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Understanding perceived climate risks to household water supply and their implications for adaptation: evidence from California

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Abstract

Rapid adaptation is necessary to maintain, let alone expand, access to reliable, safe drinking water in the face of climate change. Existing research focuses largely on the role, priorities, and incentives of local managers to pursue adaptation strategies while mostly neglecting the role of the broader public, despite the strong public support required to fund and implement many climate adaptation plans. In this paper, we interrogate the relationship between personal experiences of household water supply impacts from extreme weather events and hazard exposure with individual concern about future supply reliability among a statewide representative sample of California households. We find that more than one-third of Californians report experiencing impacts of climate change on their household water supplies and show that these reported impacts differently influence residents' concern about future water supply reliability, depending on the type of event experienced. In contrast, residents' concern about future water supplies is not significantly associated with hazard exposure. These findings emphasize the importance of local managers' attending to not only how climate change is projected to affect their water resources, but how, and whether, residents perceive these risks. The critical role of personal experience in increasing concern highlights that post-extreme events with water supply impacts may offer a critical window to advance solutions. Managers should not assume, however, that all extreme events will promote concern in the same way or to the same degree.

Keywords Climate adaptation · Drinking water · Household water security · Climate change · Risk perception · Personal experience

1 Introduction

Climate change is accelerating in speed and intensity as global emissions continue to rise and atmospheric carbon surpasses 400 parts per million (IPCC 2022). This change, in turn, poses significant threats to water security which stem from climate change's influence on

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rising temperatures, mega-droughts, floods, storms, and fires. As seen in water crises from Cape Town, South Africa, to São Paulo, Brazil, to Chennai, India, individual households will increasingly experience climate-exacerbated water insecurity (Empinotti et al. 2019; Matikinca et al. 2020; Haas et al. 2021). Individual households will also need to support and align with local preparedness, planning, and adaptation measures pursued by water managers to mitigate disruptions in water supplies. For instance, analyses of the 2018 Cape Town climate-exacerbated water crises show that the city was able to avoid a shutdown of the municipal water network, partly because households dramatically reduced water usage following public awareness campaigns (Enqvist and Ziervogel 2019; Rodina 2019). Thus, knowledge of the factors that motivate households to be responsive to local adaptations to ensure water security is crucial as we move forward into uncharted climactic territory.

To better understand how to both advance and leverage support among households for climate change adaptation, in this paper, we interrogate potential factors influencing risk perception at the household level using data from a statewide representative survey conducted in California, the most populous US state and one that is widely expected to experience intensified impacts resulting from climate change in coming years (Pathak et al. 2018; Williams et al. 2019; Swain et al. 2018). Specifically, we assess how past and future climate hazard exposure and experiences of extreme weather impacts relate to reported concerns about future water supply reliability. Our findings highlight that climate-related impacts on household water supplies are already occurring and apparent to many Californians, with more than one-third reporting at least one such impact. While projections of future hazard exposure and local records of extreme weather events (recent climate hazards) are not meaningfully associated with an individual's reported concern about future water supply reliability, personal experiences of their household supply being impacted are. This effect, however, depends on the type of event examined. While personally experiencing the impacts of some of these phenomena, particularly drought, can increase concern, some climate-induced extreme weather events such as fire and floods may also have the opposite effect. Thus, to foster support for and compliance with adaptation policies by local, regional, and even state entities, managers and decision-makers need to concern themselves with how and whether residents perceive climate risks. Risk-based and impact-based frames may vary in effectiveness depending on the degree and type of recent climate impacts to household water supply.

2 Literature review

The water security literature highlights the importance of heightened risk perception and concern among water managers for advancing sustainable water management (Dobbie and Brown 2014), including for incentivizing local preparedness, planning, and adaptation for climate change (Ekstrom et al. 2017; Bell et al. 2022). However, proactive water management requires more than foresight and motivation on the part of local water managers. Successful implementation of sustainability policies and adaptation measures, such as conservation measures or investment in supply augmentation, often necessitates the support of residents, many of whom do not know the name of their local water provider and may not be connecting climate events to local water access issues yet. That support often manifests politically in the form of voting for rate adjustments locally or bond approvals statewide, or behaviorally, in the form of adoption and compliance with new policies and measures

(Dean et al. 2016; Garcia-Cuerva et al. 2016; Flint et al. 2017; Hubbard 2020; Mooney et al. 2021; Wolters and Steel 2021). If residents are not concerned and do not perceive climate change as a risk to their water security, they are unlikely to engage in either type of activity (Howden et al. 2007; Singh et al. 2017; Michetti and Ghinoi 2020).

It is therefore important to extend this same line of inquiry beyond water managers to customers of local water agencies, yet very little research has been done on this topic (Michetti and Ghinoi 2020). A small body of literature has documented the climate-related water security concerns of various US residential populations, typically through large-scale surveys. These studies find that water security concerns are salient among some residential populations (Flint et al. 2017; Hubbard 2020) but vary based on key individual attributes like education level, race, and ethnicity (Garcia-Cuerva et al. 2016) and in their attribution of the causes of local water issues (Craig et al. 2019). We are aware of only two studies that have considered whether other non-sociopolitical factors also play a role in shaping various levels of concern about climate-related risks to water security. First, Ho et al. (2019) found among Chinese villagers that perceived water insecurity and previous disaster experience were associated with higher climate risk perception. Second, a survey of Irish private well users found that extreme weather experience was positively associated with higher median risk perception scores (Mooney et al. 2021). Notably, both findings fit within broader debates in the much more extensive literature on the relative roles of personal experiences of extreme weather impacts and hazard exposure as drivers of household or individual climate concerns generally. In the remainder of this section, we draw on this growing body of climate change literature focused on understanding these two potential drivers of climate-related water security concerns.

2.1 The role of personal experience

A substantial literature has considered the relationship between personal experience of extreme weather impacts and climate change concerns (Donner and McDaniels 2013; Taylor et al. 2014; Lujala et al. 2015; Albright and Crow 2019; Ogunbode et al. 2020; Wachinger et al. 2013). However, it is still somewhat unclear to what extent personal experience serves as an opportunity for individuals to process climate change information and consequently increase engagement and support for climate policy. Existing studies have yielded diverse and at times, contradictory, findings. Some indicate a strong positive association between experience and concern, and others show no discernible effect on concern over climate change (Ogunbode et al. 2020; Wachinger et al. 2013). Others suggest that individual experience of extreme weather can decrease the perception of climate change as a major threat (Lujala and Lein 2020). Similarly, some have argued that individual experience of climate impacts is associated with greater climate change concern than regional or neighborhood impacts (Demski et al. 2017; Ogunbode et al. 2020), whereas others have found the opposite (Taylor et al. 2014; Albright and Crow 2019).

Research seeking to untangle this complicated relationship has focused on the role of impact by event type. Whitmarsh (2008) found that experiencing air pollution was positively associated with concern about climate change, whereas personally experiencing flooding had no discernible effect. Similarly, Ngo et al. (2020, p. 442) compare factors associated with both climate and flood risks and find significant differences, highlighting a need for "further research across different types of weather and climate-related risks."

Interpreting these findings, however, is complicated by the clear potential for sociopolitical differences to moderate the effect of personal experience of extreme weather on climate concerns (Ogunbode et al. 2017). Sociopolitical factors can shape an individual's attribution of these impacts to climate change (Ogunbode et al. 2020), particularly when these experiences are disconfirming of their existing beliefs (Lord et al. 1979). In their review of 73 papers on how climate change shapes climate opinion, Howe et al. (2019) find that while there is a particularly strong relationship between self-reported impacts and concern about climate change, they question the directionality as it is feasible that concern is the driver behind the self-report rather than the outcome. In contrast, most studies that have assessed impacts using objective indicators, such as weather and spatial data, have identified little to no effect on climate concern (Howe et al. 2019). Yet the extent to which these indicators meaningfully speak to direct, personally experienced impacts as opposed to exposure, as will be discussed next, merits critical consideration.

2.2 The role of hazard exposure

The degree to which hazard exposure influences individual climate concerns is debated in the literature (Mayer et al. 2017). Exposure, as defined by the IPCC, refers to any element(s) in a place where a hazard may occur, and interacts with vulnerability to produce risk (Cardona et al. 2012). One strand of literature supports the premise that physical vulnerability, as a function of exposure, informs individual climate risk perception, underscoring the potential importance of place in understanding climate concern (Brody et al. 2008). This includes Echavarren et al. (2019) who find that among the variables modeled, biophysical natural variables—the mere presence of hazards—are more predictive of concern than political context and discourses. Importantly though, among their natural variables, they find that certain hazards, namely droughts and floods, do not significantly influence concern while water deficits and increased temperatures do. In contrast, Garcia-Cuerva et al. (2016) find that drought conditions do correlate with increased water concern among their US respondents. In their study in rural Mexico, Michetti and Ghinoi (2020) also find that individuals perceive themselves as more at risk with increased physical exposure and proximity to hazards. Research in the USA has found a similar effect of coastal proximity, with those most at risk from sea-level rise reporting a greater perceived risk from climate change (Brody et al. 2008). Notably, however, the same study also found differences within proximity in that residents of 100-year floodplains perceive the risk of climate change as lower than residents of flood-safer areas (Brody et al. 2008).

On the other hand, several recent studies have argued for a constructionist understanding of risk perception. Saleh Safi et al. (2012), Mayer et al. (2017), and Lujala et al. (2015), for example, each find that hazard exposure does relatively little to predict climate concern, when measuring exposure via current or recent conditions or as physical vulnerability to future threats. In rural Nevada, Saleh Safi et al. (2012) found among ranchers and farmers that "physical vulnerability [to water stress] alone also does not impact risk perception" compared to their sensitivity, gender, and political orientation. Lujala et al. (2015) went further to compare the effect on climate concern between personal experience and what they refer to as the place effect, or "simply living in a more exposed area" (p. 492) to a range of hazards like floods, landslides, and proximity to the coast. Their conclusion reiterated the role of personal experience with a hazard in shaping concern while generally rejecting the significance of exposure. Collectively, these studies emphasize climate concern as a social phenomenon that cannot be geographically determined based on objective and external measures of extreme events.

3 California Case Context

Climate risks to household water security are evident and growing across all countries including the US. The 4th US National Climate Assessment recently noted that "water security in the United States is increasingly in jeopardy" (USGCRP 2018, p. 149). Research and headlines alike from California demonstrate this point well. During the state's historic drought from 2012 to 2016, thousands of domestic drinking water wells ran dry, with thousands more at risk if groundwater levels continued to drop (Pauloo et al. 2020). Between 2020 and 2022, California once again found itself in a drought emergency, with household outages accelerating anew (California Department of Water Resources (CDWR) 2022). Drought conditions sparked voluntary and even mandatory water conservation measures to be enacted across the state, in some instances involving the complete prohibition of outdoor watering (PPIC 2022). Simultaneously, record breaking fires compromised drinking water sources and systems (Odimayomi et al. 2021), leading to long-term emerging contaminant concerns (Proctor et al. 2020; Pierce et al. 2021). In early 2023, California again made headlines due to back-to-back atmospheric river events that caused widespread flooding as rainfall pummeled both the Northern and Southern parts of the state (Fry et al. 2023).

Whether perceived or not by water users, these climate change-driven extreme weather events have clear implications for California household water access. Most Californians are served by a water provider, typically one with a system manager ultimately responsible for mitigating the impacts of climate change on their customers. This can provide a level of protection from extremes, particularly compared to self-supplied households (e.g., domestic well) from whom similar events can be catastrophic. However, household water security is still clearly affected when the impacts are too extreme or outsized for a system's ability to adapt and mitigate. For example, electric utilities deploy Public Safety Power Shutoffs (PSPS) to manage fire risk, which affect water systems and households alike. Without power, drinking water and wastewater providers cannot pump, treat, or distribute water, and some households may be unable to boil untreated tap water or use their groundwater well. With warmer droughts, harmful algal blooms can pose expensive water treatment challenges to providers (Klasic et al. 2022). Extreme heat days drive demand at the same time that systems are often asking their customers to conserve, and many households in certain parts of the state rely on evaporative cooling systems like swamp coolers. Flooding can also damage distribution infrastructure, drinking water, and wastewater treatment plants, and lead to contamination issues, causing households to buy replacement bottled water (US Water Alliance 2020).

The outsized challenges facing California necessitate rapid adaptation (Stewart et al. 2020), and lessons may be drawn from the California context for other US states and global nations facing similar needs to adapt to climate change in coming years. While climate change awareness is relatively high among California water managers (Ekstrom et al. 2017) and residents alike (Baldassare et al. 2021), proactive adaptive action has lagged (Ekstrom et al. 2017), particularly among small systems (Klasic et al. 2022). Among the latter group, Klasic et al. (2022) find that 82% of system operators reported that their adaptation efforts are limited by other watershed stakeholders' failure to acknowledge climate change or the importance of long-term planning. Examples from around the state clearly illustrate this critical link between individual perceptions of climate water security and system level adaptation. California's Proposition 218, passed in 1996, gives residents the right to vote on local taxes. This policy thus necessitates majority customer support for everything from water supply investments (Nylen et al. 2018) to implementing conservation-promoting tiered water rates (Mukherjee et al. 2016). As another example, Californians have differentially implemented conservation mandates during recent droughts, in part related to residential awareness of local drought conditions (Palazzo et al. 2017). Research from outside California clearly indicates the relevance of risk perception for stewardship and protective behaviors among self-supplied households as well (McDowell et al. 2021). Yet unlike system managers, the factors influencing household perceptions of water security risks under climate change have yet to be systematically investigated. Given the diversity of climate impacts present in the state and the breadth of existing research on the associated drinking water impacts, California is a fitting place to investigate these questions.

4 Data and Methods

Our analysis links Californians' reported concern about future supply reliability, based on household surveys, with survey-reported personal experiences of supply impacts, projections of future climate hazards (2035–2064), and recent observations of extreme event hazards (2016–2021). Each of these three data sources is detailed next.

4.1 Household water security survey

Data on experiences of extreme weather impacts on household water supplies and concern about future supply reliability come from a novel household water security module conducted as part of a California State University (CSU) CalSPEAKS statewide survey panel. CalSPEAKS is an initiative administered by the Institute for Social Science Research and Instructional Council at CSU Sacramento. CalSPEAKS administers between two and four surveys per year to a set panel of participants which is refreshed approximately annually. The household water security module was included in the survey administered primarily online and fielded between May 5th and June 14th, 2021.[1]

Survey questions for the module were theoretically grounded from Meehan et al. (2020) to ask about individual experiences of water accessibility, affordability, quality, and governance (the full 17 question water security survey module is available in the SI). In this analysis, we analyze the following two climate-related survey questions specifically:

1) In the last 5 years, has your household water supply been impacted by an extreme weather event? Select all that apply with the following seven options: drought, wildfire, heat waves, flood, landslide, other (please specify), and 'N/A. my water supply has not been impacted by an extreme weather event in the past 5 years'.
2) How much do you agree with this statement "I am concerned about California's water supply reliability due to future extreme weather events (e.g., droughts, wildfires, heat waves, floods)" Select only one of the following four responses: strongly disagree, disagree, agree, or strongly agree.

We summarize responses for the first question in three different ways: (1) as a binary variable representing whether the respondent reported one or more impacts or reported no impacts; (2) as an additive index representing the number of different impact types reported by each respondent;

[1] Panelists may request mailed surveys in lieu of completing them online. Mailed surveys generally make up approximately 2–3% of responses.

and (3) as a binary impacted/not impacted variables for each different impact category (to differentiate potential effects of experiencing drought impacts compared to flood impacts for example). The second Likert scale question is our dependent variable and is employed as an ordinal variable. The CalSPEAKS survey also provides several control variables used in our multivariate analysis including household income, education level, race, ideology, and gender, all of which are well-documented correlates of climate concern (Saleh Safi et al. 2012; Lujala et al. 2015; Egan and Mullin 2017; Mayer et al. 2017; Echavarren et al. 2019).

A total of nine reminders were sent to panelists to invite responses resulting in 704 survey responses received from the 1382 panelists, representing a response rate of 51%. Respondents represent every census region in the state (see Supplemental Information Table S1) and most every county (47 of 58, see Supplemental Information Figure S1). Survey responses were weighted to produce unbiased estimates of population parameters which were used for descriptive statistics except where explicitly stated (Fig. 1).[2] More information about the panel and sampling methodology can be found on the CalSPEAKS project website.[3]

4.2 Cal-Adapt climate projections

The second data source is Cal-Adapt, a collaborative data repository that includes the projections of climate change hazards and risks underpinning California's Fourth Climate Change Assessment (Thomas et al. 2018). In order to capture increasing exposure to extreme events under climate scenarios, we employ four proxy indicators representing climate impacts with key implications for water supply reliability in California for mid-century (2035–2064): annual average monthly maximum 1-day precipitation; annual average number of extreme heat days; annual average number of months with 1-month standardized precipitation-evapotranspiration index (SPEI) less than or equal to -1 (SPEI depicts the combined impacts of precipitation deficits and potential evapotranspiration on soil moisture and can be used to detect drought conditions); and wildfire area burned. Maximum precipitation, extreme heat days, and drought conditions were all derived from the Fourth Climate Assessment's 32-model maximum and represent the mean projections for each census-tract polygon. Area burned by wildfire, in turn, represents the sum of projected acres burned per census tract under a business-as-usual scenario and was derived from the CNRM-CM5 model only.[4]

We summarized these four census-tract level climate projections by zip code using HUD USPS zip code crosswalk files to link each survey respondent with their localized hazard projections. Each indicator was rescaled to range from zero to one hundred to account for differing units and we employ the mean of these four scores in our analysis to better

[2] Weights were calculated using the WgtAdjust procedure of the SUDAAN statistical software distributed by RTI International, which relies on a constrained logistic model to predict the likelihood of responding as a function of the following explanatory variables: gender, ethnicity, race, education, marital status, and income. The necessary population benchmarks used for weighting were secured from the latest American Community Survey (ACS). Figure 1 relies on unweighted survey responses to depict these responses geographically.

[3] https://www.csus.edu/center/institute-social-research/survey-research.html

[4] This data was obtained using the caladaptr API client for R (Lyons and R Development Core Team 2022) under high-emission scenario (RCP8.5) for a 30-year mid-century average (2035–2064) using the caladaptr census-tract preset.

Fig. 1 Extreme weather impacts reported by survey respondents by type (unweighted) and zip code: **a** drought ($n=188$); **b** wildfire ($n=40$); **c** heatwaves ($n=39$); **d** flood ($n=6$); **e** landslide ($n=3$); **f** other impacts ($n=7$)

understand reported concern about climate impacts to water supply.[5] Descriptive statistics for the mean score as well as the four scaled proxy indicators are provided in the Supplemental Information.

4.3 NOAA storm events database

Finally, records of extreme weather events were obtained from the National Oceanic and Atmospheric Administration (NOAA) storm events database. This database tracks significant weather phenomena that either have sufficient intensity to cause loss of life, injuries, and property damage or disrupt commerce, or are sufficiently rare enough to generate media attention. Of the many types of storm events recorded, we focus on four specific events best aligned with both the household survey question on types of extreme weather impacts and the projected indicators of future climate hazards from the Fourth Climate Assessment. These events, recorded at the county level, are drought, extreme heat, heavy rain, and wildfire. These events were queried for a 5-year period corresponding with the 5 years asked about in the CalSPEAKS survey (April 2016 to March 2021) resulting in 2358 records. A count of these events over this period was then linked to each survey

[5] We also ran all analyses with an alternate version of this variable representing an individual's maximum scaled risk score among the four indicators. Results were substantively unchanged.

respondent based on their county of residence and serve as a proxy for recent hazard exposure. Descriptive statistics are provided in the Supplemental Information.

4.4 Multivariate analysis

All data analyses were conducted using R open-source statistical software (version 4.2.1). After first employing descriptive statistics and chi-square tests (calculated using weighted survey results) to explore the distribution of reported climate impacts to household water supply across the state as well as survey respondents' concern about future potential impacts, we leverage three versions of an ordinal logistic regression implemented using the MASS package (Ripley 2022) to ascertain whether and how personal experience and hazard exposure influence reported concern about future water supply reliability. Ordinal logistic regressions model the relationship between an ordinal response dependent variable and on one or more independent variables and are thus well suited to this objective. The three models are identical except for the reported impacts to the household water supply independent variable which we use three distinct versions of a dichotomous version indicating whether the respondent had experienced any impacts; a factor version with each impact type considered independentl; and finally, an additive version where the number of distinct impact types an individual reported was summed. The log-odds coefficients of ordinal logistic regressions are exponentiated to produce odds ratios and interpreted in terms of percent change in odds of increasing (or decreasing) response category (e.g., moving for a Likert 2 to a Likert 3 or Likert 3 to a Likert 4) for a one unit increase in the predictor variable (percent change in odds $=100\times$(odds ratio $-$ 1)). We visually display the results as marginal effects (predicted probabilities) calculated using the ggeffects package (Lüdecke 2021). Given the relatively small sample sizes and the high degree of uncertainty and variability inherent in risk perception studies, we use $p<0.1$ as the threshold for significance while maintaining focus on the point estimates, effect sizes, and their relative levels of uncertainty in keeping with established best practices (Amrhein et al. 2017, 2019; Ferguson 2016).

5 Results

Just over a third of respondents (34%, 236 of 704) reported having their water supply impacted by one or more extreme weather events in the last 5 years. Of these impacts, drought was by far the most common, reported by 27% (192 of 704) of all respondents and mirroring the general distribution of survey responses (see supplementary information figure S1). Still, over one-sixth of respondents reported a non-drought impact, led by wildfire (7.5%, 53 of 704), heat waves (5.5%, 39 of 704), and other (2%, 14 of 704). The least reported impact of the 6 options was flooding, with just 0.8% (6 of 704) of respondents reporting such impacts (Fig. 1, which maps the unweighted survey responses). Among the "other" impacts, the only repeated response pertained to power outages which were reported by a similar percentage of respondents as floods. Most of the less common impact types were reported in Central California, although Southern California is also represented for floods and "other" impacts.

Reported extreme weather impacts to household water supplies are relatively evenly distributed across Californians with respect to education, income level, and water provider. Chi-squared tests, however, do indicate significant differences across gender and racial divides. Fewer men (27%, 80 of 296) report extreme weather impacts to their household water supply reliability compared to women (37%, 147 of 394). Genderqueer/non-binary respondents report an even higher rate of these impacts (77%, 3 of 4), although the small *n* for this last group limits our ability to interpret this finding with confidence. Regarding race and ethnicity, Latino and Asian American Pacific Islander (AAPI) respondents are more frequently reported being impacted than other groups (see Table 1). Notably, this difference remains but becomes less significant in the multivariate analysis ($p = 0.098$, see SI).

Overall, 85% (587 of 704) of those surveyed report being concerned about California' future water supply reliability, 52% (360 of 704) of whom agreed with the statement that they are concerned, whereas 33% (227 of 704) strongly agreed. In contrast, 6.4% (44 of 704) and 8.3% (57 of 704) respectively strongly disagreed or more generally disagreed. Geographically, there is little difference between those who agree and disagree with the statement (either strongly or not) although noticeably fewer respondents that disagree are in the northern areas of the state (See supplementary information Figure S2). Concern about future supply reliability also does not appear to vary significantly by water provider (chi-square $p = 0.6$).

To better understand these varying levels of reported concern, and the potential role of recent experiences of extreme weather, discussed previously, as well as geographic hazard exposure, we employ ordinal logit models which also account for individual characteristics which we expect to be correlated with climate concern such as ideology, education, income, gender, race, and age included as covariates. The resulting odds ratios are reported in Table 2 which can be interpreted as percent change in odds. The full model results and performance metrics are reported in the supplementary information.

Experiencing one or more impact to one's household water supply from an extreme event heightens future climate-related water security concern generally, increasing individuals' overall odds of being in a higher Likert category by nearly 150%. This effect can also be quantified at individual levels of concern (Likert values) as displayed in Fig. 2 in the form of estimated marginal means, also known as predicted probabilities (see supplemental information Figures S3, S4, and S5 for estimated marginal means for other Likert levels). For an individual reporting one or more extreme weather impacts to their household water supply, the predicted probability of strongly agreeing that they are concerned about future water supply reliability (Likert 4) is nearly 50%, compared to 28% for an un-impacted individual (see Fig. 2), whereas the probability that an individual would disagree with the statement that they are concerned (Likert 2) drops from 11 to 5% if those individual reports being impacted (see supplementary information figure S4). Critically, this effect is also *cumulative*, meaning that for each additional distinct extreme event impact reported by the respondent, their odds of being in a higher Likert category of concern increases by approximately 81%. While an individual reporting just types of extreme weather impact in the last 5 years (e.g., drought) has a 43% chance of being strongly concerned about future reliability, the predicted probability increases to 58%, 71%, and ultimately 82% as they report two, three, or four different impact types (Fig. 2).

This relationship depends on the *type* of impact reported. When considering the six reported impacts individually, the following impacts are associated with increased odds of being in a higher Likert agreement category: drought (167%), heat (59%), landslide (383%), and "other" reported impacts (249%). Interestingly, odds of being in a higher Likert category decrease as follows for those reporting fire (26%) and flood (54%) impacts. Notably, however, only the reported increases for drought are statistically significant

Table 1 Weighted frequency of recent extreme weather impacts to household water supply by water provider type, gender, income, education, and race

Variable	Number (%) reporting one or more impact	p-value[1]
Water provider		0.8
A small water system run by my community or neighbors	1 (11%)	
A water system run by a water company	58 (36%)	
A water system run by my town or city or special district	151 (33%)	
I don't know	9 (31%)	
Myself, I have a private well	9 (37%)	
Other	0	
Gender		0.033
Female	147 (37%)	
Male	80 (27%)	
Genderqueer/gender non-binary	3 (77%)	
Household income		0.2
\$0–\$50,000	58 (38%)	
\$50,000–\$100,000	48 (26%)	
\$100,000–\$200,000	88 (40%)	
\$200,000 or above	15 (25%)	
Decline to state	27 (33%)	
Education		0.2
Less than high school	5 (84%)	
High school	12 (41%)	
Some college	39 (38%)	
Associates	23 (42%)	
Bachelors	78 (35%)	
Postgraduate	77 (27%)	
Race		0.042
Asian American Pacific Islander (AAPI)	33 (41%)	
Black	7 (23%)	
Latino	51 (46%)	
Non-Hispanic white	141 (32%)	
Other	3 (8.7%)	

[1]Chi-squared statistic with Rao and Scott's second-order correction in the final column indicates whether there are significant differences in reported impacts among subgroups of each displayed variable. A non-significant finding indicates that there is no evidence to reject the null hypothesis that impacts are evenly distributed among respondents with respect to the variable

($p < 0.0001$) as demonstrated by the remainder of confidence intervals containing 1 representing some potential of either a positive or negative effect on reported concern (Fig. 2).[6]

These findings contrast with those relating recent recorded climate hazard events (2016–2021) and mid-century mean climate change exposure with respondents' concern

[6] Because an odds ratio is a ratio of odds under two different conditions, an odds ratio of one indicates that odds of one condition are the same as the odds of the comparison condition.

Table 2 Odds ratios with standard error and 90% confidence intervals for ordinal logit model terms of interest

Term	Odds ratio (exp(coef))	90% confidence interval
Impacted (yes/no)	2.48	1.89–3.28
Number of distinct impact types reported	1.81	1.49–2.20
Drought impacted	2.67	1.97–3.64
Fire impacted	0.74	0.41–1.33
Heat impacted	1.59	0.86–2.99
Flood impacted	0.46	0.11–1.85
Landslide impacted	4.83	0.64–63.51
"Other" impacted	3.49	0.922–15.02
Recorded events 2016–2021	1.001	0.998–1.005
Mid-century mean exposure	1.02	0.99–1.04

about future supply reliability. While mean mid-century projected climate exposure and reported frequency of recent extreme events are both positively associated with increased concern, both have confidence intervals centered around zero indicating high uncertainty in this relationship. Recent recorded events are estimated to have only the most minimal effect on concern (odds of 1.001 indicating a 1% increase with a 90% confidence interval ranging from 0.998 to 1.005). Mid-century climate exposure on the other hand, although also highly uncertain in effect, has the potential to be somewhat more impactful, with an estimated 2% increase in odds of being in a higher Likert agreement category for each 1-point increase on the scaled measure (0–100). As displayed in Fig. 2, the model estimates an approximately 25% increase in predicted probability of being in strong agreement moving from a mean risk of 0 (the minimum observed) to 60 (the maximum observed).[7]

Interestingly, survey-reported impacts are also seemingly unrelated to either recent local extreme event frequency or mid-century mean exposure. Respondents were no more likely to report being impacted in counties with increased observations of recent hazard events 2016–2022 ($r = -2.165$, se $= 2.911$). This remains true at the level of individual event types (see supplemental information, Figure S6). In other words, while certain reported impacts are associated with increased concern, particularly drought, the geographic distribution of individuals perceiving themselves to be drought impacted is not meaningfully associated with recent observed hazards.

6 Discussion

With this study, we contribute novel findings on the climate change-water security nexus in California and provide important insights as to the relationship between personal experience of extreme weather impacts and current and future hazard exposure on concern about future

[7] Roughly half of this large effect size can be attributed to approximately five survey respondents with local mean projected exposure scores of greater than 0.45 (across all respondents mean = 0.26 and median = 0.25), four of whom express extreme concern about future water supply reliability (with the fifth expressing some concern). Yet, even excluding outlier cases, the standard error for this model term remains large.

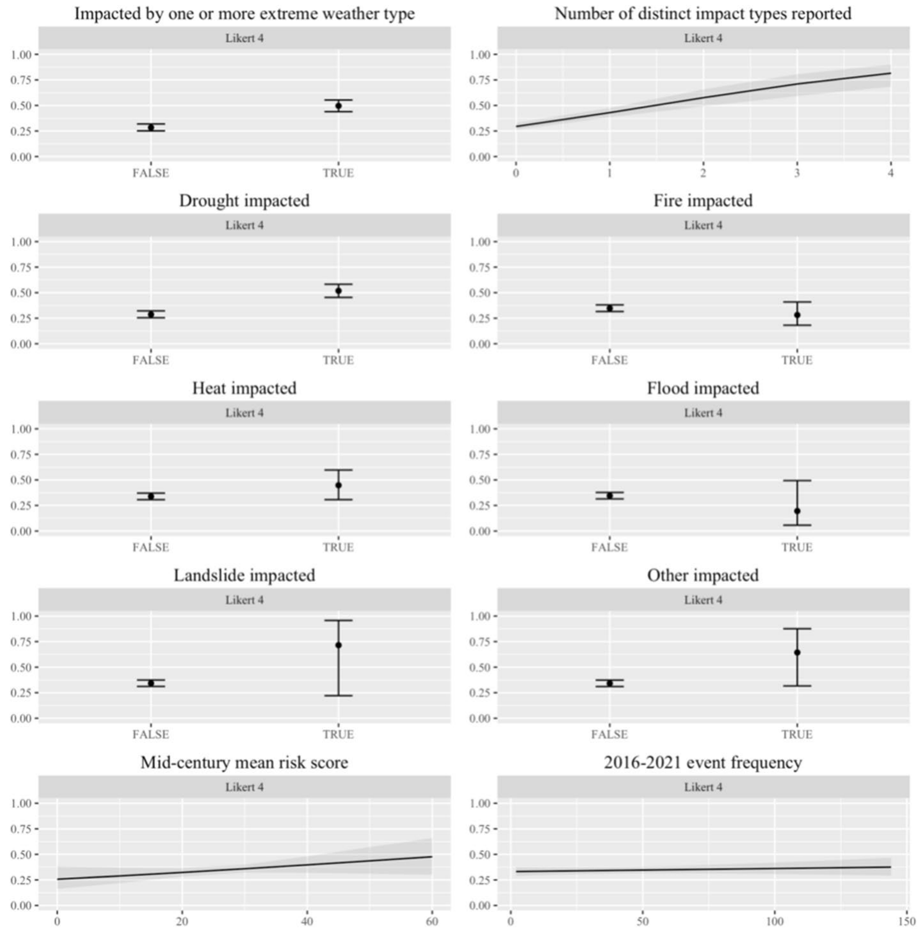

Fig. 2 Estimated marginal means (predicted probabilities) of strong concern (Likert 4) for focal model terms: one or more impact reported, sum of distinct impact types reported, reported impacts by type, mean projected climate risk of exposure score, and 5-year extreme weather event frequency

water supply reliability. Given the important role of household support and compliance for successfully adopting and implementing needed changes, these findings, in turn, have implications for advancing water security adaptation and mitigation. In this discussion, we summarize three key findings derived from the results and explore the associated opportunities and barriers for advancing water security adaptation and mitigation policies with a specific focus on communication strategies to increase household support and compliance.

First, we demonstrate that climate impacts to household water supply are not a future threat but rather are already common across the state. Principal among them are drought impacts, which the frequency of reports in our survey highlight are increasingly synonymous with California. These findings generally correspond with results from other surveys such as the 2021 statewide opinion survey on the environment by the Public Policy Institute of California which found 25% of Californians thought that drought was the most important environmental issue facing the state (Baldassare et al. 2021). It is also notable that the provided "other impacts" field yielded several mentions of power outages. While overall the number of these reports is still small, given the large number of Californians reliant on unregulated groundwater wells, which often lack backup power supplies, and that Public Safety Power Shutoffs are an increasingly common approach to wildfire hazard mitigation in extreme conditions in California, we argue that this climate impact to household water supply merits future attention.

We do not find significant patterns of disproportionate impacts across income, age, or educational levels. Surprisingly we also do not find evidence of significant differences in impact reporting across water provider types, indicating that domestic well owners are no more likely to report household water supply impacts than those served by community water systems. Given the limited number of domestic well owners in our sample ($N=25$), however, we caution against placing much weight on this finding given a significant body of evidence indicating otherwise (Pauloo et al. 2020; Pace et al. 2022). This also serves as a reminder that traditional parameters for representative weighting do not necessarily account for all key differences of interest among residents when it comes to water security.

Where we do observe significant differences is among racial/ethnic groups and across gender identities. We find that both Latino and Asian American Pacific Islander (AAPI) residents are more likely than others to report impacts to their household water supplies. Whether this is attributable to residential type and location which, in turn, informs an individual's water supply source or highlights racial differences in risk perception and climate concern cannot be answered in this present study. Observed differences are even more pronounced for women. These results align with existing research documenting persistent gender differences in water access and concern globally (Harris et al. 2017; Dickin and Caretta 2022), but this finding could also reflect differential risk perception/reporting of impacts as has been found in several previous studies (Mooney et al. 2021). While very limitedly represented in our survey and therefore subject to significant uncertainty, genderqueer and non-binary individuals have the highest rate of reported household water supply impacts (77%). If similar trends are confirmed by a larger study, this would further underscore the unique vulnerabilities LGBTQ+ community to disasters recently documented in other California studies (Goldsmith et al. 2022).

Second, we show that the experience of having your household water supply impacted by extreme weather, as already reported by so many Californians, shapes individuals' concerns about future water supply reliability. Our findings show that reporting one or more extreme event impacts on water supply is significantly associated with increased concern about future water supply reliability. Moreover, concern increases as the number of impact types reported increases (e.g., experiencing drought and fire instead of just one). This demonstrates that the relevance of these widespread impacts transcends immediate questions of water access. Rather, these findings indicate that widespread climate impacts to household water supply are bolstering concern about future reliability statewide. These findings align with recent research that shows proximity to wildfires bolsters support for wildfire adaptation policies (Hui et al. 2022). Notably, however, experiences with different types of extreme weather impacts to household water supply are differently associated with concern.

This nuance leads to our third key finding: support for the view of risk perception as primarily socially constructed rather than based on physical vulnerability measured through exposure (Saleh Safi et al. 2012; Lujala et al. 2015; Shao 2016; Mayer et al. 2017). We find no discernible effect of recent hazard events exposure on reported concern. Future exposure, as measured by mid-century climate projections for a respondent's local community, in turn, are estimated to positively correlate with concern but with a very high degree of uncertainty. Moreover, we find that exposure to recent extreme events are not correlated with reported impacts which support assertions by Howe et al. (2019) and others that not just risk perception but also impact perception is socially constructed.

Collectively, these findings emphasize the need for local managers and decision-makers to concern themselves not only how climate change is projected to affect their water resources, but how, and whether, residents perceive these risks. To the extent that local water managers and decision-makers are reliant on household support and compliance to successfully implement local adaptation strategies, understanding and mitigating household risk perception is a must. To that end, the critical role of personal experience in increasing concern highlights that post-extreme events with water supply impacts may be an especially important window to advance solutions, particularly those requiring one time support such as voting. In these efforts, messaging focused on elucidating impacts may be more effective than more intangible risk-based frames. Critically, however, managers should not assume that all extreme events will necessarily promote concern in the same way or to the same degree. Some event types, like fire and flood, may in fact reduce resident's concern about future water supply reliability, indicating that a switch towards risk-based frames might be warranted. This supports the notion that by concerning themselves with factors related to both psychological and physical distance, decision-makers may be able garner support for adaptation by increasing residents' concern (Nohrstedt & Weible 2010; Singh et al. 2017).

Additional research is needed to build on these suggestions. As noted by Singh et al. (2017), "part of a community's ability to adapt to climate change will also depend on the extent to which that community supports the government institutions focused on preparing for and adapting to climate change impacts." While we consider how to best support local water managers to adapt, it is also essential to increase our understanding of the factors influencing resident's support for these efforts and to support local managers to leverage this knowledge in their communications. After all, a stymied proactive manager is likely no more effective than an incautious one (Klasic et al. 2022).

As previously mentioned, this study is limited by the small sample size of survey responses across key factors such as water provider and gender identity. By nature of the household survey methodology, we also rely on the provider type as indicated to us by the respondent. As a result, we are unable to account for details related to an individual's actual water provider including the type of source water utilized, reliance on imported water, and potentially relevant management and outreach activities by suppliers undertaken to raise customer awareness regarding climate change. These factors are undeniably relevant to household experiences of climate impacts to water supply and merit future consideration as we increase our understanding of how to build and maintain customer support for adaptation. Moreover, California ranks relatively high among states regarding residential awareness and concern about climate change, potentially reducing the generalizability of our findings. It should also be noted that the survey was conducted during year 2 of the COVID global pandemic and during an ongoing mega-drought in the Western USA, which has had tremendous impacts on California water supplies and has been widely discussed in local, state, and national level media coverage. Nonetheless, our study undertakes an important first foray into understanding the climate-related water concerns of residents in the context of the country's most populous state and lays the groundwork for future research.

7 Conclusion

Our findings highlight climate change-driven extreme events as a present and future risk for California residents and demonstrate that related impacts to household water supplies are already being perceived by a significant portion of the population. In doing so, we provide an empirical demonstration of the climate change-household water supply nexus in California. Furthermore, we highlight the importance of attending to public perception of these risks to advance local and regional adaptation. Precisely, because resident support and compliance is pivotal to implementing adaptation strategies, water managers should heed not just to projected impacts (which can help inform the necessary strategies) but also with how their customers experience and perceive climate change risks, which can inform successful strategy implementation. For example, we show that perceived impacts have a significant and compounding influence on individual concern. These findings indicate that impactful events and impact-based messaging can support climate risk communication. However, the effectiveness of this strategy hinges on event type with some, such as fire and flood, being counterproductive in this regard.

As we show here, research that incorporates the nuanced implications of event type and psychological distance can help local managers proactively engage and effectively communicate with their constituencies in support of local adaptation. Further research is needed to fully untangle the complexities of residential risk perception as well as to directly link residential risk perception with adaptation, for example, studies investigating whether the severity or scale of perceived impacts meaningfully alters these relationships and the level of concern necessary to successfully implement adaptation strategies of different types. In the meantime, local managers and decision-makers need to concern themselves not only with how climate change is projected to affect their water resources, but how (and whether) residents perceive impacts due to climate change.

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Data availability The three datasets analyzed during the current study are available as follows: Cal-Adapt data is available from https://cal-adapt.org/data/. NOAA extreme events data is available from https://www.ncdc.noaa.gov/stormevents/. The CalSPEAKS household water security survey module responses will be available from https://calspeaks-dspace.calstate.edu/ after a 16-month embargo from the collection date.

Declarations

Competing interests The authors declare no competing interests.

References

Albright EA, Crow D (2019) Beliefs about climate change in the aftermath of extreme flooding. Clim Change 155:1–17. https://doi.org/10.1007/s10584-019-02461-2

Amrhein V, Korner-Nievergelt F, Roth T (2017) The earth is flat (p > 0,05): significance thresholds and the crisis of unreplicable research. PeerJ 5:e3544. https://doi.org/10.7717/peerj.3544

Amrhein V, Greenland S, McShane B (2019) Scientists rise up against statistical significance. Nature 567:305–307. https://doi.org/10.1038/d41586-019-00857-9

Baldassare M, Bonner D, Lawler R, Thomas D (2021) Californians and the Environment. Public Policy Institute of California. https://www.ppic.org/publication/ppic-statewide-survey-californians-and-the-environment-july-2021/. Accessed 05 Aug 2022

Bell EV, Fencl A, External MM (2022) External drivers of participation in regional collaborative water planning. Policy Stud J. https://doi.org/10.1111/psj.12473

Brody SD, Zahran S, Vedlitz A, Grover H (2008) Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. Environ Behav 40:72–95. https://doi.org/10.1177/0013916506298800

California Department of Water Resources (CDWR) (2022) Statewide summary: locally reported dry wells for drought assistance. Dry well reporting system. https://mydrywell.water.ca.gov/report/publicpage. Accessed 31 May 2022

Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, Sinh BT (2012) Determinants of risk: exposure and vulnerability. In: Field CB et al (eds) Managing the risks of extreme events and disasters to advance climate change adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, New York, pp 65–108

Craig CA, Feng S, Gilbertz S (2019) Water crisis, drought, and climate change in the southeast United States. Land Use Policy 88:104110. https://doi.org/10.1016/j.landusepol.2019.104110

Dean AJ, Fielding KS, Newton FJ (2016) Community knowledge about water: who has better knowledge and is this associated with water-related behaviors and support for water-related policies? PLoS One 11:e0159063. https://doi.org/10.1371/journal.pone.0159063

Demski C, Capstick S, Pidgeon N et al (2017) Experience of extreme weather affects climate change mitigation and adaptation responses. Clim Change 140:149–164. https://doi.org/10.1007/s10584-016-1837-4

Dickin S, Caretta MA (2022) Examining water and gender narratives and realities. WIREs Water 9(5):1–10. https://doi.org/10.1002/wat2.1602

Dobbie MF, Brown RR (2014) A framework for understanding risk perception, explored from the perspective of the water practitioner. Risk Anal 34:294–308. https://doi.org/10.1111/risa.12100

Donner SD, McDaniels J (2013) The influence of national temperature fluctuations on opinions about climate change in the US since 1990. Clim Change 118:537–550. https://doi.org/10.1007/s10584-012-0690-3

Echavarren JM, Balžekienė A, Telešienė A (2019) Multilevel analysis of climate change risk perception in Europe: natural hazards, political contexts and mediating individual effects. Saf Sci 120:813–823. https://doi.org/10.1016/j.ssci.2019.08.024

Egan PJ, Mullin M (2017) Climate change: US public opinion. Annu Rev Polit Sci 20:209–227. https://doi.org/10.1146/annurev-polisci-051215-022857

Ekstrom JA, Bedsworth L, Fencl A (2017) Gauging climate preparedness to inform adaptation needs: local level adaptation in drinking water quality in CA, USA. Clim Change 140:467–481. https://doi.org/10.1007/s10584-016-1870-3

Empinotti VL, Budds J, Aversa M (2019) Governance and water security: the role of the water institutional framework in the 2013–15 water crisis in São Paulo, Brazil. Geoforum 98:46–54. https://doi.org/10.1016/j.geoforum.2018.09.022

Enqvist JP, Ziervogel G (2019) Water governance and justice in Cape Town: an overview. WIREs Water 6(4):1–15. https://doi.org/10.1002/wat2.1354

Ferguson CJ (2016) An effect size primer: a guide for clinicians and researchers. Prof Psychol Res Pract 40(5):532–538. https://doi.org/10.1037/a0015808

Flint CG, Dai X, Jackson-Smith D et al (2017) Social and geographic contexts of water concerns in Utah. Soc Nat Resour 30:885–902. https://doi.org/10.1080/08941920.2016.1264653
Fry H, Lin S, Garrison J, Lin II R-G (2023) California storm death toll reaches 17 as more rain, winds arrive. Damage could top $1 billion. Los Angeles Times. https://www.latimes.com/california/story/2023-01-10/storm-northern-california. Accessed 10 Jan 2023
Garcia-Cuerva L, Berglund EZ, Binder AR (2016) Public perceptions of water shortages, conservation behaviors, and support for water reuse in the US. Resour Conserv Recycl 113:106–115. https://doi.org/10.1016/j.resconrec.2016.06.006
Goldsmith L, Raditz V, Méndez M (2022) Queer and present danger: understanding the disparate impacts of disasters on LGBTQ+ communities. Disasters 46:946–973. https://doi.org/10.1111/disa.12509
Haas S, Gianoli A, Van Eerd M (2021) The roles of community resilience and risk appraisal in climate change adaptation: the experience of the Kannagi Nagar resettlement in Chennai. Environ Urban 33:560–578. https://doi.org/10.1177/0956247821993391
Harris L, Kleiber D, Goldin J et al (2017) Intersections of gender and water: comparative approaches to everyday gendered negotiations of water access in underserved areas of Accra, Ghana and Cape Town, South Africa. J Gend Stud 26:561–582. https://doi.org/10.1080/09589236.2016.1150819
Ho JY, Chan EYY, Lam HCY et al (2019) Is "perceived water insecurity" associated with disaster risk perception, preparedness attitudes, and coping ability in rural China? Int J Environ Res Public Health 16:1254. https://doi.org/10.3390/ijerph16071254
Howden SM, Soussana J-F, Tubiello FN et al (2007) Adapting agriculture to climate change. Proc Natl Acad Sci 104:19691–19696. https://doi.org/10.1073/pnas.0701890104
Howe PD, Marlon JR, Mildenberger M, Shield BS (2019) How will climate change shape climate opinion? Environ Res Lett 14:113001. https://doi.org/10.1088/1748-9326/ab466a
Hubbard ML (2020) The risky business of water resources management: assessment of the public's risk perception of Oregon's water resources. Hum Ecol Risk Assess Int J 26:1970–1987. https://doi.org/10.1080/10807039.2019.1632167
Hui I, Zhao A, Cain BE, Driscoll AM (2022) Baptism by wildfire? Wildfire experiences and public support for wildfire adaptation policies. Am Politics Res 50(1):108–116. https://doi.org/10.1177/1532673X211023926
IPCC (2022) Summary for Policymakers. In: Shukla PR et al (eds) Climate change 2022: mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, pp 1–50. https://doi.org/10.1017/9781009157926.001
Klasic M, Fencl A, Ekstrom JA, Ford A (2022) Adapting to extreme events: small drinking water system manager perspectives on the 2012–2016 California Drought. Clim Change 170:1–25. https://doi.org/10.1007/s10584-021-03305-8
Lord CG, Ross L, Lepper MR (1979) Biased assimilation and attitude polarization: the effects of prior theories on subsequently considered evidence. J Pers Soc Psychol 37:2098–2109. https://doi.org/10.1037/0022-3514.37.11.2098
Lüdecke D (2021) ggeffects: create tidy data frames of marginal effects for "ggplot" from Model Outputs. https://strengejacke.github.io/ggeffects/. Accessed 28 Feb 2022
Lujala P, Lein H (2020) The role of personal experiences in Norwegian perceptions of climate change. Nor Geogr Tidsskr-nor J Geogr 74:138–151. https://doi.org/10.1080/00291951.2020.1731850
Lujala P, Lein H, Rød JK (2015) Climate change, natural hazards, and risk perception: the role of proximity and personal experience. Local Environ 20:489–509. https://doi.org/10.1080/13549839.2014.887666
Lyons A, R Development Core Team (2022) caladaptr: tools for the Cal-Adapt API in R. https://ucanr-igis.github.io/caladaptr. Accessed 08 Feb 2022
Matikinca P, Ziervogel G, Enqvist JP (2020) Drought response impacts on household water use practices in Cape Town, South Africa. Water Policy 22:483–500. https://doi.org/10.2166/wp.2020.169
Mayer A, Shelley TO, Chiricos T, Gertz M (2017) Environmental risk exposure, risk perception, political ideology and support for climate policy. Sociol Focus 50:309–328. https://doi.org/10.1080/00380237.2017.1312855
McDowell CP, Andrade L, Re V, O'Dwyer J, Hynds PD, O'Neill E (2021) Exploring risk perception and behaviours at the intersection of flood events and private groundwater supplies: a qualitative focus group study. Water 13(23):3467. https://doi.org/10.3390/w13233467
Meehan K, Jurjevich JR, Chun NMJW, Sherrill J (2020) Geographies of insecure water access and the housing–water nexus in US cities. Proc Natl Acad Sci. https://doi.org/10.1073/pnas.2007361117
Michetti M, Ghinoi S (2020) Climate-driven vulnerability and risk perception: implications for climate change adaptation in rural Mexico. J Environ Stud Sci 10:290–302. https://doi.org/10.1007/s13412-020-00607-8

Mooney S, O'Dwyer J, Lavallee S, Hynds PD (2021) Private groundwater contamination and extreme weather events: the role of demographics, experience and cognitive factors on risk perceptions of Irish private well users. Sci Total Environ 784:147118. https://doi.org/10.1016/j.scitotenv.2021.147118
Mukherjee M, Mika K, Gold M (2016) Overcoming the challenges to using tiered water rates to enhance water conservation. Calif J Polit Policy 8:3. https://doi.org/10.5070/P2cjpp8331954
Ngo CC, Poortvliet PM, Feindt PH (2020) Drivers of flood and climate change risk perceptions and intention to adapt: an explorative survey in coastal and delta Vietnam. J Risk Res 23:424–446. https://doi.org/10.1080/13669877.2019.1591484
Nohrstedt D, Weible CM (2010) The logic of policy change after crisis: proximity and subsystem interaction. Risk Hazards Crisis Public Policy 1(2):1–32. https://doi.org/10.2202/1944-4079.1035
Nylen NG, Pannu C, Kiparsky M (2018) Learning from California's experience with small water system consolidations. https://www.law.berkeley.edu/research/clee/research/wheeler/learning-from-consolidations/ Accessed 16 Jan 2023
Odimayomi TO, Proctor CR, Wang QE et al (2021) Water safety attitudes, risk perception, experiences, and education for households impacted by the 2018 Camp Fire, California. Nat Hazards 108:947–975. https://doi.org/10.1007/s11069-021-04714-9
Ogunbode CA, Liu Y, Tausch N (2017) The moderating role of political affiliation in the link between flooding experience and preparedness to reduce energy use. Clim Change 145:445–458. https://doi.org/10.1007/s10584-017-2089-7
Ogunbode CA, Doran R, Böhm G (2020) Individual and local flooding experiences are differentially associated with subjective attribution and climate change concern. Clim Change 162:2243–2255. https://doi.org/10.1007/s10584-020-02793-4
Pace C, Balazs C, Bangia K et al (2022) Inequities in drinking water quality among domestic well communities and community water systems, California, 2011–2019. Am J Public Health 112:88–97. https://doi.org/10.2105/ajph.2021.306561
Palazzo J, Li O, Stillinger T, Song R, Wang Y, Hiroyasu E, Zenteno J, Anderson S, Tague C (2017) Urban responses to restrictive conservation policy during drought. Water Resour Res 53(5):4459–4475. https://doi.org/10.1002/2016WR020136
Pathak TB, Maskey ML, Dahlberg JA, Kearns F, Bali KM, Zaccaria D (2018) Climate change trends and impacts on California agriculture: a detailed review. Agronomy 8(3):25. https://doi.org/10.3390/agronomy8030025
Pauloo RA, Escriva-Bou A, Dahlke H et al (2020) Domestic well vulnerability to drought duration and unsustainable groundwater management in California's Central Valley. Environ Res Lett 15:044010. https://doi.org/10.1088/1748-9326/ab6f10
Pierce G, Roquemore P, Kearns F (2021) Wildfire & water supply in California: advancing a research and policy agenda. University of California, Los Angeles. https://innovation.luskin.ucla.edu/wp-content/uploads/2021/12/Wildfire-and-Water-Supply-in-California.pdf. Accessed 5 Aug 2022
PPIC (2022) Our experts weigh in on the drought. Public Policy Inst. Calif. https://www.ppic.org/blog/our-experts-weigh-in-on-the-drought/. Accessed 29 Aug 2022
Proctor CR, Lee J, Yu D, Shah AD, Whelton A (2020) Wildfire caused widespread drinking water distribution network contamination. AWWA Water Science e1183. https://doi.org/10.1002/aws2.1183
Ripley B (2022) MASS: modern applied statistics with S. http://www.stats.ox.ac.uk/pub/MASS4/. Accessed 08 Feb 2022
Rodina L (2019) Defining "water resilience": debates, concepts, approaches, and gaps. WIREs Water 6(2):e1334. https://doi.org/10.1002/wat2.1334
Saleh Safi A, James Smith Jr W, Liu Z (2012) Rural Nevada and climate change: vulnerability, beliefs, and risk perception. Risk Anal Int J 32:1041–1059. https://doi.org/10.1111/j.1539-6924.2012.01836.x
Shao W (2016) Are actual weather and perceived weather the same? Understanding perceptions of local weather and their effects on risk perceptions of global warming. J Risk Res. https://doi.org/10.1080/13669877.2014.1003956
Singh AS, Zwickle A, Bruskotter JT, Wilson R (2017) The perceived psychological distance of climate change impacts and its influence on support for adaptation policy. Environ Sci Policy 73:93–99. https://doi.org/10.1016/j.envsci.2017.04.011
Stewart IT, Rogers J, Graham A (2020) Water security under severe drought and climate change: disparate impacts of the recent severe drought on environmental flows and water supplies in Central California. J Hydrol X 7:100054. https://doi.org/10.1016/j.hydroa.2020.100054
Swain DL, Langenbrunner B, Neelin JD, Hall A (2018) Increasing precipitation volatility in twenty-first-century California. Nat Clim Chang 8(5):427–433. https://doi.org/10.1038/s41558-018-0140-y
Taylor A, de Bruin WB, Dessai S (2014) Climate change beliefs and perceptions of weather-related changes in the United Kingdom. Risk Anal 34:1995–2004. https://doi.org/10.1111/risa.12234

Thomas N, Mukhtyar S, Galey B, Kelly M (2018) Cal-Adapt: linking climate science with energy sector resilience and practitioner need. In: Report prepared for California's fourth climate change assessment. California Governor's Office of planning and research, California natural resources agency, and California energy commission. https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-015_ADA.pdf. Accessed 29 March 2023

US Water Alliance (2020) Water rising: equitable approaches to urban flooding. https://www.uswateralliance.org/sites/uswateralliance.org/files/publications/Water%20Rising%20paper.pdf. Accessed 13 Dec 2022

Wachinger G, Renn O, Begg C, Kuhlicke C (2013) The risk perception paradox-implications for governance and communication of natural hazards. Risk Anal 33:1049–1065. https://doi.org/10.1111/j.1539-6924.2012.01942.x

Whitmarsh L (2008) Are flood victims more concerned about climate change than other people? The role of direct experience in risk perception and behavioural response. J Risk Res 11:351–374. https://doi.org/10.1080/13669870701552235

Williams AP, Abatzoglou JT, Gershunov A, Guzman-Morales J, Bishop DA, Balch JK, Lettenmaier DP (2019) Observed impacts of anthropogenic climate change on wildfire in California. Earth's Future 7(8):892–910. https://doi.org/10.1029/2019EF001210

Wolters EA, Steel BS (2021) Environmental efficacy, climate change beliefs, ideology, and public water policy preferences. IJERPH 18:7000. https://doi.org/10.3390/ijerph18137000

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