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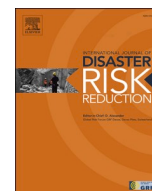
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Wildfire risk perception and communication in disadvantaged communities: Insights from Eastern Coachella Valley in Southern California

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ABSTRACT

Understanding factors associated with wildfire risk perception and preferences for risk communication strategies is crucial for promoting individual risk reduction behaviors and enhancing educational campaigns. Given a lack of research focusing on disadvantaged communities with low socioeconomic status, we administered an in-person survey from February to April 2023 in four unincorporated communities in Eastern Coachella Valley to collect information on wildfire experiences and community preparedness. We used multivariate logistic regressions to identify potential predictors of wildfire risk perception, such as sociodemographic characteristics, previous wildfire experiences, and social participation. We performed Chi-square or Fisher's exact tests to examine whether preferences for risk communication varied across sociodemographic groups. Among 115 participants with wildfire experiences, 113 (98.3 %) were self-identified as Hispanic/Latino and 69 (60.0 %) had an annual household income below \$25,000. Higher safety awareness, more participation in community or social groups, and poorer health were associated with increased wildfire risk perception. Short messages were preferred for wildfire alerts, and television was the most favored information channel. Social media was the most preferred channel among young adults. Elderly individuals and those lacking a high school education were more likely to seek information from doctors than other groups. Agricultural workers relied more on mobile phone texts and personal observations than those in other occupations. Our study highlights significant gaps in preparedness and the inadequacies of current wildfire risk communication in these disadvantaged communities, underscoring the importance of leveraging social interactions to enhance wildfire risk awareness and implementing tailored communication strategies that effectively reach targeted populations.

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1. Introduction

Wildfire frequency and the total area burned in the United States have significantly increased in the past few decades, posing significant threats to the safety of individuals, communities, and their properties [1]. Disadvantaged communities have been disproportionately affected by wildfire disasters [2,3]. These communities are more vulnerable due to several determinants, including low socioeconomic status (SES), language and education barriers, housing and transportation challenges, and demographic factors, thereby leading to higher sensitivity and limited adaptive capacity [4–6]. Census tracts where the majority of the population is Black, Hispanic, or Native American can experience about 50 % more wildfire vulnerability compared with other regions [4]. Additionally, prior studies have also identified risk perception as a social determinant of fire hazard vulnerability for high-risk communities [7]; risk perception involves the assessment of the likely occurrence of an event and the likely consequences that will be incurred [8–10].

Risk perception can influence the development of mitigation decisions and risk reduction behaviors [8,11,12]. According to the Protection Motivation Theory, both the perceived probability and consequences of a threatening event, along with the perceived effectiveness of coping behaviors, can positively affect an individual's intention to adopt mitigation measures [13,14]. Higher wildfire risk perception has been linked to individual health-protective actions and evacuation decisions [9,12,15–17]. Lower perception may result in inadequate mitigation behaviors and increased safety and property threats. For example, during the 2009 Victorian 'Black Saturday' bushfires, one of the worst bushfire disasters recorded in Australia's history, many residents chose to stay and defend their properties with the belief that they would succeed despite the extreme fire danger; this resulted in the significant destruction of their homes and endangerment of lives [18]. Furthermore, despite evacuation policies, a study from New Mexico, United States, found that 11 % of residents would not evacuate even under a mandatory order [12], making them especially vulnerable.

Access to information is essential for raising awareness about a hazard, including understanding its potential consequences and ways to mitigate damage, which ultimately influences an individual's risk perception [10]. However, underserved and disadvantaged communities usually face language barriers, have limited access to information resources, and experience historical marginalization in disaster planning processes [6,19]. These factors might introduce misinformation and biases into their estimates of wildfire risks, potentially leading to inadequate risk perception and increased social vulnerability [10,20]. Understanding the factors that can influence the wildfire risk perception of residents in disadvantaged communities is key to developing interventions that encourage self-protection measures and strengthen their ability to cope with increased wildfire risks, thereby promoting environmental justice.

Increased scientific knowledge about environmental hazards can improve the accuracy of risk estimates; in the context of wildfires, a deeper understanding of fire-related issues has been associated with higher risk perception [21]. Effective wildfire risk communication plays a vital role in disseminating such knowledge, announcing fire hazards, and providing safety precautions and guidance for future wildfire responses, which can help raise public awareness and strengthen risk perception. Communication efficacy can be influenced by factors such as media choice, message content and style, and timing [22–24]. While traditional media such as television and emergency broadcasts remain the primary channels for wildfire alerts, social media platforms such as Facebook and Twitter are emerging as important sources [25,26]. Subpopulations can display unique preferences and varying degrees of adherence to different communication strategies [22,23,27]. Using simple keyword phrases and providing actionable guidance when communicating wildfire-related health risks is crucial for enhancing public compliance with health advisories [22,26]. Higher compliance has generally been observed among individuals who are primarily English speakers, full-time employees, or those with post-secondary education, higher annual incomes, or previous wildfire experiences [26]. Recognizing and addressing the specific needs of different sociodemographic subgroups for wildfire risk communication is essential to reducing their vulnerability.

Previous wildfire-related research has typically focused on wildland-urban interface (WUI) communities and has used mail, web-based, or phone surveys. However, communities with low SES usually face significant barriers, including limited access to digital communication technologies (e.g., Internet, email, or smartphones) and language obstacles that impede their understanding of surveys in English. These factors can result in low participation of those communities in wildfire-related investigations, particularly in phone or online surveys. In addition, migrant or farmworker families in these disadvantaged communities may not be responsive to mail or phone surveys due to the informal nature of their housing and the absence of their phone numbers or addresses from publicly available lists [28]. Given their social vulnerability to environmental threats [29], it is critical to conduct research in these areas to guide future wildfire risk management and educational campaigns. Our study aimed to conduct a questionnaire survey in disadvantaged communities to 1) identify factors that influence an individual's perception of wildfire risk and 2) understand how the local government can communicate wildfire risks more effectively and provide better services and mitigation strategies.

2. Factors associated with wildfire risk perception

Wildfire risk perception can vary across subpopulations and be shaped by social environments. Existing literature has linked personal characteristics, such as sociodemographic factors and prior wildfire experiences, to variations in wildfire risk perception [8]. Recent studies have further incorporated individual safety awareness into the prediction models of wildfire risk perception [15,30]. In our study, to identify subpopulations with relatively lower wildfire risk perception and explore the potential of social interaction to enhance these perceptions, we considered the following factors.

2.1. Sociodemographic factors

We considered age, gender, educational attainment, household income, parcel size, and the number of household members. Studies

among residents in WUI communities have found that older individuals tended to exhibit low levels of wildfire risk perception [8,31]. This may be because they perceive themselves as less vulnerable potentially due to greater experience and knowledge of fire hazards compared with younger populations. However, the older population can be particularly vulnerable to wildfires given age-related physiological changes, such as weakened cardiorespiratory system and limited mobility [32,33]. Understanding the relationship between age and wildfire risk perception can help design targeted interventions and health educational campaigns.

Some studies have concluded that across all age groups, more objective knowledge about wildfires and higher educational attainment may increase wildfire risk perception and make individuals more likely to adopt mitigation measures or comply with evacuation orders [9,14,15]. Income level can also positively influence a household's concern about the potential danger of wildfires [12]. These findings suggested the importance of prioritizing risk communication for populations with lower income and education levels to improve their preparedness for mitigating risks or evacuating effectively.

Furthermore, previous studies have reported gender differences in wildfire risk perception, with females exhibiting relatively higher levels of perceived environmental health risks [8,34,35]. This association might be partly explained by the role of females as nurturers and caregivers within families, as they may have greater concerns about the health and safety issues of family members [36]. Additionally, family structure may also play a role in shaping risk perception. Households with more adults tend to perceive lower wildfire risks, a pattern consistent with findings from studies on floods [15].

We considered the number of rooms in the house as a proxy for lot size. Parcel size has been commonly examined in several studies on social vulnerability to wildfires [20,37], risk perception [8,34,38], and mitigation behavior intentions [39,40]. A larger lot size can increase the effort required for fuel management and influence aspects of risk interdependency, such as the length of property boundaries shared with neighbors and the diversity of adjacent property owners [8,41]. Associations between parcel size and wildfire risk perception among homeowners may reflect the emotional attachment to a home or a sense of personal responsibility to protect one's property [18,42].

2.2. Wildfire experiences and related health conditions

We considered the total number of experienced wildfires, experiencing wildfires within 10 miles of home, experiencing or hearing about property and life losses, seeing fire flames, evacuation experiences, general health conditions, and experiencing physical or mental symptoms during a wildfire in our study. Prior wildfire experience is one of the most extensively studied factors associated with risk perception. Several studies have demonstrated its positive influence [8,12,14,30,34,43], although some studies have reported nonsignificant results [9,15].

Wildfire experience may lead to increased knowledge and more positive attitudes [44]. Its association with risk perception can also be explained by the availability heuristic, which suggests that people assess the frequency or probability of a future event based on "occurrences that are brought to mind" [45]. Furthermore, researchers have proposed the concepts of post-exposure wake-up call and post-exposure letdown to explain changes in wildfire risk perception after experiencing a wildfire event [34,38,46,47]. While experiencing a wildfire may heighten an individual's perceived susceptibility to future wildfires, it can also lead to the belief that such a wildfire event was a low-probability occurrence, thereby reducing their perceived likelihood of recurrence [46].

Recent studies by Kuligowski et al. have examined more specific fire cues (e.g., seeing flames or embers, and seeing or smelling smoke) and suggested that asking respondents about these experiences may provide deeper insights into the influence of wildfire experiences [15,30,48]. Additionally, they examined health conditions and found that having a medical condition was associated with an increase in risk perception [15,48]. Guided by these findings, our study incorporated various indicators of wildfire experience and related health issues.

2.3. Individual safety awareness during wildfires

A household's risk rating of wildfires in their living area can increase concerns about potential wildfire damage to their home [12]. However, some studies have observed a negative influence of prior awareness of fire risk on wildfire risk perception. Kuligowski et al. found that believing wildfires could pose a problem in one's living area was associated with a decrease in respondents' belief that themselves, others, pets, or livestock could be injured or die when deciding whether to evacuate [15,30]. These results suggested that while individuals recognized wildfires as an issue, they may not have fully understood the personal risks involved. Therefore, we considered individual safety awareness in previous wildfires to better understand its influence on wildfire risk perception.

2.4. Participation in social interactions

Adequate social interaction may foster a deeper understanding of wildfire risks and improve individuals' preparedness and response strategies [8]. Following the study of Brenkert-Smith et al., we differentiated between formal and informal interactions. Formal interactions involve participating in social groups at least monthly and participating in community groups at least monthly, while informal interactions include having close neighbors less than 100 feet away, interacting with neighbors at least monthly, and talking to neighbors about wildfires. Both types of interaction have been shown to positively influence wildfire risk perception [8,34,49]. Interactions among social groups can shape how an individual interprets and assesses risk information, influenced by the embodied frame of values within the group [50]. At the community level, interactions may contribute to building social capital and strengthening community cohesion, which can influence wildfire perception and preparedness [51–53]. Furthermore, these interactions may affect risk interdependency by fostering a sense of shared responsibility or serving as vital sources of information [8].

3. Methods

3.1. Study area

From February to April 2023, we administered an in-person survey in Eastern Coachella Valley (ECV), an area in the eastern section of an arid rift valley in Riverside County, California (Fig. 1). ECV has a typical desert climate and is considered highly vulnerable to wildfires due to its extreme temperatures, dry conditions, flammable vegetation, and wind patterns [54–56]. ECV faces significant economic hardship, with a predominantly Hispanic/Latino immigrant population and many working in farms or fields [57–59]. The socio-economic issues in ECV, such as poverty, limited access to education and healthcare, and inadequate housing, further contribute to its vulnerability to environmental disasters.

We aimed to survey residents in four unincorporated communities located on the north shore of the Salton Sea, i.e., Mecca, North Shore, Thermal, and Oasis, where residents live in more rural and isolated areas and are predominantly monolingual Spanish speakers [60]. These areas in ECV are designated as disadvantaged communities with a high cumulative exposure to air pollution. The local wildfire risk and associated pollution are compounded by the lack of municipal governance, limited resources for emergency responses, and inadequate mitigation efforts. In response to Assembly Bill (AB) 617, which aims to support communities disproportionately burdened by air pollution and address local sources, these communities were selected for the Community Air Monitoring Plan and Community Emissions Reduction Program by the California Air Resources Board (CARB) and South Coast Air Quality Management District (SCAQMD) in 2019 [61]. The local Community Steering Committee (CSC) plays a critical role in promoting community engagement in the development and implementation of these programs. The Institutional Review Board of the University of California, Irvine has approved this study.

3.2. Sampling strategy and final sample

We collaborated with Communities for a New California Education Fund (CNC EF), a non-profit ECV community-based organization and an active member of the ECV CSC, to conduct focus group discussions and surveys. We recruited community residents with self-reported wildfire experiences through purposive sampling. Recruitment methods included distributing print flyers in person at community events, during door-to-door canvassing, and at monthly meetings of the ECV CSC. Additionally, the flyers were shared digitally via the Instagram account of the CNC EF to ensure a comprehensive outreach. The outreach effort yielded 10 in-person focus groups and 118 participants in total. It is important to note that our non-random sampling method may lead to selection bias. Individuals who were more cognizant of or more vulnerable to wildfire risks due to a lack of resources might be disproportionately represented in our sample, contributing to an overestimation of risk perception in our findings.

At the beginning of each focus group, the anonymous survey was administered following a comprehensive review of the consent form with the community participants. Participants were compensated with a \$50 cash card for their participation. This study focused on the analysis of quantitative statistics obtained from the survey; more detailed information regarding the focus group discussions can be found elsewhere [62]. We collected 115 completed surveys from participants who reported wildfire experiences during the past five years and excluded 3 participants with no recent wildfire experiences.

The sociodemographic characteristics of study participants ($n = 115$) are shown in Table 1. The majority were young adults (18–44 years, 39.1 %) and middle-aged adults (45–64 years, 43.5 %). The percentage of older participants (≥ 65 years) was 15.7 %, slightly lower than the 19.8 % observed in Coachella Valley [63]. The median age of our sample was 49.5 years ($SD = 16.23$), relatively higher

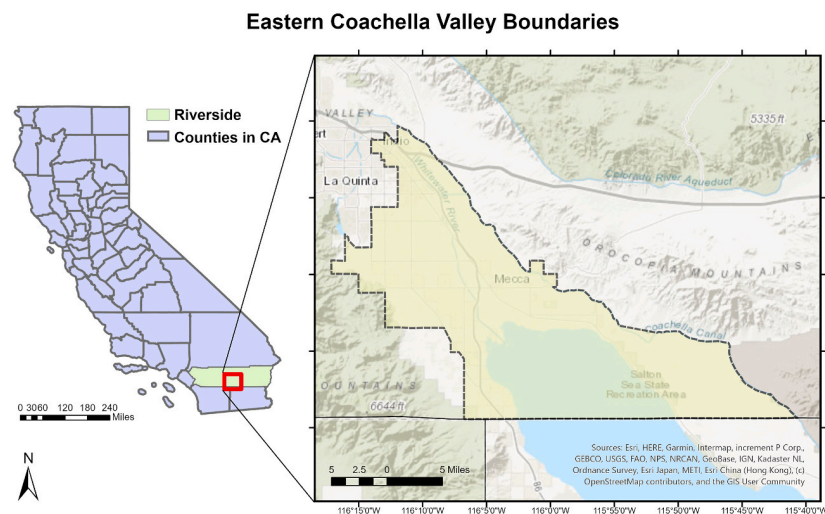


Fig. 1. The boundaries of the Eastern Coachella Valley in Riverside County, California (CA), United States.

than the median age of 40.7 years in Coachella Valley. Approximately two-thirds (68.7 %) of the participants were females, a higher percentage than in Coachella Valley (50.1 %). Almost all the participants self-identified as Hispanic/Latino (98.3 %). About 44.4 % of our participants had not attended high school and only 6.1 % held a bachelor's degree or higher. Sixty percent reported an annual household income lower than \$25,000 (the federal poverty level). The educational attainment and household income of our study participants were both lower than the Coachella Valley averages, where 18.8 % of individuals have a bachelor's degree or higher and the median household income is \$65,105. In addition, 46.1 % of the participants had an occupation related to farm work or agriculture. Overall, participants from the four unincorporated communities were older, had a higher proportion of females, and had lower SES compared with the Coachella Valley averages.

3.3. Survey instrument

The survey development was theory-guided based on a wildfire vulnerability framework that considers structural and individual determinants of wildfire risk to assess community capacity to respond to wildfire risk [4]. The wildfire community vulnerability framework focuses on two main components: (1) wildfire hazard potential, for which our survey included questions about previous wildfire experiences and their impacts on health and daily life, and (2) adaptive capacity, where we asked about mitigation measures and available resources to reduce exposure to wildfire smoke. Additionally, to inform future community preparedness efforts, we collected data on wildfire-related risk perception, attitudes, social interactions, and preferences for risk communication strategies.

The 57-item survey questionnaire in both English and Spanish was organized into seven sections: wildfire experiences, impacts of wildfires, wildfire risk perception, social interactions, mitigation behaviors, wildfire risk communication, and socio-demographics. We

Table 1
The sociodemographic characteristics of the survey study participants (n = 115).

Characteristics	Total participants (n = 115)	Mecca (n = 61)	North Shore (n = 39)	Other ^a (n = 15)
Age, y				
Median $\pm$ SD	49.5 $\pm$ 16.23	41 $\pm$ 14.94	56 $\pm$ 15.07	61.5 $\pm$ 13.61
<18 ^b	1 (0.87)	0	1 (2.56)	0
18–44	45 (39.13)	34 (55.74)	8 (20.51)	3 (20.00)
45–64	50 (43.48)	22 (36.07)	21 (53.85)	7 (46.67)
≥ 65	18 (15.65)	5 (8.20)	9 (23.08)	4 (26.67)
Missing/prefer not to answer	1 (0.87)	0	0	1 (6.67)
Gender				
Female	79 (68.70)	43 (70.49)	25 (64.10)	11 (73.33)
Male	35 (30.43)	18 (29.51)	14 (35.90)	3 (20.00)
Missing/prefer not to answer	1 (0.87)	0	0	1 (6.67)
Race/ethnicity				
Asian	1 (0.87)	0	1 (2.56)	0
Hispanic/Latino	113 (98.26)	61 (100.00)	38 (97.44)	14 (93.33)
Missing/prefer not to answer	1 (0.87)	0	0	1 (6.67)
Education level				
No formal education	22 (19.13)	11 (18.03)	9 (23.08)	2 (13.33)
Primary school	29 (25.22)	15 (24.59)	9 (23.08)	5 (33.33)
Junior high school	34 (29.57)	20 (32.79)	10 (25.64)	4 (26.67)
Senior high school	11 (9.57)	9 (14.75)	1 (2.56)	1 (6.67)
Some college	9 (7.83)	5 (8.20)	3 (7.69)	1 (6.67)
Bachelor's degree or higher	7 (6.09)	1 (1.64)	5 (12.82)	1 (6.67)
Missing/prefer not to answer	3 (2.61)	0	2 (5.12)	1 (6.67)
Household income level, \$				
<\$25,000	69 (60.00)	36 (59.02)	24 (61.54)	9 (60.00)
\$25,000–\$34,999	16 (13.91)	9 (14.75)	6 (15.38)	1 (6.67)
\$35,000–\$49,999	3 (2.61)	2 (3.28)	1 (2.56)	0
\$50,000–\$74,999	0	0	0	0
\$75,000–\$99,999	0	0	0	0
\$100,000–\$124,999	0	0	0	0
\$125,000–\$199,999	0	0	0	0
$\geq$ \$200,000	3 (2.61)	1 (1.64)	1 (2.56)	1 (6.67)
Missing/prefer not to answer	24 (20.87)	13 (21.31)	7 (17.95)	4 (26.67)
Occupation				
Farm/agriculture worker	53 (46.09)	31 (50.82)	19 (48.72)	3 (20.00)
Other ^c	26 (22.61)	15 (24.59)	9 (23.08)	2 (13.33)
Retired/unemployed	20 (17.39)	10 (16.39)	6 (15.38)	4 (26.67)
Missing/prefer not to answer	16 (13.91)	5 (8.20)	5 (12.82)	6 (40.00)

^a The “Other” group includes people from Thermal (n = 5), Coachella City (n = 2), and people who prefer not to report the residential information (n = 8).

^b The age of this participant was 17 years old.

^c The “Other” group includes people in various occupations including gardeners (n = 5), hospitality workers (n = 1), retail store employees (n = 3), administrative positions (n = 1), non-profit organization staff (n = 1), county or city affiliates (n = 1), homemakers (n = 12), and other unspecified occupations (n = 2).

incorporated questions from existing instruments for sections such as wildfire experiences and social interactions [4,8,34]. A summary of the survey studies referenced in our investigation of factors associated with wildfire risk perception is provided in the supplementary materials (Tables S1–S2). Furthermore, drawing on the prior experience of the CNC EF staff working with communities of the ECV, as well as insights gained from our outreach efforts and pre-experiments, we tailored additional sections of our questionnaire to specifically address wildfire impacts, attitudes, mitigation behaviors, and risk communication. These sections were developed to account for the unique characteristics of our target population and to reflect their specific concerns and needs. Considering their typically lower SES and primary occupations in agriculture or farm work, our questionnaire asked about the impact of wildfires on work-related challenges and access to essential life supplies such as food, water, and power/energy. We also included items addressing language or technical barriers that could affect the understanding of wildfire notifications. Furthermore, we customized some question options to reflect specific circumstances faced by the residents, such as physical symptoms related to wildfires (e.g., skin conditions like eczema) and the availability of mitigation measures and information sources, which may be inadequate in this unincorporated area. The survey in both English and Spanish is included in the supplementary materials.

3.4. Statistical analysis

Descriptive statistics on the frequency and percentage of survey responses were first summarized. We then performed multivariate logistic regression models to identify the factors associated with wildfire risk perception. As suggested by existing literature, we assessed wildfire risk perception as a combination of the perceived probability and consequences. However, due to the high homogeneity of responses regarding the perceived probability (i.e., 88.7 % of participants perceived a high level of wildfire occurrence in ECV), we assessed only the perceived consequences of wildfires in our regression models. Participants rated their level of concern regarding the risk that wildfires pose to their lives and homes using the following categories: a great deal of risk ($n = 64$, 55.7 %), some risk ($n = 40$, 34.8 %), not much risk ($n = 9$, 7.8 %), and no risk at all ($n = 2$, 1.7 %). To create more statistically robust categories, these responses were further dichotomized into high (i.e., “a great deal of risk”) vs. low (i.e., “some risk”, “not much risk”, or “no risk at all”) ($n = 51$, 44.3 %).

To examine factors associated with the perceived consequences of wildfires, we first conducted multivariate regressions separately for each category, i.e., sociodemographic factors, wildfire experiences, health conditions, safety awareness, and participation in social interactions. Sociodemographic factors were controlled in the models for the other four categories. Race/ethnicity was not considered a predictor variable due to the homogeneity of our study population, with 98.3 % of participants being Hispanic/Latino. The number of rooms in the house, household members, and experienced wildfires were categorized for regression analysis. Correlations between two related categorical factors in each group were measured based on Cramer’s V coefficient, and factors with strong correlations were combined. Subsequently, we conducted a second-stage comprehensive multivariate regression incorporating all significant predictors from the various categories to examine their associations with risk perception and adjusted for sociodemographic factors. Since about 20.9 % of participants did not disclose their household income level, to avoid a reduction in sample size in our data analysis, we applied multiple imputation by using the PROC MI procedure in SAS to estimate missing income data (i.e., <\$25,000 or ≥\$25,000) based on age, gender, and educational attainment [30].

To understand the preference for wildfire-related risk communication strategies, we performed chi-square tests or Fisher’s exact tests to examine how the preferences for wildfire risk communication styles and channels vary among participants with different demographic characteristics, including age (18–44 y, 45–64 y, and ≥65 y), gender (female vs. male), education level (less than high school, high school, and college or higher), and occupation (farm/agriculture worker, other occupations, and retired/unemployed). A two-sided p -value <0.05 was considered statistically significant, while a p -value between 0.05 and 0.1 was considered marginally significant. All analyses were conducted with SAS version 9.4.

4. Results

The descriptive statistics of the survey are shown in Table 1 and Tables S3–S11. For attitudes related to wildfire risks (Table S6), a majority of participants (93.0 %) acknowledged that climate change could increase the risk of wildfires. Additionally, 88.7 % of participants perceived an increasing wildfire risk in ECV, yet only 27.8 % believed that adequate measures had been implemented to mitigate this risk. About half of the participants (54.8 %) recognized the importance of having a more informed and prepared ECV to prevent and reduce wildfire risk. Furthermore, most participants (72.2 %) agreed that wildfires could contribute to diseases or illnesses, and 54.8 % acknowledged the potential of wildfire exposure to cause adverse pregnancy outcomes.

Regarding personal safety awareness and preparedness during wildfires (Table S6), 28.7 % of participants rated their safety awareness as very high and 27.0 % as somewhat high. In contrast, 17.4 % reported their awareness as somewhat low, 14.8 % as very low, and 11.3 % were uncertain. Factors heightening safety awareness of wildfires included actual property damage or injury to a friend or neighbor (55.7 %), news stories about potential severe wildfires (48.7 %), personal or family property damage or injury (47.8 %), and reading or hearing statistics about the likelihood of severe wildfire events (47.0 %).

The survey data showed that only 11 participants (9.6 %) had signed up for wildfire alert messages, and only 43 (37.4 %) had received health advice or air quality notifications that prompt actions during a wildfire. Among these 43 participants, the most received messages were “stay indoors” (72.1 %), “keep home windows closed” (65.1 %), and “drink bottled water” (60.5 %) (Table S9). Most of them found these messages clear (90.7 %), although 60.5 % indicated that language could be a potential obstacle to understanding, and 32.6 % worried about some messages being too technical. The preferred language for risk communication among all participants was Spanish (86.1 %), with a small subset (4.4 %) suggesting that messages should be bilingual as their children only learn

English in school.

A majority of participants (87.8 %) strongly agree or somewhat agree that the alerts related to wildfires could help them reduce exposure to wildfire smoke (Table S10). They expressed a substantial need for information on the health impacts of wildfire smoke (77.4 %), with specific preventive measures as a secondary focus (45.2 %). Only 16.5 % of participants expressed an interest in learning more information about the costs associated with specific prevention measures.

More details regarding wildfire experiences (Table S4), impacts of wildfires (Table S5), social interactions (Table S7), and mitigation measures (Table S8) are described in the supplementary materials.

4.1. Factors influencing wildfire risk perception

The associations between different groups of factors and the perceived consequences of wildfires after estimating missing household income values through multiple imputation are shown in Table 2. We observed that individual safety awareness and participation in social/community groups were significantly associated with the perceived consequences of wildfires. Marginally significant associations were observed for gender and general health conditions, with females and individuals in poor health condition more likely to perceive greater consequences of wildfires. We found no significant associations with previous wildfire experiences. The

Table 2

Associations between factors of different categories and the perceived consequences of wildfires estimated separately in multivariate logistic regression models.

Variables	Beta estimate	Std. Error	P value	Adjusted OR (95 % CI)
Sociodemographic factors				
Age: 45–64 years ^a	0.59	0.54	0.28	1.80 (0.63–5.15)
Age: ≥64 years ^a	1.13	0.91	0.22	3.09 (0.52–18.46)
Female ^b	0.98	0.51	0.06	2.65 (0.98–7.20)
Education: primary school ^c	−0.81	0.82	0.32	0.45 (0.09–2.22)
Education: high school ^c	−0.38	0.69	0.59	0.69 (0.18–2.66)
Education: college or higher ^c	−0.94	0.95	0.32	0.39 (0.06–2.53)
Income: ≥\$25,000 ^d	1.11	0.73	0.13	3.05 (0.73–12.78)
No. of rooms: ≥4 ^e	−0.44	0.53	0.41	0.65 (0.23–1.82)
No. of household members: 4–6 ^f	−0.02	0.61	0.97	0.98 (0.30–3.24)
No. of household members: ≥6 ^f	0.19	0.65	0.77	1.21 (0.34–4.33)
Wildfire experiences ^g				
No. of experienced wildfires: 4–6 ^h	0.28	0.62	0.65	1.32 (0.40–4.42)
No. of experienced wildfires: ≥7 ^h	−0.20	0.56	0.72	0.82 (0.27–2.44)
Property/life loss	0.31	0.57	0.58	1.37 (0.45–4.17)
Experiencing wildfires within 10 miles of homes	0.34	0.57	0.55	1.41 (0.46–4.27)
Seeing fire flames	0.18	0.55	0.75	1.19 (0.41–3.50)
Evacuation experiences	0.30	0.52	0.56	1.36 (0.49–3.77)
Health conditions ^g				
General health condition: moderate ⁱ	1.21	0.83	0.15	3.35 (0.65–17.14)
General health condition: poor ⁱ	1.68	0.88	0.05	5.37 (0.97–29.89)
Health symptoms related to wildfires: having both physical and mental symptoms ^j	0.45	0.78	0.56	1.57 (0.34–7.26)
Health symptoms related to wildfires: having physical or mental symptoms ^j	−0.43	1.03	0.68	0.65 (0.09–4.88)
Safety awareness ^g				
Having a high level of safety awareness ^k	1.38	0.51	0.01	3.99 (1.46–10.86)
Social interactions ^g				
Having close neighbors less than 100 feet away	−0.25	0.73	0.73	0.78 (0.19–3.24)
Interacting with neighbors ^l	0.53	0.82	0.51	1.70 (0.34–8.42)
Participating in social/community groups ^m	1.37	0.53	0.01	3.93 (1.39–11.07)

Abbreviations: CI, confidence interval; OR, odds ratio.

^a Reference group, age group <45 years.

^b Reference group, the male group.

^c Reference group, no formal education; high school group, junior or senior high school; college or higher group, some college, bachelor or higher degree.

^d Reference group, household income <\$25,000. The missing household income values were estimated through multiple imputation.

^e Reference group, ≤3 rooms in the house.

^f Reference group, ≤3 household members (including adults and children) in the family.

^g Models were adjusted for all sociodemographic factors, including age, gender, educational attainment, household income level, the number of rooms in the house, and the number of household members. The missing household income values were estimated through multiple imputation.

^h Reference group, ≤3 experienced wildfire events.

ⁱ Reference group, the group with excellent or very good health condition; moderate group, the group with good health condition; poor group, the group with fair or poor health condition.

^j Reference group, having no physical or mental symptoms.

^k Reference group, somewhat low or very low safety awareness; high safety awareness group, very high or somewhat high.

^l The group consists of participants interacting with neighbors at least monthly or discussing wildfires with a neighbor.

^m The group consists of participants participating in social or community groups at least monthly.

results of sociodemographic factors before and after multiple imputation are presented in Table S12.

The second-stage multivariate regression incorporated individual safety awareness, participation in social/community groups, gender, and general health conditions, while adjusting for other sociodemographic factors (Table 3). We observed that participants with a higher level of safety awareness (adjusted OR = 3.64, 95 % CI: 1.24–10.69; P value = 0.02) and who attended social or community groups at least monthly (adjusted OR = 3.92, 95 % CI: 1.35–11.43; P value = 0.01) were more likely to have greater perceived consequences of wildfires. In addition, we observed a marginally significant association between general health conditions and wildfire risk perception, where people in poor health condition tended to have greater perceived consequences of wildfires compared with those in good health condition (adjusted OR = 4.40, 95 % CI: 0.78–24.84; P value = 0.09).

4.2. Preferences for wildfire risk communication

Our analysis of information style preferences revealed that most participants (78.3 %) favored short messages, followed by conversations (33.0 %) and videos (31.3 %) (Table S11). Individual preferences varied significantly by age (Table S13) and gender (Table S14), but not by education (Table S15) or occupation (Table S16). Young adults (88.9 %) and middle-aged adults (76.0 %) preferred short messages more than the elderly (55.6 %) (Fig. 2). In contrast, a higher proportion of middle-aged (42.0 %) and elderly adults (50.0 %) favored conversations over young adults (17.8 %). Furthermore, male participants (45.7 %) preferred wildfire information in video format more than female participants (25.3 %).

Regarding information channels, television (70.4 %), radio (67.8 %), mobile phone texts (63.5 %), and social media (53.9 %) were the most popular among our participants (Table S11), and individual preferences varied significantly with demographic factors (Fig. 2). Young adults preferred social media significantly more (73.3 %) than middle-aged (46.0 %) and elderly adults (27.8 %) (Table S17). Additionally, elderly individuals (44.4 %) were more likely to seek information from doctors compared with young (13.3 %) and middle-aged adults (26.0 %). A higher preference for television was observed among male participants (85.7 %) relative to females (64.6 %) (Table S18). Moreover, those without a high school education were more inclined to consult doctors (35.3 %), compared with high school graduates (11.1 %) and college-educated individuals (18.8 %) (Table S19). Occupation also played a role in channel preferences; individuals in farming or agricultural occupations relied more on mobile phone texts (73.6 %) and personal observations (45.3 %) compared with those in other professions (42.3 % and 19.2 %, respectively) or retired or unemployed individuals (55.0 % and 25.0 %, respectively) (Table S20).

5. Discussion

Our survey in ECV characterizes risk perception and preferences for risk communication strategies among residents of unincorporated communities. These residents, primarily monolingual Spanish speakers, are geographically and linguistically isolated, with little to no local government or public services. They predominantly depend on the county fire department; however, the department engages with them minimally. Community-level characteristics likely shape residents' risk perceptions about the consequences of wildfires, especially since they have experienced receiving minimal post-fire assistance [62]. Given the frequent wildfires in this grass-covered arid desert region, where smoke poses a significant health hazard, residents may focus their risk perception on immediate consequences, such as the respiratory health impacts of smoke and the potential loss of their homes or trailers, leading to homelessness. Furthermore, factors such as linguistic isolation, limited formal education, low household income, and possibly limited transportation can hinder their ability to take protective actions. Prior literature has shown the importance of agency-community interactions in preparing communities pre-fire to respond adequately [8,52]. With initially limited agency-community interaction in ECV, this factor may significantly shape risk perceptions in future wildfire management efforts.

Various definitions and measures of wildfire risk perception have been suggested in existing literature. A previous study that aimed to develop a broad measure of risk perception for environmental disasters has highlighted the need for a universal measure of risk

Table 3

Associations between gender, general health conditions, safety awareness, social interactions, and the perceived consequences of wildfires in the multivariate regression model.

Variables	Beta estimate	Std. Error	P value	Adjusted OR (95 % CI) ^a
Female ^b	0.83	0.56	0.14	2.29 (0.76–6.89)
General health condition: moderate ^c	1.04	0.85	0.22	2.83 (0.53–15.05)
General health condition: poor ^c	1.48	0.88	0.09	4.40 (0.78–24.84)
Having a high level of safety awareness ^d	1.29	0.55	0.02	3.64 (1.24–10.69)
Participating in social/community groups ^e	1.37	0.55	0.01	3.92 (1.35–11.43)

Abbreviations: CI, confidence interval; OR, odds ratio.

^a Model was adjusted for all the other sociodemographic factors, including age, educational attainment, household income level, the number of rooms in the house, and the number of household members. The missing household income values were estimated through multiple imputation.

^b Reference group, the male group.

^c Reference group, the group with excellent or very good health condition; moderate group, the group with good health condition; poor group, the group with fair or poor health condition.

^d Reference group, somewhat low or very low safety awareness; high safety awareness group, very high or somewhat high safety awareness.

^e The group consists of participants participating in social or community groups at least monthly.

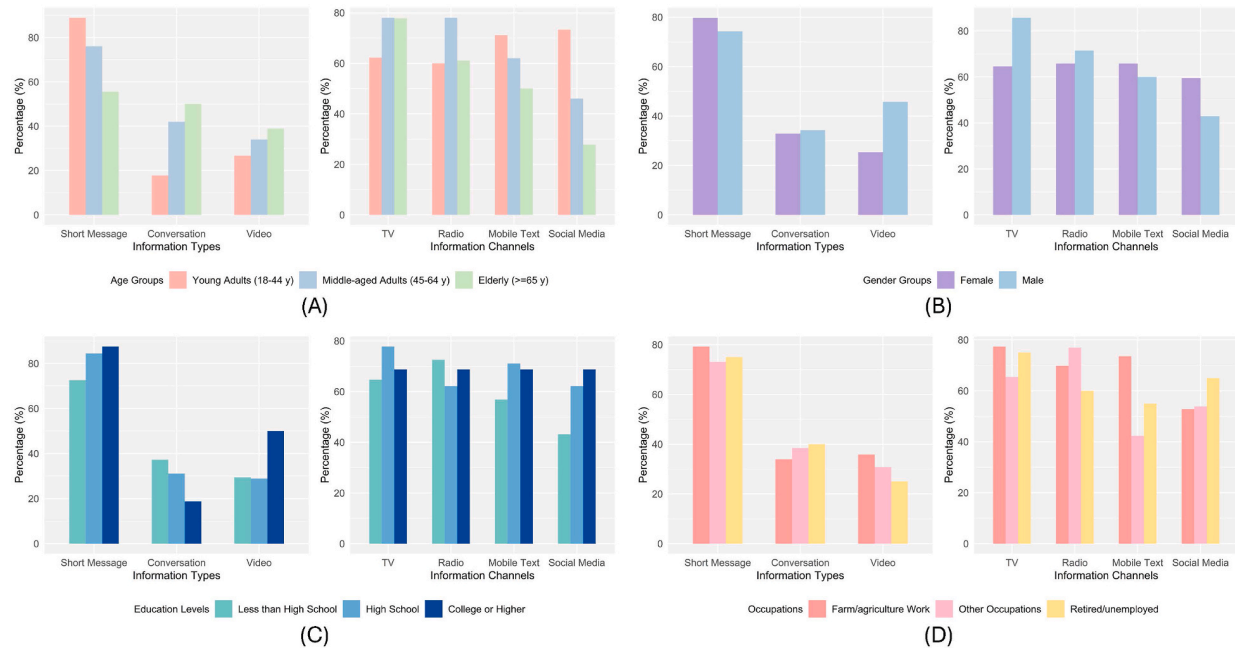


Fig. 2. The preferences for the most popular information types and channels among study participants stratified by age (A), gender (B), educational attainment (C), and occupation (D).

perception and proposed that risk perception is a multidimensional construct [64]. They mentioned that certain aspects may be more influential in shaping an individual's risk perception as a whole; for example, measuring the probability of potential future disasters may not be as critical as measuring their effects of consequences, while perceived probability may be beneficial when providing insights into behavioral intentions. In our study, we assessed both aspects of wildfire risk perception. However, since 88.7 % of participants perceived a high probability of wildfire occurrence in the ECV, we focused on the perceived consequences when examining the factors associated with wildfire risk perception.

Although previous research has documented the impact of various sociodemographic characteristics and wildfire experiences on wildfire risk perception, our study found these factors to be nonsignificant. This may be due to the homogeneity of our purposively sampled population, predominantly Hispanic individuals with comparably low SES. While our participants exhibited varying wildfire experiences, including frequency of occurrence, property or life loss, and evacuation, the frequent occurrence of wildfires in the study region may have contributed to desensitization [30,65]. Associations between various factors and wildfire risk perception have shown notable inconsistency across studies. Unlike our studies focusing on disadvantaged populations, previous studies usually focused on populations directly affected by specific wildfire events [15,30,48] or WUI residents at higher risk of wildfires [8,14,34,43]. Some other studies have explored more public opinions or concerns among the general population [66,67]. Regional disparities in social and natural environments can influence the probability and recurrence of wildfires, as well as the local wildfire management practices or evacuation policies [15,34]. Furthermore, climate change has exacerbated wildfire severity, potentially reshaping initial risk perceptions. The potential numbing effect of long-term smoke exposure and the prevalence of wildfire warnings may also influence these perceptions [30].

Previous studies found that fire-specific informal social interaction such as talking to neighbors about fires was associated with wildfire risk perception [8,34]. A review study that assessed flood risk perception also found that information from neighbors and friends can be more influential than institutional information [68]. Over 80 % of our participants reported regular communication with neighbors, and more than 60 % had specifically discussed wildfires. Despite these frequent interactions, our analysis found a positive but non-significant association between informal social interactions and the perceived consequences of wildfires. In contrast, we observed that formal interactions occurring within structured settings such as social and community groups tended to increase wildfire risk perception. According to the Contagion theory, individuals who interact with others frequently are more likely to share similar attitudes, beliefs, and behaviors [50]. Participation in formal social interactions can provide more opportunities to exchange ideas and receive information from community organizers or other expert sources (e.g., fire department) [8], which can be critical for residents with relatively low SES and limited educational attainment in disadvantaged communities.

In our study, we identified a critical need for wildfire risk communication among ECV residents, as only a small proportion of participants have proactively signed up for wildfire alerts or received health-related messages during prior wildfires. Previous research has highlighted the importance of targeting specific populations, maintaining information consistency, and using simple keyword phrases such as "stay indoors" and "reduce outdoor activity" for effective risk communication [22,26,69,70]. Our study corroborated these findings, revealing that short messages (e.g., a one-line sentence or phrase) were the most preferred message style. The goal of

health alerts is to quickly grab attention, simplify message comprehension, and guide appropriate action [71,72]. As opposed to complex or financial-related recommendations such as using masks or air filters, simplicity in messaging can significantly enhance recall and compliance among the general population [26,73]. In addition, integrating wildfire risk messaging with alerts that people are already familiar with, such as warnings on poor air quality days, may make them more receptive to the messages [74].

In terms of communication media, many people have been receiving wildfire messages through either television or emergency broadcasts [25,75,76]. A telephone survey conducted after the 2003 Australian bushfire smoke event reported that 67.6 % of respondents who were aware of health advisories identified television as the most likely information source [69]. Another survey following the 2007 San Diego wildfire found that approximately 77 % of respondents recalled receiving emergency messages via television [26]. Similarly, our survey found that about 70 % of participants chose television and radio as their preferred communication media. Compared with mass public announcements on television, radio has a unique and vital role in providing more local advice and information to nearby rural populations as well as emotional support [23]. Although public trust in different channels may differ [22], timely information dissemination through a multi-channel approach can ensure broader reach and enhance message penetration both in urban and rural areas [27]. Other flexible media options, such as mobile phone text messaging, can serve as suitable additional information channels, particularly for individuals working in fields. Furthermore, although social media has become an important information source and allows users to use keywords and quickly locate specific health messages [72], it may not effectively reach the elderly and individuals with lower educational attainment (e.g., less than high school). These populations may rely more on and trust doctors for authoritative and targeted health advice.

Our research uniquely focused on the intersections of environmental vulnerability to wildfires and social disadvantages. By targeting incorporated communities of the ECV, we highlighted the specific challenges faced by socially vulnerable populations who experience multiple environmental stressors. In-person interactions during the survey process helped enhance the quality of our study to some extent compared with those utilizing web-based or mail surveys. Our study may have practical implications for wildfire mitigation planning and educational outreach, particularly for disadvantaged communities where residents are geographically and linguistically isolated:

Building on our findings, enhanced cooperation and interaction among neighbors at the community level, such as forming community help groups and hosting educational sessions led by community organizers, may significantly improve wildfire preparedness and response while fostering a sense of solidarity. For instance, participants from the North Shore Community reported that their community organized a digital group chat via WhatsApp [62]. This group chat enables residents to stay informed about local emergencies, exchange messages, find useful resources, and receive alerts and safety precautions. To strengthen community ties, it would be beneficial to train residents to act as first responders during emergencies, such as involving veterans in neighborhood watches and leveraging their experience and skills. These individuals can serve as communication links between emergency services and the community and help provide essential first-aid resources such as bandages, disinfectants, and masks.

Furthermore, it is crucial for county governments, which serve as the primary governmental authority in these unincorporated communities, to enhance their interactions with these areas and improve education on wildfire preparedness and evacuation procedures. Offering educational sessions and distributing specialized handbooks or manuals in Spanish are crucial steps. These educational materials should emphasize the dangers of underestimating wildfire threats, encourage active participation in community groups, and provide detailed information on the impacts of wildfires, along with strategies for preparation and response. Regular training sessions can be organized at accessible venues, such as community centers, parks, and libraries, and scheduled at convenient times for residents, like weekends, evenings, or during other community events to effectively engage subgroups with lower risk perception. These sessions should allow residents to directly interact with emergency responders or fire safety experts, enabling them to express concerns and receive tailored advice.

Moreover, recognizing the critical role of effective risk communication [77], our study recommended clear and concise messaging in Spanish for wildfire alerts that include essential details such as the wildfire's location, suggested evacuation routes, and safety precautions [78,79]. To maximize reach across diverse demographics, our study suggested employing at least a dual-channel communication strategy utilizing social media and local radio broadcasts to provide more localized and accessible advice.

Some limitations should be acknowledged. First, our sample may not be representative of all residents in those unincorporated communities of ECV due to the relatively small sample size and the adoption of non-probability sampling [15,30]. Self-selection bias was inevitable, as individuals more affected by wildfires may be more motivated to participate in our survey to express their concerns and seek support. Consequently, our findings might be more reflective of the perceptions and needs of low SES groups who are more affected by wildfires and in greater need of resources and community support. Second, the results of our study may not be directly generalized to a broader demographic as we mainly focused on residents with low SES and monolingual Spanish speakers, and our questionnaire was designed to accommodate their characteristics. Third, the recall bias cannot be overlooked, particularly concerning questions about previous wildfire experiences (e.g., the number of experienced wildfires). In addition, since we utilized only the term "risk" in questions assessing the perceived probability and consequences of wildfires without explicitly specifying these two aspects, there might be some ambiguity in how our survey respondents interpreted these two questions, despite the community organizer who led the survey providing detailed explanations during the survey process.

6. Conclusions

By conducting a comprehensive survey in unincorporated communities of the ECV, our study addressed specific concerns by highlighting their lack of preparedness and inadequacy of wildfire risk communication. We found that increased participation in formal social interactions can be crucial for enhancing wildfire risk perception, particularly in unincorporated communities that lack

resources and services. Additionally, diverse information channels are necessary to reach farm workers and community members in these small, rural, and monolingual Spanish-speaking communities for distributing wildfire and smoke alerts. Our findings provided insights to equip vulnerable communities to respond more effectively to wildfire risks.

CRedit authorship contribution statement

Anqi Jiao: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Anna Lisa Vargas:** Investigation, Data curation. **Yuliya D. Gluhova:** Writing – original draft, Data curation. **Kathryne Headon:** Writing – original draft, Data curation. **Lilia Rangel:** Data curation. **Sara Abdallah:** Data curation. **Erika C. Ramsey:** Writing – review & editing, Data curation. **Keira Truong:** Data curation. **Aiden M. Chal:** Resources. **Suellen Hopfer:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Jun Wu:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijdr.2025.105186>.

Data availability

The individual data collected in this study were protected and not publicly available.

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