Spatial Analyzing Wildfire Risk and Socioeconomic Vulnerability in California

Kunming Du, JoChen Lee

PPD631-Geographic Information Systems for Public Policy, Planning & Development

Instructor: Barry Waite and Bonnie Shrewsbury

University of Southern California Fall 2024

1. Project summary

California's wildfires have hit communities hard, especially in places like Fresno County where folks struggle to make ends meet. When flames threaten their homes, many families can't just pack up and leave - they lack the money and resources to evacuate quickly. On Nov. 6th, 2024, it ripped through 62 square kilometers in just five hours, forcing thousands to flee their homes. This was not just a natural disaster, but a major test of human coping capacity. We looked at real neighborhoods across California, trying to understand why some communities get hit harder by fires than others. Our findings show that economically disadvantaged communities experience more severe wildfire impacts, while urban areas struggle with environmental damage from fire prevention measures.

2. Problem Statement

Wildfires in California are becoming more dangerous every year, but their impacts aren't felt equally across all communities. Factors like income levels, housing conditions, and population density play a big role in determining who is most vulnerable. This project uses GIS tools to explore two important questions:

1) How do factors like income and housing values relate to wildfire vulnerability?
2) Which areas face the highest risks, and why?

By mapping these relationships across California's diverse regions, we hope to uncover patterns that can lead to smarter and fairer wildfire policies.

.

3. Literature Review- Recent Studies on Wildfire Vulnerability

The story of California's wildfire vulnerability has taken concerning turns in recent years. Research by Fleishman et al. (2023) showed that the number of socially vulnerable people exposed to wildfires tripled between 2000 and 2021. This raised deeper questions about who bears the greatest burden when fires strike.

For instance, Modaresi Rad and Sadegh (2023) found that Native American communities are disproportionately exposed to wildfires. They also noted that as household incomes rise, wildfire risks tend to decrease—suggesting that financial stability plays a key role in safety.

Other studies have highlighted long-term effects on property values. Davies et al. (2023) showed that neighborhoods frequently affected by fires often see slower home value growth compared to safer areas. A PLOS Climate study (2023) further revealed that areas with high fire activity often overlap with lower-income neighborhoods, compounding their vulnerability.

4. Data Sources

We used three main datasets for this analysis:

1) Family income and living conditions from U.S. Census Bureau and Zillow (2020-2022), selected to measure community resilience capacity.
2) Tree mortality data, from CAL FIRE, as an indicator of ecological impact.
3) Wildfire intensity records (2020-2022), from FEMA, providing validated

measures of fire severity.

These sources provide comprehensive coverage of both environmental and social factors affecting wildfire vulnerability. After finding out these datasets, the first step is to clean the data. Cleaned out missing values and narrowed down to more specific data, and clipped spatial boundaries to California's extent. Second, use ArcGIS Pro to overlay wildfire intensity, which is categorized into five classes, and tree mortality data with socioeconomic datasets.

5. Analysis Approach

We mapped out fire-prone areas and looked at who lives there - their income, types of homes, and access to resources. The patterns we found tell a pretty clear story about who's most at risk when wildfires strike. Here's what we focused on:

1) Calculating how much of each county falls within high-risk wildfire zones.
2) Comparing this with factors like poverty rates and education levels.
3) Running hotspot analyses to find clusters where high fire risk overlaps with socioeconomic challenges.

Finally, we created an overlay analysis map, combining these factors into one comprehensive measure.

Figure 1. Socioeconomic Vulnerability Map of California Counties (2022)

This map shows how wildfire risks in California often align with economic challenges. The darker shades in rural counties highlight communities facing double hardships: fewer resources to prevent fires and limited ability to recover afterward. These areas are especially vulnerable and require targeted support.

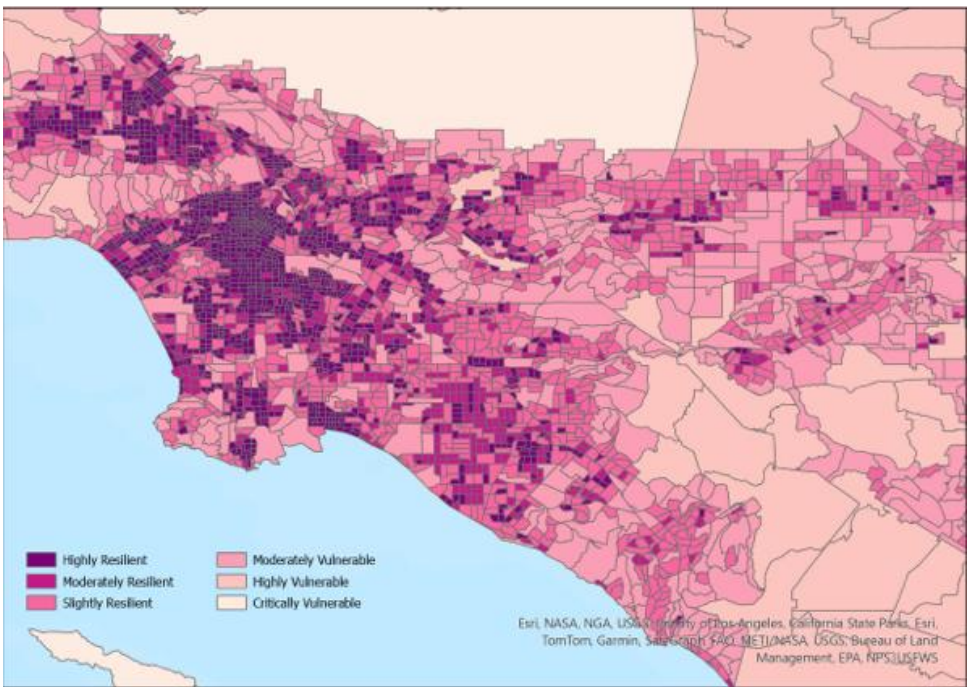

Figure 2. Socioeconomic Vulnerability Map, focusing cities (2022)

This map zooms in on major urban areas like Los Angeles and San Diego. The lighter orange shades represent wealthier metropolitan regions, contrasting sharply with the surrounding inland areas, where socioeconomic vulnerability is higher.

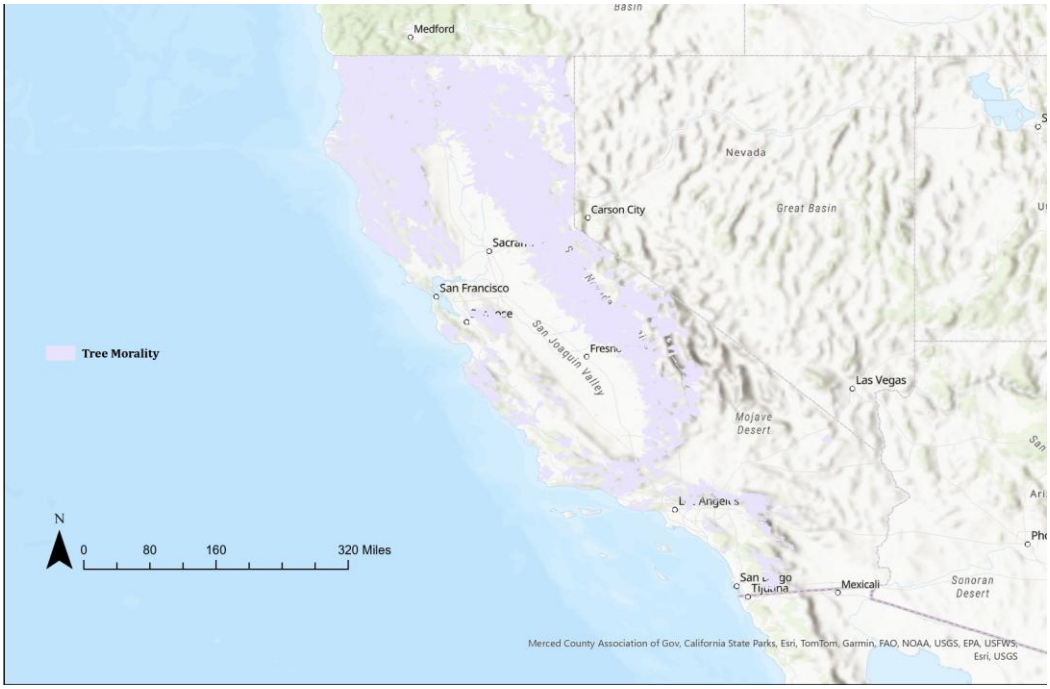

Figure 3. Tree Mortality Due to Wildfires in California (2020-2022)

The purple-shaded regions on this map show areas where wildfires caused significant tree mortality. Damage is most severe along the Sierra Nevada range and parts of Northern California, with smaller clusters near San Francisco Bay and coastal areas. The white spaces indicate non-forested or unaffected regions.

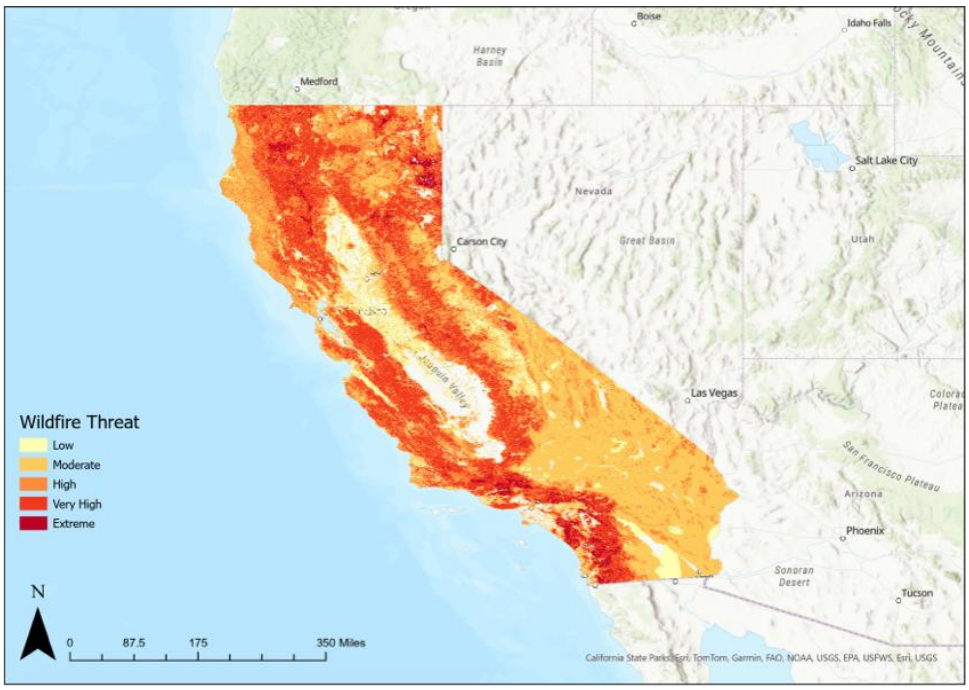

Figure 4. Wildfire Intensity Distribution in California (2020-2022)

This map illustrates wildfire intensity across California, ranging from low (blue) to extreme (pink). High-intensity fires are concentrated in rural areas like Fresno County and Northern California, while urban centers like Los Angeles experience lower-intensity fires.

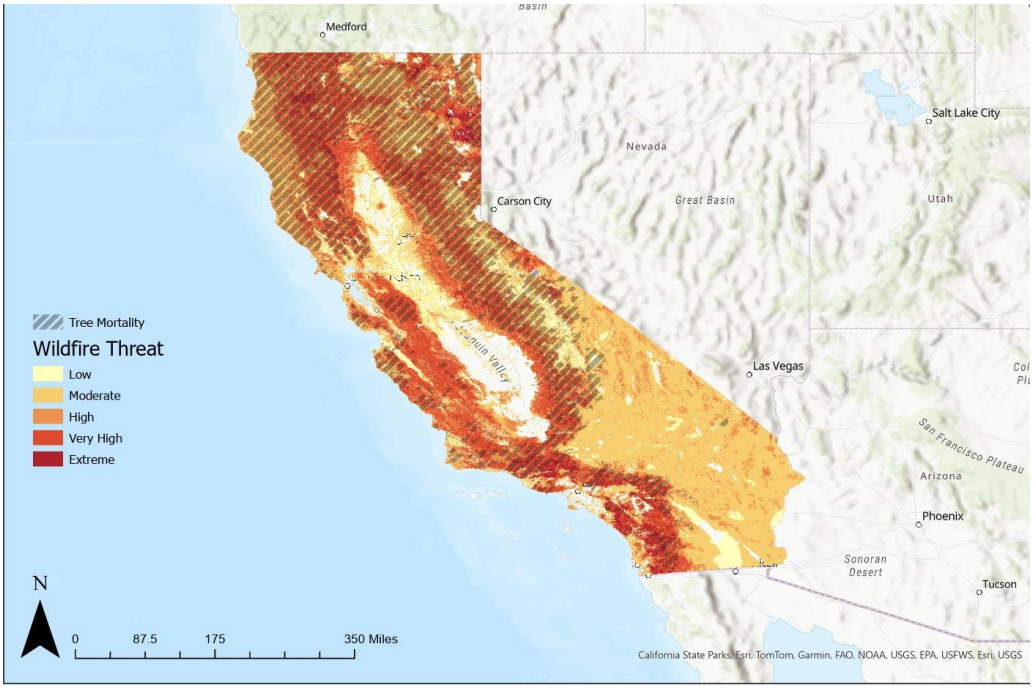

Figure 5. Validation Analysis: Overlay of Tree Mortality and Wildfire Intensity Distribution in California (2020-2022)

This map overlays tree mortality data with wildfire intensity levels, revealing a strong association between high-intensity fires and significant tree loss. Northern California and the Sierra Nevada region show the clearest alignment, validating the relationship between fire severity and ecological damage.

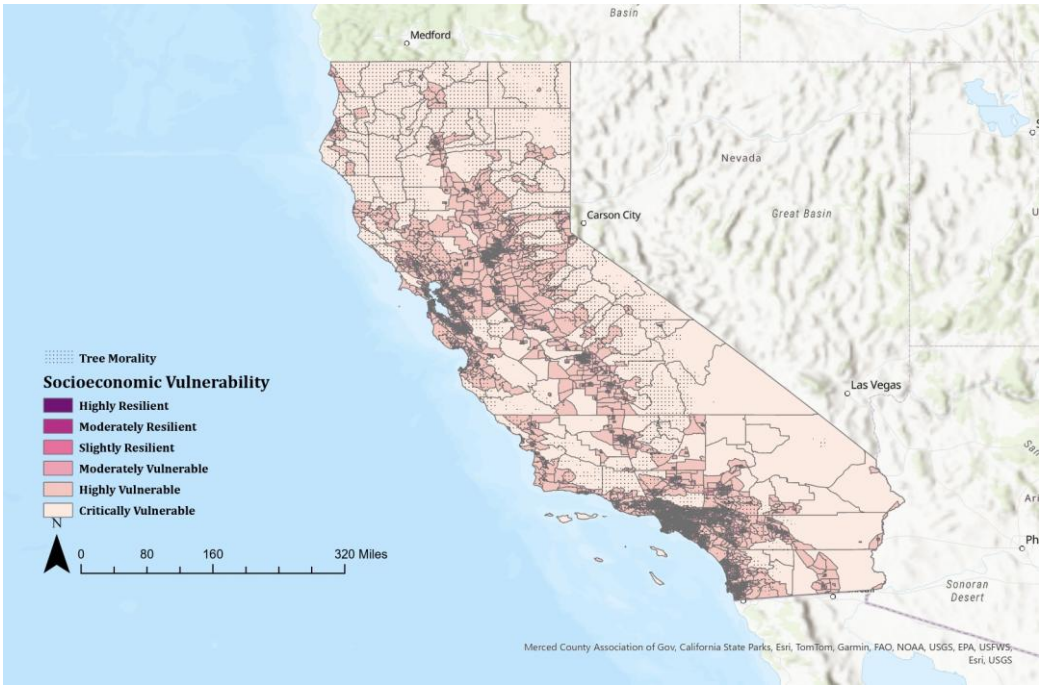

Figure 6. Overlay Analysis of Socioeconomic Vulnerability and Wildfire Impact in California

This final map combines wildfire impact data with socioeconomic vulnerability patterns across California. Purple areas represent tree mortality zones, while brown shading highlights economically vulnerable communities. The overlap is most pronounced in Northern California and the Sierra Nevada region, emphasizing the need for targeted interventions.

6. Expected Results and Discussion

Our analysis reveals several significant findings regarding the relationship between wildfire vulnerability and socioeconomic conditions in California:

1) clear connections

When we mapped wildfire damage against income data, clear patterns emerged showing how lower-income areas consistently faced greater fire risks. Northern California and the Sierra Nevada region consistently show an overlap between high tree mortality, intense wildfire activity, and lower socioeconomic indicators. This relationship is validated through our multi-layer analysis approach, combining tree mortality data, wildfire intensity distributions, and socioeconomic indicators.

2) Urban-Rural Divide

The analysis reveals a distinct pattern of vulnerability that transcends simple urban-rural categorization. While rural communities, particularly in Northern California and Sierra Nevada, face immediate challenges from limited resources and higher fire exposure, urban areas confront long-term sustainability challenges through their fire management approaches. This spatial distribution of risk and resilience suggests the need for regionally tailored intervention strategies.

3) Socioeconomic Impact Patterns

Our analysis corroborates recent research findings regarding communities with high fire exposure in California. These communities consistently demonstrate lower median household incomes and experience slower property value appreciation compared to areas with minimal fire activity. The data also reveals that these same communities often struggle with limited access to wildfire preparation resources. Furthermore, these areas tend to have higher concentrations of vulnerable populations, particularly older adults and non-English speaking residents, making them especially susceptible to wildfire impacts. This pattern of overlapping vulnerabilities, supported by both our

spatial analysis and recent literature, underscores the compounding nature of socioeconomic challenges in high-fire-risk areas.

The findings highlight a complex interplay between wildfire risks, ecological impacts, and socioeconomic vulnerabilities:

(1) Rural northern California communities face compound challenges: lower incomes, fewer resources, and higher fire risks.

(2) Urban areas show better economic resilience but struggle with ecological trade-offs from fire prevention measures.

(3) Communities with frequent fire exposure consistently show lower income levels and slower property value growth.

These dynamics underscore the need for differentiated policies balancing fire prevention, ecological health, and equity. However, the data limitations are still there. The limitations of our study are primarily restricted by two key methodological constraints. The aggregation of data at the county level, while providing a broad overview, potentially masks important socioeconomic and wildfire risk variations that exist within individual counties. Additionally, our reliance on static data from 2020-2022 restricts our ability to analyze long-term trends and patterns in the relationship between wildfire impacts and socioeconomic vulnerability over time. These temporal constraints limit our understanding of how these relationships may evolve in response to changing climate conditions and demographic shifts.

7. Conclusion

This project highlights how wildfire risks in California are deeply tied to socioeconomic challenges. By using GIS tools to analyze data on tree mortality, wildfire intensity, and community demographics, we uncovered clear patterns showing that lower-income communities face the greatest threats. These findings aren’t just numbers—they’re a

reflection of real people's struggles when disasters strike.

Our analysis revealed that rural areas with limited resources are especially vulnerable, while urban regions deal with long-term environmental trade-offs from fire prevention efforts. These overlapping vulnerabilities point to an urgent need for action. Based on what we've learned, here are three practical steps California can take:

1) Focus resources on high-risk rural areas to help them prepare for and recover from wildfires.
2) Build stronger support systems for communities with limited financial means or access to emergency services.
3) Develop region-specific fire management strategies that balance environmental protection with community resilience.

By acting on these recommendations, California can take meaningful steps toward fairer and more effective wildfire management. The goal is simple: ensure every community—regardless of income or location—has the tools to stay safe and recover quickly when wildfires happen. This isn't just about protecting homes; it's about creating a future where everyone has a fair chance to thrive, even in the face of natural disasters. This version uses a more relatable tone while keeping the analysis grounded in evidence-based recommendations. It avoids overly formal phrasing and incorporates empathy for affected communities.

References

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. Social Science Quarterly, 84(2), 242-261.

Davies, I. P., Haugo, R. D., Robertson, J. C., & Levin, P. S. (2018). The unequal vulnerability of communities of color to wildfire. PloS one, 13(11), e0205825.

Emrich, C. T., & Cutter, S. L. (2011). Social vulnerability to climate-sensitive hazards in the southern United States. Weather, Climate, and Society, 3(3), 193-208.

Paveglio, T. B., Prato, T., Edgeley, C., & Nalle, D. (2015). Evaluating the characteristics of social vulnerability to wildfire: demographics, perceptions, and parcel characteristics. Environmental management, 55(6), 1322-1337.

Fleishman, E., Modaresi Rad, A., & Sadegh, M. (2023). Socially vulnerable populations are disproportionately exposed to wildfires in the West, study finds. Science Advances. https://doi.org/10.1126/sciadv.adh4615

Modaresi Rad, A., & Sadegh, M. (2023). Social vulnerability of the people exposed to wildfires in U.S. West Coast states. Science Advances, 9(38). https://doi.org/10.1126/sciadv.adh4615

Vargo, J., Kosnik, K., Benson, M., & Davies, I. P. (2023). Social vulnerability in US communities affected by wildfire smoke, 2011 to 2021. Northwest Fire Science Consortium.

Davies, I. P., Haugo, R. D., Robertson, J. C., & Levin, P. S. (2023). The unequal vulnerability of communities to wildfire. PLOS Climate, 2(2), e0000087. https://doi.org/10.1371/journal.pclm.0000087