Spatial Disparities in Disaster Recovery: Assessing Flood Risk, Resilience, and Federal Aid Distribution in Western North Carolina After Tropical Storm Helene

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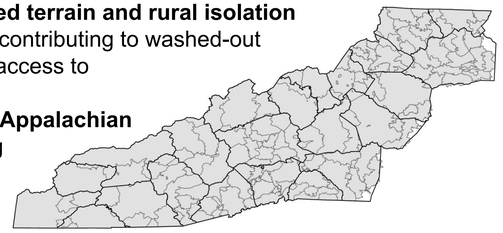
INTRODUCTION

- Tropical Storm Helene brought catastrophic flooding to Western North Carolina, dropping **20–30 inches of rain in 24 hours** and causing the deadliest mainland storm event since Hurricane Katrina, with an estimated **230 deaths**.
- In the Appalachian region, **rugged terrain and rural isolation worsened the disaster's impact,** contributing to washed-out roads, power outages, and limited access to emergency aid.
- The **storm hit vulnerable rural Appalachian communities hardest**, highlighting deep-rooted social and economic inequalities.



OBJECTIVES

1. **Assess the impacts of Tropical Storm Helene in Western North Carolina, with a focus on flooding, infrastructure disruptions, and the disproportionate burden on rural and isolated communities.**
2. **Examine how social vulnerability indicators and environmental exposure influenced access to FEMA assistance across varying community contexts.**
3. **Identify geographic disparities in disaster recovery outcomes to inform more equitable and resilient response strategies in Appalachian regions.**

METHODS

Data Collection

- **FEMA's** Individual and Household Program
- American Community Survey 2023
- DOT Road Closures
- PRISM Precipitation
- First Street Flood Data
- RUCA rural/urban codes

Data Processing

- Filtered all necessary datasets down to Western North Carolina
- Converted PRISM raster precipitation data to ZCTA-level averages
- Standardized FEMA values per 1,000 people

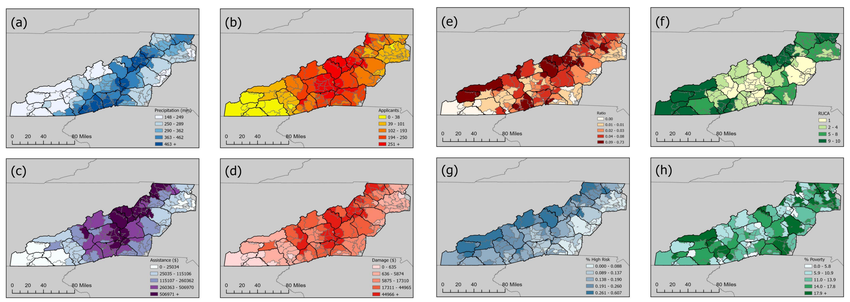
Data Integration

- Crosswalked ZIPs to ZCTAs
- Performed left join in R to merge datasets
- Final shapefile and equivalent csv file were created
- Mapped aid and vulnerability

Spatial Analysis and Regression

- Compared rural vs. urban ZCTAs
- **LASSO** regression to identify key predictors for IHP Assistance per 100,000 people and FEMA applications per 100,000 people
- Bivariate Spatial Association (**Lee's L**)
- Interaction analysis

These panel maps illustrate the spatial distribution of environmental hazards, infrastructure disruptions, and social vulnerability factors across Western North Carolina. Mapping these variables helps contextualize patterns of storm impact and support the analysis of disaster assistance disparities.



Spatial distribution of key variables in Western North Carolina: a) Total Precipitation, b) FEMA Applicants per 1,000 People, c) FEMA Assistance per 1,000 People, d) Property Damage per 1,000 People.

Spatial distribution of key variables in Western North Carolina: e) Road Closure Ratio, f) Rural vs Urban, g) Properties at High Risk for Flooding, h) Persons Living in Poverty.

RESULTS + DISCUSSION

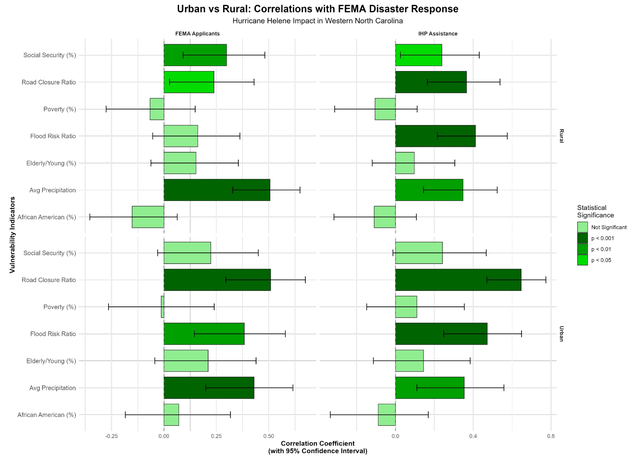
After Tropical Storm Helene, urban areas in Western North Carolina received more FEMA aid per 1,000 people ($p = 0.005$) and had higher application rates ($p < 0.001$). However, rural areas showed greater social vulnerability—more children and seniors (32.78% vs. 26.17%, $p = 0.009$), higher vacancy rates (31.39% vs. 21.99%, $p = 0.006$), and more reliance on social security (46.08% vs. 38.73%, $p = 0.013$).

LASSO regression confirmed these disparities after controlling for other variables:

- Urban advantage in application rates remained (35.4%)
- Urban areas received 54.3% more IHP assistance, despite rural areas having slightly higher raw per capita totals
- Road closure ratio and total precipitation were the strongest positive predictors of FEMA response, indicating aid was more strongly associated with infrastructure damage than vulnerability in both urban and rural areas
- Higher vulnerability was negatively correlated with both assistance and application rates, especially in rural ZCTAs

		IHP Assistance		FEMA Applicants	
Category	**Variable**	**IHP Coef**	**IHP % Effect**	**Applicants Coef**	**Applicants % Effect**
Environmental	**Road Closure Ratio**	1.4016913	**+306.2%**	0.9777812	**+165.9%**
	Log(Total Precipitation)	1.2871722	**+262.3%**	0.6597966	**+93.4%**
	High Flood Risk Properties (%)	1.0857738	**+196.2%**	Not Significant	
Sociodemographic	**African American (%)**	0.0393484	**+4%**	0.0364065	**+3.7%**
	Poverty Rate (%)	-0.0151829	**-1.5%**	-0.0119316	**-1.2%**
	Under 5 or Over 65 (%)	-0.0155058	**-1.5%**	-0.0038010	**-0.4%**
	Social Security Dependence (%)	-0.0039175	**-0.4%**	-0.0070625	**-0.7%**

These findings highlight a systemic mismatch: **FEMA assistance favors areas with high physical damage or property values**, not necessarily those with the greatest need. Vulnerable **rural communities**, facing barriers like limited internet access, transportation challenges, and communication breakdowns, **were less likely to access available aid, further widening pre-existing disparities.**

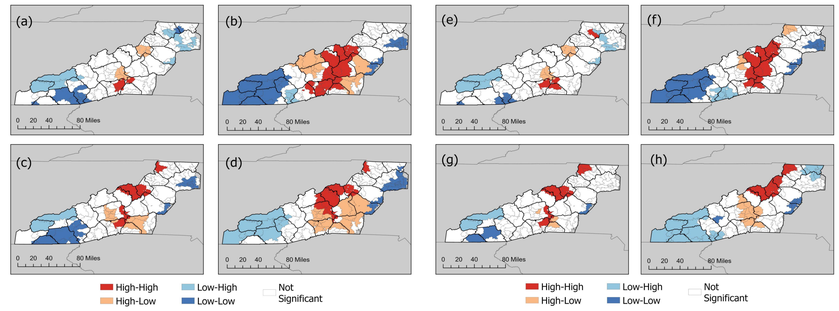


This figure displays standardized coefficients showing how environmental and social variables interact with urban vs. rural status to predict FEMA Applicants (left) and IHP Assistance (right) per 1,000 people. **The top half of the figure displays rural areas**, while **the bottom half displays urban areas**.

Bars to the left of the centerline indicate negative associations, while bars to the right reflect positive ones. **Darker green shading** indicates stronger statistical significance.

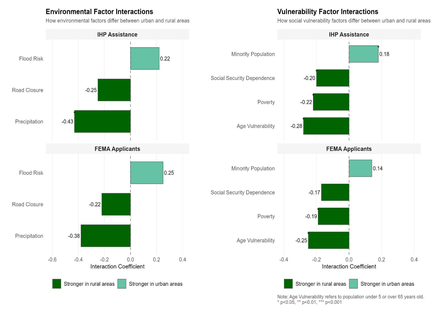
Environmental factors like **precipitation** and **road closures** had stronger effects in **rural areas**, while **flood risk** and **minority population** were more influential in **urban settings**—highlighting how geographic context shapes disaster vulnerability and response.

These panel maps reveal spatial disparities in the distribution of FEMA assistance, showing where support did not align with levels of environmental impact or community vulnerability. The results highlight how rural and socially vulnerable communities often received less assistance despite facing greater challenges. **Red** indicates high values of both variables clustered together (**high-need, high-vulnerability**), while **blue** areas show low-low clusters. **Orange** and **light blue** reflect mismatches-counties where need and vulnerability are not aligned. White areas are not statistically significant.



Lee's L Bivariate spatial association between applicants per 1,000 people and key explanatory variables: (a) percentage of female-headed households, (b) total precipitation, (c) road closure ratio, and (d) rural vs. urban classification.

Lee's L Bivariate spatial association between IHP assistance per 1,000 people and key explanatory variables: (e) percentage of female-headed households, (f) total precipitation, (g) road closure ratio, and (h) rural vs. urban classification.



Environmental Factor Interactions (Left Panel)

- **Precipitation** had a strong negative interaction with urban status (−0.43 for IHP, −0.38 for applicants), meaning it had a much stronger effect in rural areas. Heavy rain disproportionately reduced assistance in these regions. **Road Closures** also showed negative interactions (−0.25 for IHP, −0.22 for applicants), highlighting greater access issues in rural areas during infrastructure disruptions.
- **Flood Risk** showed positive interactions (0.22 for IHP, 0.25 for applicants), indicating urban areas at high risk were better able to mobilize and receive assistance.

Social Vulnerability Interactions (Right Panel)

- **Age Vulnerability** had the strongest negative interaction (−0.28 for IHP, −0.25 for applicants), showing that rural areas with more elderly and children faced greater disadvantages.
- **Poverty** (−0.22 for IHP, −0.19 for applicants) and **Social Security Dependence** (−0.20 for IHP, −0.17 for applicants) both worsened assistance in rural settings.
- **Minority Population** showed positive interactions (0.18 for IHP, 0.14 for applicants), suggesting urban minority communities accessed more assistance than rural counterparts.

CONCLUSIONS

- Tropical Storm Helene's devastating impact on Western North Carolina revealed **systemic inequities** in the distribution of disaster assistance, disproportionately affecting rural communities.
- Our spatial analysis shows that current response frameworks fail to account for the unique vulnerabilities of Appalachian mountain communities, where geographic isolation intensifies disaster impacts and slows recovery.
- The spatial relationships between assistance metrics and vulnerability indicators demonstrate that recovery systems tied to property values overlook communities experiencing higher relative losses despite lower absolute property values.

MOVING FORWARD

Vulnerability Assessments

Localized Community Driven Efforts:
- Partner with **local organizations** to identify risks before disaster

Equitable Funding Formulas

Weighted by Need, Not Wealth:
- Consider **percent wealth lost and economic vulnerability**

Accessible Applications Systems

Beyond Internet Access:
- **Mobile Centers**, Paper Forms, Staffed Phone Lines

Strengthen Rural Preparedness

Roads, Comms, Supply Hubs:
- Redundant roads, warning systems, **emergency stockpiles**

ACKNOWLEDGMENTS

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