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The cover image of Ann Raiho with a canoe, is courtesy of Natalie Warren.

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Editorial Staff

Contact Us

Open Rivers
Institute for Advanced Study
University of Minnesota
Northrop
84 Church Street SE
Minneapolis, MN 55455

Telephone: (612) 626-5054
Fax: (612) 625-8583
E-mail: openrvrs@umn.edu
Web Site: http://openrivers.umn.edu

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FLOODPLAINS AND HURRICANES: MAPPING NATURAL DISASTERS TO UNCOVER VULNERABLE COMMUNITIES

By Kristin Osiecki

It is interesting how maps have transformed over the years. When I was younger, I remember wrangling a folded paper map (that never quite folded back) under a dim car light. Then, in the mid-1990s, a web-based mapping service called MapQuest revolutionized driving. Users

Harris County flood rescue.
Image by Lt. Zachary West, 100th MPAD/Texas Military Department.

could type in an address and print a map with step-by-step navigation instructions. Ten years later, I remember standing in line at 4am hoping to score a heavily discounted portable GPS system for my car the day after Thanksgiving. By the time I purchased my smartphone, a multitude of apps could direct me to my destination. Yet, even with the latest mapping technology, I still get lost and use a compass that is always a feature in my vehicle and on my keychain to orient myself.

I never thought my propensity for getting lost would prepare me to be a public health geographic information systems (GIS) specialist. Nor did I realize that the heavily industrialized area where I grew up would inspire me to work on issues of environmental health. As a first-generation college student, cis-gender female who grew up in a working-class community with a diverse population, I remember watching the oil refinery plumes and the barges slowly moving along a murky man-made canal strewn with garbage along the shore. Now, I design maps and analyze space to understand the complex relationships between humans and their environment. Through this lens, I see how environmental injustices disproportionately impact populations that have the fewest resources—whether political or financial—to mitigate or recover from hazardous exposures to toxins in the water, soil, and air. These exposures to toxins come from a range of sources, such as toxic waste dumps, industrial polluters, and the aftermath of man-made or natural disasters.

This article focuses on water-related natural disasters in the Houston Metropolitan Area (HMA) which is highly susceptible to hurricanes, tropical storms, and excessive flooding. By using GIS mapping, I can identify at-risk communities most impacted by these extreme weather events. Furthermore, geospatial analysis reveals that at-risk communities are not randomly distributed throughout the HMA and space where people live is a significant factor during a disaster. This article examines how vulnerable populations like women and children are at higher risk of disproportionate outcomes during flooding events. Mapping these kinds of environmental health outcomes and environmental injustices is challenging and sometimes heartbreaking work, especially when I see media coverage after a disaster and see the devastation that could have been mitigated with additional resources and thoughtful preventative actions.

The Role of Maps in Addressing Environmental Injustices

With GIS, I can see the world within the spaces, the people living within those places, and I can look at different kinds of factors such as poverty, pollution, food insecurity, and gender. GIS tells a compelling story by transforming numbers, statistics, and rates into maps that show complex inequities and injustices that reveal patterns and relationships with place. It is usually the case that injustices are not randomly distributed in our society but connected to larger systems of oppression. I not only connect disparate ideas, but disparate conditions. For example, I investigate how water impacts human health; more specifically, I research the environmental injustices surrounding water that contribute to negative human health outcomes.

Flooding and Climate Change Impacts

Yet environmental stressors keep coming. Climate change is creating extreme weather patterns in a way we have never seen before. Twenty years ago, risk assessment models predicted large categorical hurricanes (e.g., Hurricane Katrina) as one-hundred-year events. Our rapidly changing climate makes this model no longer valid. Excessive heat waves, droughts, wildfires, flooding, hurricanes, and rising ocean levels are no longer just predictions. From 2016 to 2020 extreme weather events quintupled, with an average 16.2 annually; 2020 alone had 22 natural disasters exceeding $1 billion in damages (NOAA 2021).

As an emergency preparedness/response researcher, I examine flooding—the number one environmental hazard worldwide and the most common natural disaster in the United States (FEMA 2010). Floodplains, low-lying areas adjacent to waterways that are at high-risk for being inundated with water, are found in every state across the country, unlike area-specific natural disasters. Unexpectedly heavy downpours, higher than average rainfall, living near a waterway, severe storms and hurricanes, or even normal rainfall coupled with the loss of power can overwhelm water systems and contribute to potential flooding disasters. In some way or another, most people have experienced the impacts of flooding or know someone who has. I have driven in severe storms and encountered flooded streets at low spots in the terrain. I have seen people drive through high water successfully while others stall out or float by and chalk it up to bad luck. Sometimes people drown in the floodwaters. Many flooding-related accidents are preventable for those with the privilege to make decisions about when and how to move and act during natural disasters. Disadvantaged populations, however, have no choices. For them, “bad luck” is being born into a designated group with the deck stacked against you. For example, individuals who cannot afford a vehicle are reliant on public transportation to evacuate prior to a hurricane. During Hurricane Katrina, up to 200,000 people were unable to leave the area due to lack of resources and transportation (Goldman et al. 2007).

Uneven Impacts of Flooding

Studies of flood impacts, emergency response, and post-event recovery show disproportionate hardships in disadvantaged communities. Socially marginalized populations have minimal capacity to evacuate during a flood or to recover from flood damage (Jonkman et al. 2009). Additionally, these groups experience higher rates of mortality and morbidity due to increased exposure to flooding during the actual flood event and decreased access to life-saving resources (Elliot and Pais, 2006). These rates can be attributed to an inability to evacuate prior to the event, dilapidated housing that cannot withstand the forces of water, low-income residents living in flood-prone areas, or a lack of access to health resources, to name a few. Ultimately, those with social and economic disadvantages are more likely to experience devastating socioeconomic, environmental, and health consequences after a disaster because they cannot afford flood, home, rental, auto, or health insurance (Zahran et al. 2008). Furthermore, low-income families reliant on government entitlement programs must stand in line to enroll for emergency assistance, often taking off work to wait for funds distributed through various levels of government. If marginalized populations *are* able to evacuate, another challenge is displacement to other areas within or outside the state that may not have available housing and resources to support low-income populations. High-level policies and institutional-level approaches perpetuate systemic racism, segregation, and discrimination. For example, minorities living in poverty are often segregated within a community by housing, education, and employment opportunities within a major urban area.

In environmental justice research, the words "marginalized" and "disadvantaged" are commonly used to describe communities and groups in a way that frames them as "less than" in a patriarchal society. The term "less than" is an institutional-level construct that further exacerbates inequalities by facilitating the development of policies that contribute to structural racism and sexism that strips some communities of political capital and, in turn, evacuation resources. This discernment shifts blame of disparate outcomes from the individual to unfair systemic policies. For example, individuals living below the poverty line are often stereotyped as lazy and unwilling to work but constructs like this only perpetuate generational poverty.

Neighborhood disadvantage looks at things like unemployment, lack of education attainment, pollution, poor living conditions, and food insecurity. Disadvantaged individuals are then socially categorized by gender, race, and poverty. There are populations that face more challenges than others. In the U.S., 25% of female-headed households—which includes 11.9 million children younger than the age of 18—are living in poverty

A view of Houston, Texas, showing the proximity of the ship channel and the city. Note also the pollution in the air. Image by United States Coast Guard, PA2 James Dillard.

(Bleiweis, Boesch and Gaines, 2020). Women working full-time jobs earn $0.82 on the $1.00 compared to men (Bleiweis, 2020). Women of color earn even less: Black $0.62, Latina $0.54, and Indigenous $0.52 (Bleiweis, 2020). This gap cannot be explained away by occupation or education level (Bleiweis, 2020). A patriarchal, hierarchical structure benefits those with power and privilege and perpetuates systems of social oppression such as racism, sexism, ageism, ableism, classism, and/or heterosexism. In emergency management terms, these flooding disasters often position oppressed communities as resilient and able to mitigate disaster risk: the ability to foresee, cope, resist, and escape from disaster. However, this understanding of marginalized populations as "resilient" perpetuates the institutional-level forces that drive oppression and hinder recovery in disadvantaged populations.

HGB Case Study

This case study involves the Houston-Galveston-Brazoria (HGB) region, an urban area that includes eight counties and the city of Houston. The HGB region has a long disaster history related to hurricanes and tropical storms such as Hurricane Alicia (1983), tropical storm Allison (2001), Hurricane Rita (2005), and Hurricane Ike (2005) (National Hurricane Center 2015). In August 2017, Hurricane Harvey caused $125 billion in damage (Blake and Zelinsky 2018). I spent two years in HGB researching environmental injustice and health inequity, looking at a variety of issues including potential disasters caused by hurricanes and flooding along the Houston Ship Channel (HSC). HSC is the number one conduit for exports and transports the largest amount of petrochemical manufacturing in the United States. There is little emergency preparedness and disaster response research that looks at flooding or wind damage resulting in fire, explosions, or releases of toxic chemicals into the surrounding environment. Furthermore, there is no buffer between the HSC and residential areas that are primarily inhabited by disadvantaged populations.

On a personal note, I experienced Tropical Cyclone Bill in 2015 with a rainfall of over 10 inches hunkering in an older first floor apartment. When I finally ventured out 24 hours later, I realized luck was on my side because my car, parked on second level, did not meet the fate of the 20-30 cars floating in the flooded lower-level parking areas. Multiple trees were down, several first-floor apartments flooded, and all roads (including the main roads outside our complex) were indefinitely closed. At least I had electrical power to survive the humid 89-degree heat compared to others with no air conditioning. The entire city of Houston was underwater, which was no surprise because everyone—including the local government—was aware that the city lacked an adequate sewer system to accommodate the increasing population and severe flooding events.

The following maps portray those most impacted by flood events like what I experienced during my time in HGB. These maps examine the HGB region, the percent of female-headed households, and four other factors of people living in these flood zones. Data is collected from the 2015–2019 American Community Survey and the US Federal Emergency Management Agency. ESRI ArcGIS and Geoda GIS software were used for mapping and spatial analysis.

Map visualizations allow us to represent data within specified geographic boundaries. Boundaries are like nesting dolls in which one fits inside another from the smallest boundary to the largest boundary. This allows us to zoom in to find detail in a smaller area or zoom out to examine a big area. For example, from largest to smallest: United States; State; County; City;

Neighborhood; Census Tract. In addition, other items can be mapped, such as topographical features (floodplains, waterways, parks, etc.).

Figure 1 shows the eight counties within HGB in which each county boundary is highlighted in light blue. Underneath the county boundaries is a topographical map that shows floodplains in fluorescent green. Here we can see a large fluorescent green area in the lower right corner bordering the ocean with smaller floodplains along rivers, lakes, or low-lying areas. This map shows that all eight counties have floodplains and four counties with larger areas are more vulnerable to flooding.

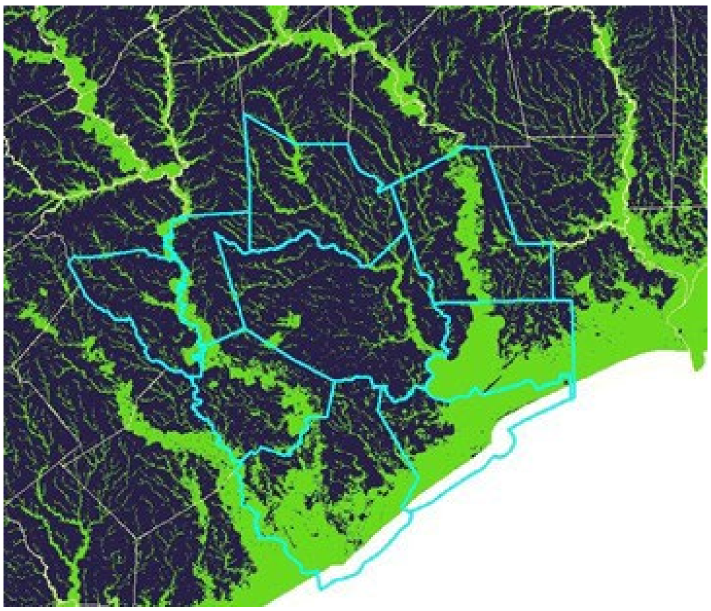

Figure 1. The Houston-Galveston-Brazoria region with county boundaries highlighted in light blue. Map courtesy of Kristin Osiecki.

In Figure 2, five different quantile maps (data divided into classes with the same number of values) of the HGB were created using socioeconomic data using census tract boundaries. Tract boundaries are drawn based on population that includes a range of 2,500-5,000 people (census tracts are used by governmental entities to allocate resources). Smaller census tracts are common in densely populated areas while larger tracts are found in low population areas. The five different variables chosen are commonly used to define disadvantage in a population: female-headed household, unemployment, less than high school diploma, poverty, and median income. To better understand these maps, visualize five different buckets in front of you, and imagine you have 100 pieces of candy that need to be divided equally into each bucket, resulting in 20 pieces per bucket. This is the idea behind quantile maps—each class (or color on this map) having the same number of data; it is a useful tool to compare data not only within a map but between maps. If you look closely at each map, you will seek darker patterns of color occurring in similar geographic boundaries across them.

Patterns of disadvantaged populations exist within the center of Houston and around the perimeter. From these patterns, we can hypothesize that there are two distinct disadvantaged populations: a densely populated area in the city of Houston and less populated areas in the surrounding counties.

Patterns allow us to see the distribution of data, but spatial analysis examines the significance of space to understand these patterns. The analysis in Figure 3 investigates the significance of space within the female-headed household living below poverty indicator. The map on the left consists of green census tracts that were found to be significant or in spatial terms; space is an important component within the data. The scatterplot in the middle allows us to see the correlation between the two variables (female-headed household and poverty). (Note that this is not interpreted the same as a scatterplot normally seen in inferential statistics because there is a weight structure and significance is defined differently.) The takeaway is the Moran's T-Value, 0.307, which confirms that our data is not randomly distributed throughout the HGB. The map on the right shows census tracts in blue that are also located next to census tracts in blue. This means that female-headed households living in poverty live in areas next to each other or clustered together. Finding these clusters allows us to focus

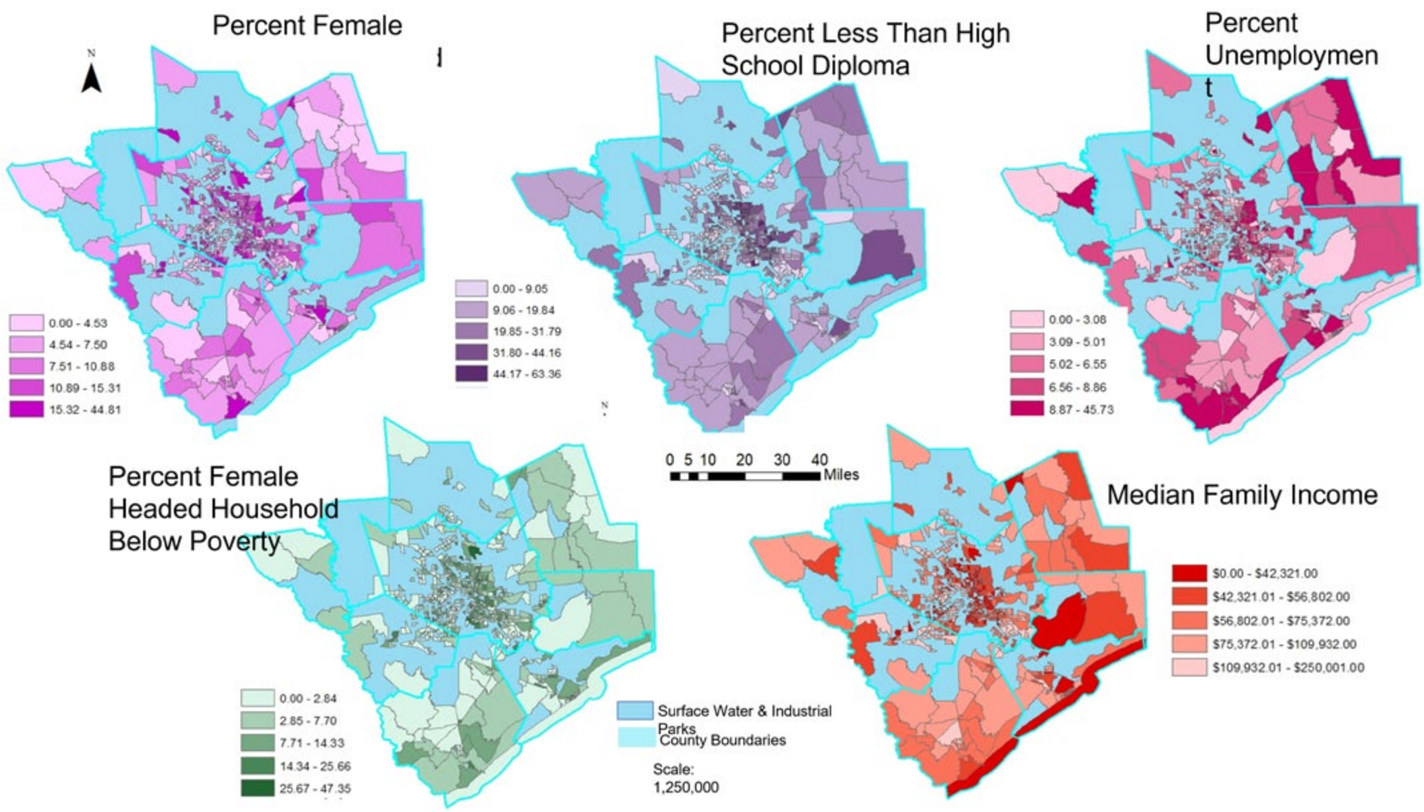

Figure 2. Maps of the disadvantaged population variables. Map courtesy of Kristin Osiecki.

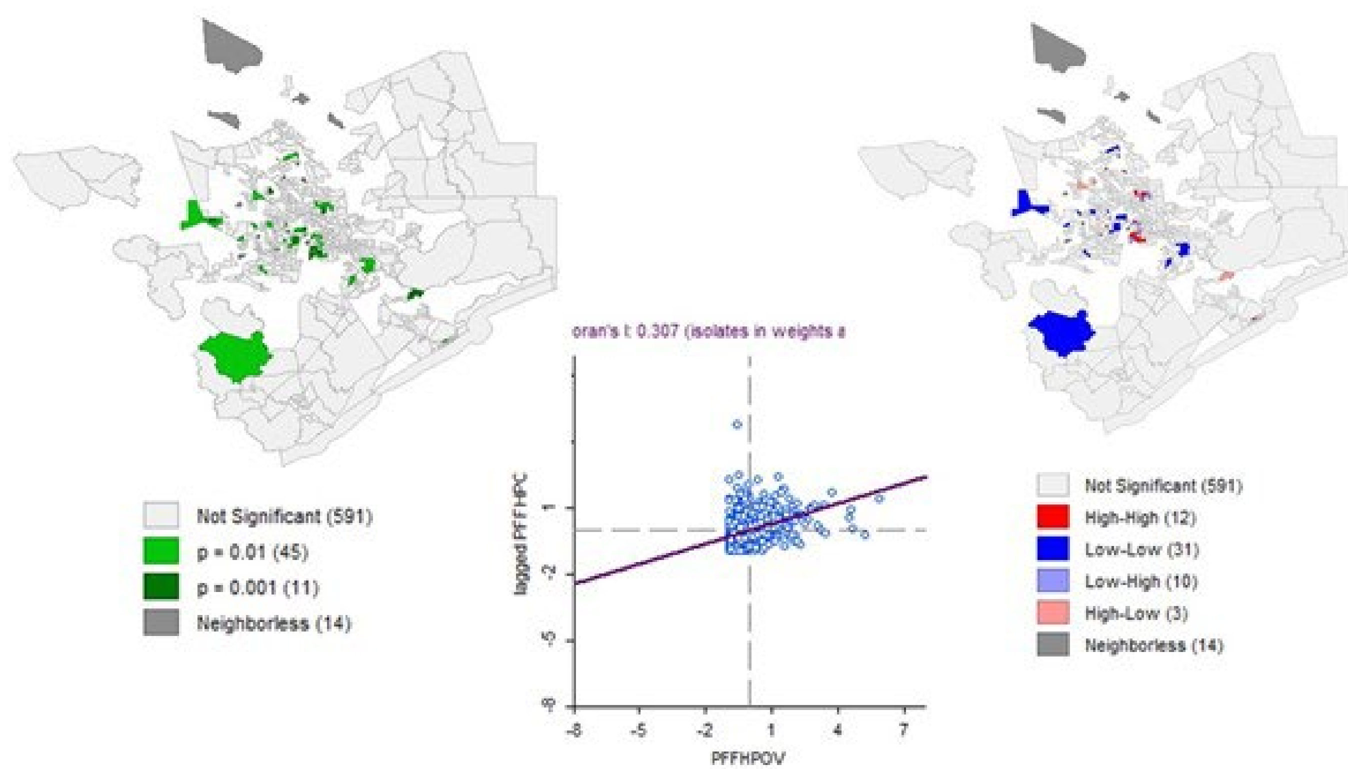

Figure 3. Exploratory spatial data analysis with percent of female-headed households living in poverty. Map courtesy of Kristin Osiecki.

emergency preparedness and response resources and programs within these census tracts.

Significant clusters are identified on the two maps with twelve distinct clusters of areas with the highest risk within the floodplain which impacts thousands of disadvantaged residents. Thus female-headed households living in poverty are more at risk for the effects of flooding. This highlights the power of GIS and uncovering populations that need additional assistance during natural disasters.

Conclusion

Water is often seen as a precious resource to conserve. However, emergency preparedness/response researchers see water through a different lens; floodwaters are a dangerous force that disproportionately affect disadvantaged populations. As climate change increases extreme weather events, the most vulnerable communities continue to experience the greatest consequences. With GIS software, we can utilize data to predict those most at risk for adverse outcomes during flood events and design measures to help disadvantaged populations prepare, evacuate, and recover from extreme water-related disasters.

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About the Author

Kristin Osiecki is a proclaimed city girl aware of her surroundings and enthralled with industrial beauty: swirling air plumes choked with pollution, sizzling welding sparks from old factory windows, and poofs of algae blooms among floating garbage. As a health inequity and environmental injustice researcher, she tries to understand the complex relationships between humans, nature, and places in our communities. She is a very passionate undergraduate public health assistant professor and embraces engaged and experiential learning in and outside the classroom. She is begrudgingly finding her inner Minnesotan outdoor goddess with primitive camping, kayaking, and eradicating buckthorn.