotspot census tracts with a GI* Statistic of $p < .10$ for both SVI and water shortage volume. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 5.

Table A20. MLR estimates of exposure to water shortage as a function of SVI theme scores in high shortage, high SVI hotspots (Gi* statistic $p < .10$); census tract and county-level controls.

	Y = Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Socioeconomic	3.357*	−1.819	9.277*	3.711	1.277
	(2.014)	(2.073)	(4.731)	(4.593)	(2.283)
Household composition	0.265	1.753	5.998**	0.262	−3.356*
	(1.455)	(1.167)	(3.018)	(2.189)	(1.985)
Minority status/language	−2.116	−0.798	0.327	−8.169	−3.975
	(2.169)	(1.508)	(6.859)	(5.575)	(3.259)
Housing type & transportation	1.197	2.394	−3.696	−0.430	2.970**
	(0.970)	(1.558)	(2.275)	(2.564)	(1.176)
Agriculture (%)	7.672***	4.251	6.373**	19.07***	0.800
	(2.285)	(6.810)	(3.205)	(6.673)	(1.829)
Pop. density (pp./mi2)	5.65×10^{-05}	6.67×10^{-05}	−0.0002v69	0.0008 70**	7.38×10^{-05}
	(6.65×10^{-05})	(6.41×10^{-05})	(0.0001 71)	(0.0004 29)	(0.0001 48)
County GDP (adj. $2012)	-4.67×10^{-08}***	-3.44×10^{-08}***	-7.44×10^{-08}**	-1.06×10^{-07}	-2.33×10^{-08}
	(9.66×10^{-09})	(4.54×10^{-09})	(3.24×10^{-08})	(6.77×10^{-08})	(1.71×10^{-08})
Observations	71 195	30 453	10 193	6,906	23 643
R-squared	0.308	0.587	0.131	0.403	0.117
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1\text{Theme1}_i + \beta_2\text{Theme2}_i + \beta_3\text{Theme3}_i + \beta_4\text{Theme4}_i + \beta 5\gamma_i + \beta 6\delta_c + \xi_{\text{state}} + u_i$$

Where Theme1_i is socioeconomic vulnerability, Theme2_i household composition, Theme3_i is minority status, and Theme4_i is housing and transportation vulnerability. Models include hotspot census tracts with a GI* Statistic of $p < .10$ for both SVI and water shortage volume. Models include state FE to account for state-level social, economic, and water policies. The unit of measurement for SVI themes is percentile rank. Standard errors clustered at the county level are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 5.

Table A21. MLR Estimates of Exposure to Water Shortage as a Function of SVI Variable Scores in High Shortage, High SVI Hotspots (Gi* statistic $p < .10$).

	Y = Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below Poverty	3.017*	2.886	9.576***	−0.983	−0.928
	(1.733)	(2.120)	(3.359)	(3.662)	(1.496)
Unemployment	−0.583	0.947	−0.479	−2.598	−0.150
	(1.106)	(0.984)	(3.048)	(2.588)	(1.142)
Per capita income	3.556	−2.324	−0.849	13.28**	3.804
	(2.372)	(3.006)	(5.190)	(6.510)	(2.903)
No H.S. Diploma	0.183	−4.285*	2.007	−5.033	2.621**
	(2.529)	(2.435)	(6.817)	(4.988)	(1.231)
Persons aged ⩾ 65	−2.123	−1.150	3.013	1.620	−2.221
	(1.462)	(1.360)	(3.761)	(2.978)	(2.011)
Persons aged ⩽ 17	3.293***	3.389**	15.510***	−7.409*	−2.121
	(1.275)	(1.394)	(2.996)	(4.045)	(1.502)
Persons with disability	−0.426	2.377**	−1.420	−1.140	−0.708
	(1.711)	(1.134)	(4.026)	(3.990)	(1.343)
Single parent household	−0.313	−0.561	1.130	7.986*	−0.547
	(1.075)	(0.909)	(2.689)	(4.237)	(0.897)
Minorities	−6.319**	2.189	16.430*	−13.160**	−9.645***
	(3.000)	(2.980)	(9.943)	(6.140)	(2.586)
English 'less than well'	−0.580	2.413**	−18.970**	4.843	−0.654
	(1.285)	(1.160)	(7.447)	(3.654)	(1.733)
Housing > 10 units	0.0216	2.758**	−7.019***	−3.045	1.923
	(0.977)	(1.336)	(2.430)	(2.380)	(1.317)
Mobile homes	0.784	0.362	0.943	2.576	(0.056)
	(0.926)	(0.670)	(1.698)	(1.866)	(0.738)
People > rooms in HH)	−1.584**	−0.861	−5.242**	1.276	0.556
	(0.775)	(0.776)	(2.333)	(2.304)	(0.912)
No vehicle	−0.333	−3.769	3.666	−3.124	−0.0981
	(1.351)	(2.600)	(2.853)	(3.006)	(0.906)
Persons in group quarters	1.622***	1.854**	1.201	2.172	1.519*
	(0.592)	(0.761)	(1.494)	(1.743)	(0.776)
Observations	3,373	790	1,160	233	1,190
R-Squared	0.278	0.548	0.138	0.388	0.147
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2\gamma_i + \beta 3\delta_c + \xi_{\text{state}} + u_i$$

Where SVI Indicators is a vector of the 15 ACS indicators used to construct SVI. Sample is restricted to census tracts in high shortage, high SVI hotspots, where both shortage and SVI have a Gi* statistical significance of p<.10. Models include state FE to account for state-level social, economic, and water policies. Partitions in table separate variables into SVI themes. The unit of measurement for SVI variables is percentile rank. Standard errors allowing for spatial autocorrelation across 10km are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 5.

Table A22. MLR Estimates of Exposure to Water Shortage as a Function of SVI Variable Scores in High Shortage, High SVI Hotspots (Gi* statistic $p < .10$); Census Tract Controls.

	Y = Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below Poverty	2.821*	3.033	8.230**	1.622	−0.994
	(1.689)	(1.890)	(3.288)	(3.710)	(1.500)
Unemployment	−0.638	0.768	−1.519	−1.971	−0.132
	(1.051)	(1.042)	(2.663)	(2.261)	(1.144)
Per Capita Income	4.462*	−2.299	3.580	12.970**	3.869
	(2.298)	(2.775)	(4.666)	(6.130)	(2.954)
No H.S. Diploma	−1.050	−4.391*	−1.064	−6.584	2.572**
	(2.401)	(2.526)	(6.477)	(4.853)	(1.237)
Persons aged ⩾ 65	−2.454*	−1.185	2.220	1.936	−2.222
	(1.485)	(1.486)	(3.749)	(2.976)	(2.004)
Persons aged ⩽ 17	2.395*	3.418**	13.130***	−5.468	−2.218
	(1.242)	(1.476)	(2.738)	(3.390)	(1.456)
Persons with Disability	−0.147	2.290**	−0.468	−0.307	−0.744
	(1.653)	(1.143)	(3.909)	(3.766)	(1.353)
Single Parent Household	0.588	−0.618	3.169	5.384	−0.44
	(1.025)	(0.869)	(2.558)	(3.412)	(0.902)
Minorities	−7.117**	2.390	18.490*	−9.708*	−9.670***
	(2.899)	(2.965)	(9.445)	(5.161)	(2.596)
English 'less than well'	−0.258	2.503**	−19.680***	2.533	−0.633
	(1.273)	(1.151)	(7.347)	(3.177)	(1.744)
Housing > 10 units	0.668	2.735**	−4.533*	−2.830	2.026
	(0.948)	(1.360)	(2.361)	(2.116)	(1.315)
Mobile Homes	−0.844	0.159	−2.155	1.341	−0.226
	(0.822)	(0.657)	(1.579)	(1.512)	(0.703)
People > Rooms in HH)	−1.562**	−0.886	−5.469**	0.311	0.538
	(0.776)	(0.811)	(2.373)	(2.171)	(0.911)
No Vehicle	0.937	−3.457	4.699*	−3.145	0.0527
	(1.311)	(2.412)	(2.748)	(2.845)	(0.891)
Persons in Group Quarters	1.551***	1.819**	1.182	3.020*	1.490**
	(0.592)	(0.769)	(1.461)	(1.681)	(0.748)
Agriculture (%)	0.090***	0.085	0.085***	0.183***	0.010
	(0.022)	(0.078)	(0.031)	(0.061)	(0.017)
Pop. Density (pp/mi2)	−0.00008	−0.00001	−0.00046***	0.00057*	−0.00002
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	3373	790	1160	233	1190
R-Squared	0.302	0.550	0.183	0.450	0.148
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2\gamma_i + \beta 3\delta_c + \xi_{\text{state}} + u_i$$

Where SVI Indicators is a vector of the 15 ACS indicators used to construct SVI. Sample is restricted to census tracts in high shortage, high SVI hotspots, where both shortage and SVI have a Gi* statistical significance of p<.10. Models include state FE to account for state-level social, economic, and water policies. Partitions in table separate variables into SVI themes. The unit of measurement for SVI variables is percentile rank. Standard errors allowing for spatial autocorrelation across 10km are in parentheses. *** $p < .01$, ** $p < .05$, * $p < .1$. Return to figure 5.

Table A23. MLR Estimates of Exposure to Water Shortage as a Function of SVI Variable Scores in High Shortage, High SVI Hotspots (Gi* statistic $p < .10$); Census Tract and County-Level Controls.

	Y = Water Shortage (MCM/mo.)				
	(1) U.S.	(2) North	(3) Pacific	(4) Rocky Mtn.	(5) South
Persons below poverty	3.542**	3.298*	10.02***	0.756	−0.990
	(1.607)	(1.720)	(3.106)	(3.721)	(1.497)
Unemployment	−0.534	1.270	−1.400	−1.279	−0.139
	(1.058)	(0.971)	(2.695)	(2.080)	(1.138)
Per capita income	3.056	−2.794	1.944	12.900**	3.696
	(2.215)	(2.571)	(4.394)	(5.997)	(2.884)
No H.S. Diploma	−2.157	−4.771*	−5.120	−6.285	2.555**
	(2.278)	(2.503)	(6.312)	(4.573)	(1.240)
Persons aged ⩾ 65	−2.528*	0.154	1.527	0.870	−2.346
	(1.448)	(1.194)	(3.657)	(2.774)	(1.934)
Persons aged ⩽ 17	1.692	3.056*	11.130***	−6.292*	−2.241
	(1.217)	(1.574)	(2.675)	(3.431)	(1.447)
Persons with Disability	−0.628	1.363	−1.912	−0.547	−0.731
	(1.630)	(1.087)	(3.827)	(3.715)	(1.342)
Single parent household	0.484	−0.797	3.115	7.119*	−0.467
	(1.005)	(0.886)	(2.504)	(3.993)	(0.905)
Minorities	−3.776	2.286	20.470**	−13.200**	−9.351***
	(2.896)	(2.797)	(8.829)	(5.394)	(2.619)
English ‘less than well’	−0.775	1.276	−16.810**	1.704	−0.581
	(1.254)	(1.011)	(7.217)	(2.993)	(1.756)
Housing >10 units	0.025	1.312	−5.503**	−2.366	2.021
	(0.937)	(1.239)	(2.270)	(2.104)	(1.317)
Mobile homes	−1.034	−0.141	−2.157	1.119	−0.245
	(0.792)	(0.582)	(1.564)	(1.548)	(0.681)
People < Rooms in HH	−1.609**	−1.060	−4.682*	0.0248	0.531
	(0.774)	(0.757)	(2.407)	(2.144)	(0.912)
No Vehicle	1.787	0.818	5.481**	−3.859	0.0457
	(1.262)	(1.498)	(2.645)	(2.914)	(0.895)
Persons in group quarters	1.257**	1.117*	1.126	2.679*	1.486**
	(0.572)	(0.663)	(1.418)	(1.553)	(0.746)
Agriculture (%)	0.085***	0.082	0.057*	0.174***	0.010
	(0.022)	(0.073)	(0.030)	(0.058)	(0.017)
Pop. Density (pp/mi2)	−0.00001	0.00006	−0.00051***	0.000 98**	−0.000 02
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
County GDP (adj. $2012)	-4.80×10^{-08}***	-3.62×10^{-08}***	-8.14×10^{-08}**	-1.36×10^{-07}*	-4.61×10^{-09}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	3373	790	1160	233	1190
R-Squared	0.323	0.618	0.21	0.464	0.148
State FE	Yes	Yes	Yes	Yes	Yes

Notes: MLR models are adapted from equation (2) and are specified as:

$$\text{Shortage}_i = \beta_0 + \beta_1 \text{SVI Indicators}_i + \beta_2\gamma_i + \beta 3\delta_c + \xi_{\text{state}} + u_i$$

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