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Mapping Physical Risk and Social Vulnerability to Hydrologic Hazards in the Intermountain West

Jozi Renken

Atmospheric Sciences
The University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Mentor(s): Caitlin Crossett

Abstract

The increasing prevalence of hydrologic hazards as the climate changes creates a pressing need to identify and assess which areas will be most at risk when these hazards do occur. While there has been research into what areas will be most at risk for individual hazards there is limited research that looks at multiple hazards together. In addition, there is limited research that also looks at social vulnerability and how that affects an area's level of risk. The focus of this research is the Intermountain West, which represents an interconnected regional system that faces a similar set of water-related challenges. For this project, QGIS was used to explore data from FEMAs National Risk Index. In addition, supplemental socioeconomic data was used. The areas where drought, wildfire, and flooding are likely to coincide and which communities in this region will most likely experience the highest risk from these hazards were identified. This was done by normalizing the data and finding the counties in the top twenty percent for each variable. The states of Arizona, California, New Mexico, and Nevada presented as the most at-risk states while in general Colorado, Montana, Idaho, and Wyoming are areas of less concern.

1. Introduction

The hazards of flooding, drought, and wildfires can have major effects on people's lives, the economy, and the natural world (Binita et al. 2020; Rezvani et al. 2023). They can lead to people dying and cause many other negative effects such as a decrease in water and air quality, agricultural losses, and infrastructure damage (Binita et al. 2020; Coen et al. 2013; Cravens et al. 2021; Pourghasemi et al. 2020; Rezvani et al. 2023).

These hazards often prove to be damaging enough on their own but when they occur together they can exacerbate the severity of either individual hazard (Binita et al. 2020; Pourghasemi et al. 2020; Rezvani et al. 2023). Intense wildfires can increase the risk for flash flooding and debris flows (Jong-Levinger et al. 2022). Droughts can affect how the soil absorbs water and increase the risk of flooding after prolonged periods of drought (Rezvani et al. 2023). As the climate warms, these hazards will increase in both frequency and severity. In addition, these compounding effects are also expected to worsen (Binita et al. 2020; Chang et al. 2012; Jong-Levinger et al. 2022; Rezvani et al. 2023). Without mitigation these effects will become more pronounced over time (Rezvani et al. 2023). While this paper only looks at historical data and does not use predictive models, the increasing risk of these hazards due to climate change makes the overall study of them more relevant than ever.

Certain demographics and socioeconomic groups are more vulnerable to the impacts of these hazards (Binita et al. 2020; Flanagan et al. 2011). These factors can be quantified into a Social Vulnerability Index to better analyze which communities might feel the effects of these hazards the most strongly (Flanagan et al. 2011). These increased impacts mean that particularly vulnerable groups are more likely to struggle with recovery after a hazard and are more likely to die from them (Flanagan et al. 2011). Properly addressing social vulnerability can decrease both the short and long term impacts of the hazards (Flanagan et al. 2011).

This paper will investigate the overlap in the hazards of flooding, droughts, and wildfires along with locating highly socially vulnerable areas in the Intermountain West. It will show a snapshot of the current situation so that areas of interest can be investigated further. These hazards will be looked at together due to the compounding effects of these hazards and the fact that they are all predicted to get worse in a warming climate. Incorporating social vulnerability will show what areas might struggle more to recover from these hazards, even if the hazards themselves are comparatively less likely to occur in those areas.

2. Data & Methods

The study area comprises the Intermountain West, which includes 252 counties in Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming. The data set used was FEMA's National Risk Index (NRI) (Zuzack et al. 2023). This was chosen as it contains a large amount of data that is standard across multiple hazards so that they can be compared directly. Some of the data was unrelated to the goals of this project so only data from the following categories were kept for each hazard: The Number of Events, Annualized Frequency, Total Exposure, Exposure By Impacted Area (Sq Mi), Total Rating of Historic Loss Ratio, Total Expected Annual Loss, Expected Annual Loss Score, Expected Annual Loss Rating, National Percentile of Expected Annual Loss Rate, Hazard Type Risk Index Value, Hazard Type Risk Index Score, and Hazard Type Risk Index Rating.

The data were then normalized to be on a scale from 0 to 1. This was done to be able to more directly compare the different metrics available. For each hazard the normalized data were then averaged together for each hazard to form a general index of risk. To evaluate risk the data were split into five equal groups from lowest to highest risk and that uppermost group was then labeled 'high risk'. Social vulnerability data were handled in a similar manner. The social vulnerability data were combined with community resilience data as they are closely related. This was done because in this case social vulnerability is being used as an indicator of how a community might be affected by a hazard and how well it might recover from a hazard, which is part of what community resilience would be measuring. While poverty is an important factor in social vulnerability, other included factors are ones such as age, race, education, disability, employment, and more. The NRI calculated community resilience by determining how resilient a community is in six categories: economic, community capital, institutional capacity, housing/infrastructure, and environmental. These data categories were kept: Social Vulnerability Score, Social Vulnerability Rating, Social Vulnerability State Percentile, Community Resilience Score, Community Resilience Rating, Community Resilience Value, Community Risk Factor Value, and Community Resilience State Percentile

The most recent data is from 2022. This means that while this analysis cannot be used as an indicator of how the placement of these hazards will be altered by climate change it does offer a snapshot of the recent past and shows which areas were disproportionately affected by these hazards. While climate change will affect the placement and severity of these hazards the knowledge of how they have presented in the past can still offer valuable insight and provide a foundation to work from.

In addition, supplemental data from the US Census Bureau were used (SAIPE, 2021). This data comprises population, median household income, and poverty data from 2021. This data were used to find specific patterns relating to the hazards and how they relate to these factors individually

3. Results & Discussion

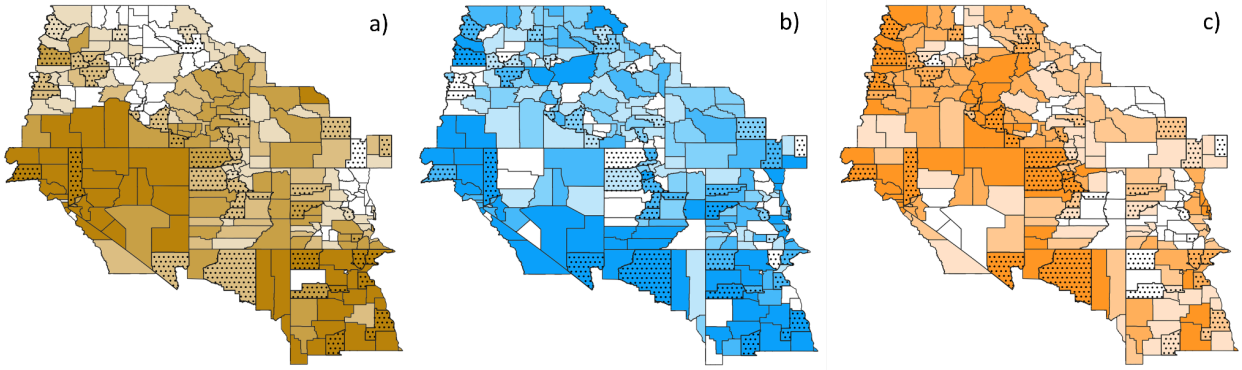

Figure 1: Risk and social vulnerability maps for a) drought, b) flooding, and c) wildfire with darker colors indicating higher risk. The dotted hatching indicates highly socially vulnerable counties.

Fig. 1 shows the spatial distribution of each individual hazard. Fig. 1a shows that drought is more prevalent as an issue in the south and west portions as shown by the darker shading, but it is still present in the remaining areas. Fig. 1b shows that flood risk is heavily concentrated along the southwestern edges of the region but remains present throughout the rest of the region as well. Fig. 1c shows that wildfire risk is most noticeable in the western half of the region. This shows that, with exceptions, the southern and western areas of the region are the most likely to be impacted by these hazards compared to the northern or eastern areas.

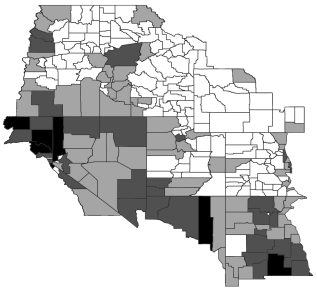

Figure 2: Number of hazards a county is at high risk from, with darker colors indicating higher risk.

Fig. 2 leads to a similar conclusion by showing the spatial distribution of the number of hazards any given county is at high risk from. All of the counties at high risk from all three hazards fall along the southern or western edges of the region as shown by the darker shading, and the likelihood of being at high risk from more than one hazard tends to be higher in the south and west.

Of the counties at high risk from two hazards, analysis showed it was roughly twice as common to see high risk from flood and wildfire and from flood and drought compared to drought and wildfire. This was initially surprising as drought and wildfire seem like they should occur more with each other than flooding. However both drought

and wildfires make an area more prone to flooding in the aftermath: drought by reducing the soil's ability to properly absorb water, and wildfire by reducing vegetation which negatively impacts the ground's ability to absorb water properly (Rezvani et al. 2023; Jong-Levinger et al. 2022). There does not seem to be any notable relation between high social vulnerability and any particular hazard or the likelihood a country is at high risk from multiple hazards.

When looking for patterns in the supplemental data, it was found that there is some relation between the risk from these hazards and population, poverty rates, and median household income. Counties with over 100,000 residents are more than twice as likely to be at high risk from both flooding and wildfires compared to what the averages for the entire region would lead one to expect. The higher risk of flooding likely comes in part from the impermeability of the asphalt and concrete that often makes up a larger portion of the surfaces in cities which can impact the way rain water is absorbed into the ground (National Levee Database, 2017). As almost 90% of wildfires are caused at least in part by humans it makes sense that areas with large amounts of humans would have more fires (Congressional Research Service, 2023). Drought occurs at a similar rate in high population areas compared to the entire region. In addition, the relation between population and risk also makes sense due to how risk is calculated, because part of what was considered was the historic and annual loss of life, property, and agriculture. There is not as much loss of those when there are nearly no people around.

While there does not seem to be a relation between the overall risk from these hazards and median household income, the specific hazards an area is at risk from do seem to have some connection. In the counties that make up the top twenty percent by median household income it is roughly twice as common as one would expect for a county to be at high risk from wildfires but is near about the exact level one would expect for drought and flooding. In contrast, half of the counties in the bottom twenty percent by median household income are at high risk for drought when it would be expected to be around one in five. In addition, being at high risk for flooding is about twice as common as expected, but wildfires are less of a risk than expected. 83% of those low income counties that are at high risk for drought are also counties in New Mexico. This may simply indicate that New Mexico has abnormally prominent issues with both income and drought rather than drought risk inherently relating to income in any way. It is a notable point nonetheless because, at least in this region, drought is disproportionately affecting low income areas, which could affect what steps need to be taken to mitigate the effects of it. Poverty seems to relate to the level of risk to some extent and relates to what particular hazards are present as well. For example, of the seven most at risk counties four of them show high levels of poverty compared to the rest of the dataset, with only one of those counties having a comparatively low level of poverty which shows an overrepresentation of more impoverished communities in more high risk areas. While this paper can not suggest nor determine if one is causing the other in any way there is a pattern that lower income areas are more likely to face a higher level of risk from these hazards and that disproportionality should be addressed in planning regardless of if one is in some way the cause of the other.

Percent of Counties at High Risk from X Number of Hazards				
	High Risk from 0 Hazards	High Risk from 1 Hazard	High Risk from 2 Hazards	High Risk from 3 Hazards
Intermountain West	57.5%	27.0%	12.7%	2.8%
AZ	0.0%	40.0%	40.0%	20.0%
CA	8.7%	16.7%	41.7%	33.0%
CO	76.7%	18.6%	4.7%	0.0%
ID	72.7%	25.0%	2.3%	0.0%
MT	89.5%	10.5%	0.0%	0.0%
NM	6.9%	51.7%	37.9%	3.4%
NV	11.8%	52.9%	29.4%	5.9%
OR	61.1%	33.3%	5.6%	0.0%
UT	62.1%	27.6%	10.3%	0.0%
WA	75.0%	15.0%	10.0%	0.0%
WY	87.5%	12.5%	0.0%	0.0%

Table 1: The percentage of counties in each region or state at high risk from 0, 1, 2, or 3 hazards.

This shows how the risk from these hazards is not distributed equally across space, population, or income. This marks some areas as being of greater concern because they are either more likely to experience these hazards or because they experience some outside factor that could affect an area's recovery from these hazards even if the risk is comparatively lower. In addition, being at high risk from multiple hazards could put a county at a higher risk of compound hazard events. Table 1 demonstrates this well by showing what percentage of counties in each state are at high risk from different numbers of hazards. It shows Arizona and California as the most notable examples as more than half of the counties in those states in the research area are at high risk from two or more hazards.

4. Conclusions

Some states and counties face disproportionate risk and are of more concern. Due to that, they will likely continue to present as such as the climate warms. This disproportionate risk seems most heavily centered in the southwest section of the region in Arizona, California, New Mexico, and to some extent Nevada. Meanwhile some areas of lower risk are Montana and Wyoming with the remaining states falling somewhere in between. The states of most concern with respect to compound hazard events would be Arizona and California due to their overrepresentation in both the counties at high risk for all three hazards and counties at high risk for two or more hazards. Some potential avenues for future work would be a different or expanded area, more or different hazards, or a similar study of hazard overlap and placement using climate models to predict how it might affect these hazards and their placement over time at different thresholds and potentially how this would affect the risk for compounding hazards.

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