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Here comes the rain: Assessing storm hazards vulnerability in Northeast Ohio

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ABSTRACT

The frequency and intensity of coastal storm events in the Great Lakes region, USA is predicted to increase in the coming decades, exposing at-risk populations to potential hazards including flooding, erosion, and combined sewer overflows. In response, applied research is needed to identify communities that are most vulnerable to storm hazards, and to support municipal officials and local residents with building capacity for resilience. This study analyzes the storm hazards vulnerability of 42 communities that are located within the Northeast Ohio Regional Sewer District (NEORSD), including the city of Cleveland and its inner and outer ring suburbs. Communities are ranked against each other for vulnerability according to a social and environmental indicator, each of which is comprised of five variables that operationalize the sociodemographic and biophysical challenges facing local populations. The indicators are combined to produce a composite Storm Hazards Vulnerability Index (SHVI). Results suggest that the most environmentally vulnerable communities are not always home to the most socially vulnerable populations. Overall storm hazards vulnerability correlates more closely with the environmental indicator than the social, especially among the most vulnerable communities.

1. Introduction

Coastal storms and resulting flood events have historically been the most destructive natural hazards in northeast Ohio in the USA. According to the Cuyahoga County, OH Natural Hazards Mitigation Plan (2011) [18], storms and heavy rains are responsible for 9 of the past 11 presidential declarations of disaster in the county resulting in over $650 million in damages from 1950 to 2010.

Climatic changes are predicted to worsen these hazards by producing increased precipitation and more frequent and severe storm events [2]. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) [38] indicates that these storms have the potential to cause problems for existing urban water infrastructure and can be detrimental to water systems in North America.

Rising atmospheric temperatures lead to increased water temperatures, which contributes to the formation of such storms. Most importantly, climate change is increasing the number of the most extreme storm events that can cause flooding, erosion, and excess runoff. In fact, in the Great Lakes region, some climate models predict that by mid-century precipitation in 50-year storms (storms that have a 1 in 50 chance of occurring in any given year) may increase up to 29% from historic levels [19].

For some communities in northeast Ohio, the physical and economic impact of storm hazards are particularly difficult to absorb due to a lack of institutional resources (personnel, financial and technical resources) and large percentage of low-income home and business owners. Residents can be at risk due to environmental factors, such as proximity of housing structures to flood zones, as well as sociodemographic challenges that make recovering from coastal storms more difficult. This is especially true in many of the inner ring suburbs of the city of Cleveland, where urban blight and shrinking tax bases have left municipal governments strained for resources.

In response, applied research is needed to identify communities that are increasingly vulnerable to storm hazards, and to support municipal officials and local residents with building capacity for resilience. This study attempts to accomplish this goal by analyzing the storm hazards vulnerability of 42 communities that are located entirely within the Northeast Ohio Regional Sewer District (NEORSD), including the city of Cleveland and its inner and outer ring suburbs.

Communities are categorized for vulnerability according to a social and environmental indicator, each of which is comprised of five variables that operationalize the sociodemographic and biophysical challenges facing local populations. The social and environmental indicators are combined to produce a Storm Hazards Vulnerability Index (SHVI), which allows evaluation of trends across variables as well as a measure of overall vulnerability. The SHVI can help inform decision-making regarding storm hazard mitigation and emergency management preparedness strategies in the most vulnerable communities in the

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region.

In the sections that follow are a brief background on the evolution of theory related to vulnerability studies, the methodology, results of the analysis, discussion of the implications of this work, and a conclusion including limitations and guidance on further research needs.

2. Theory

The emphasis of this project aligns directly with the second stated recommendation of the Cuyahoga County, OH Natural Hazards Mitigation Plan (2011) [18] – "Develop strategies and priorities to mitigate risk from natural hazards and identify action steps or projects to reduce the risk." Risk and vulnerability are different, yet related concepts for our purposes. Following Clark et al. [8] and an earlier review of vulnerability studies by Dow [20], ***vulnerability*** is defined as a population's inability to "deal with hazards, based on the position of groups and individuals within both the physical and social worlds." These authors and others in the field suggest *vulnerability* equates to the potential for loss [10]. ***Risk***, according to Clark et al. [8], is related to exposure, or the likelihood of experiencing hazardous events. The ultimate goal of this research is to consider both the physical and social risks facing 42 communities in northeast Ohio, and how they combine to predict the vulnerability of place.

The idea of vulnerability as a social product grew out of debate over existing paradigms that tried to describe society's relationship to natural hazards. For example, attempts to incorporate psychological tests into development fieldwork helped define the hazard perception paradigm, but were ultimately dismissed when it became clear that different people simply perceived natural hazards differently [43]. It was also suggested that "Social, economic, and political conditions were required to turn the hazard into a disaster" ([43], pg. 6). Race, ethnicity, gender, and economic status appeared to play a role in how different groups of people were impacted by natural hazards. Previous concepts including the perception paradigm and the hazard-focused paradigm were ultimately replaced by a vulnerability paradigm that focused on specific constraints and threats facing individual populations (Blaikie et al., 1994; [43]).

More recent studies on vulnerability to natural hazards have emerged from equally disparate formulas, as reviewed in detail elsewhere [1,10,20,43]. Although 'potential for loss' is a common theme there are often several competing perspectives on vulnerability. One approach considers vulnerability simply as the potential exposure to physical hazards, while another accepts exposure to hazards as given and instead explores the social construction of vulnerability among individuals or communities [44]. Building on a robust catalog of studies investigating vulnerability, Cutter [10] offered a third path coined the 'hazards of place' model of vulnerability. This approach takes into account both environmental factors and social response within a defined geographical area.

In the twenty years since the inception of the hazards of place framework, researchers have found it useful to analyze how people are affected by and respond to coastal storm hazards, particularly given the increasing risk of communities to more frequent and severe storms. The hazards of place methodology along with various adaptations has been used to assess the vulnerability of several east coast communities to sea-level rise, extreme coastal storms, storm surges, and to develop a social vulnerability index for coastal flooding and climate adaptation planning [32,39,44,8].

While much work has been done on hazards of place and coastal storms, there are relatively few studies within this field that focus on the Great Lakes region. The National Oceanic and Atmospheric Administration (NOAA) [34] released a pair of pilot studies on "Economic Assessment of Green Infrastructure Strategies for Climate Change Adaptation" in the Great Lakes Region in 2014 that offer related examples from Duluth, MN and Toledo, OH. Similarly, Noordyk and Harrison [35] conducted a needs assessment survey for the NOAA Great Lakes Coastal Storms Program on "Great Lakes Planning and Mitigation Needs for Coastal Storm Hazards."

Among Great Lakes states, Ohio faces specific challenges in terms of vulnerability. In urban areas, historically unprecedented warming trends are projected by the end of the 21st century [26]. These areas, where population density is high, a majority of residents are minorities, and a large percentage of households live below the poverty threshold, have exhibited increased social vulnerability in other states [15]. Communities in rural Ohio are also vulnerable to changes in extreme weather, given the large percentage of the state's economy that is dependent on agriculture [26]. Spring flooding in particular poses a risk to Ohio's agricultural industry and the livelihoods of agrarian populations.

In northeast Ohio's largest city of Cleveland, social conditions and land use patterns are suggested to magnify the impact of climate change, including frequency and intensity of coastal storms. The Cleveland Climate Resiliency and Urban Opportunity Plan indicates that urban sprawl and an overall decline in population has led to concentrated poverty in urban neighborhoods, redundant infrastructure, and growing economic and racial stressors [9], all of which can impact the vulnerability of local populations.

2.1. Developing a storm hazards vulnerability index (SHVI)

2.1.1. Social vulnerability

Within the field of social vulnerability several factors are generally accepted as being influential. These include, "lack of access to resources (including information, knowledge, and technology); limited access to political power and representation; social capital, including social networks and connections; beliefs and customs; building stock and age; frail and physically limited individuals; and type and density of infrastructure and lifelines" ([14], pg. 245).

Some researchers have sought to go beyond these broad themes and focus on the social construction of vulnerability [21,3,8]. Such studies suggest that a wide variety of socio-demographic indicators can increase vulnerability, many of which can be extracted from U.S. Census Bureau data (see [14]).

Recent efforts have sought to summarize our understanding of social vulnerability to natural hazards in different locations and at different scales. Tapsell et al. [40] published a report that examines social vulnerability in relation to natural hazards in Europe. Dwyer et al. [23] quantified social vulnerability to natural hazards in Australia. Cutter and Finch [15] summarized changes in social vulnerability to natural hazards in the United States with the goal of better informing emergency management response. Some scholars have also updated earlier assessments, like Blaikie et al. [3] who released a second edition after 15 years of their seminal text on the relationship among natural hazards, people's vulnerability and natural disasters, highlighting important findings since the publication of the original version.

Others have zeroed in on the construction of social vulnerability within certain populations or in response to specific biophysical events. Susan Cutter [11] revisited decades-old research on vulnerability among women to highlight how social transformations like increasing wealth gaps, large-scale population movements, and violence against females impact the environmental burdens on women and children. Another recent effort by Cutter [12] looks at the social vulnerability of food supply chains in the face of natural disaster. Others have employed GIS techniques as a tool for mapping social vulnerability to natural hazards [27], such as seismic hazards in Italy [28,5]. Some have looked more specifically at social vulnerability of storm-related hazards, including Koks et al. [31], who investigated the social vulnerability of flood risk management in the Netherlands, and Fekete [25], who developed a social vulnerability index for river floods in Germany.

2.1.2. Environmental vulnerability

Historically, measures related to environmental vulnerability have

Table 1
Social vulnerability measures.
Source: Adapted from [14].

Measure	Explanation
Percentage of females	Sector-specific employment, lower wages and family care responsibilities more commonly associated with women can negatively impact the ability to recover from hazards.
Percentage of non-white residents	Contributes to social vulnerability due to the social, economic, and political marginalization that is often associated with racial disparities.
Percentage of people under 18 and over 65	Extremes of the age spectrum affect the movement out of harm's way. Parents lose time and money caring for children when daycare facilities are affected; elderly may have mobility constraints or mobility concerns increasing the burden of care and lack of resilience.
Percentage of renter-occupied housing units	People that rent are often transient or do not have the financial resources to purchase a home. They can lack access to information about financial aid during recovery and shelter options when lodging becomes uninhabitable or too costly to afford.
Percentage of households under the poverty threshold	Poor communities have difficulty absorbing and recovering from hazards due to gaps in insurance and insufficient social safety nets.

often focused on resource dependence of the population rather than potential risks to the natural resources themselves [32]. More recent work has shifted attention to impairment of the resources, indicating that this can have a direct impact on vital local assets such as residences, businesses, utilities, and transportation routes ([32,37]). For this study, environmental vulnerability considers the distribution of natural resources at risk of impairment from coastal storm hazards and their relation to community assets.

When compared to indicators of social vulnerability, the designation of environmental vulnerability has been suggested to be less defined. Villa and McLeod [42] went as far as to say "measures are often calculated with little scientific justification and high subjectivity…" Of course, this is not always the case. Theoretical frameworks such as the Coastal Vulnerability Index (CVI) have been used to assess biophysical vulnerability [4], often in conjunction with a social assessment tool such as the Social Vulnerability Index [13]. Huang et al. [29] used a similar approach when employing an Exposure Index (EI) to compare the vulnerability of coastal communities to land use change in China. Chakraborty et al. [6] followed suite by developing a Geophysical Risk Index (GRI) based on National Hurricane Center and National Flood Insurance Program data, in conjunction with social indicators, to explore severe storm evacuation patterns in Hillsborough County, FL.

Research further posits that environmental vulnerability is inherently location specific. "The focus on place provides an opportunity to examine some of the underlying social and biophysical elements that contribute to vulnerability, as well as to assess their interaction and intersection. Place vulnerability can change over time based on alterations in risk, mitigation, and the variable contexts within which hazards occur" ([13], pg. 716). For example, the threats and subsequent mitigation strategies outlined in this project are specific to northeast Ohio, and will evolve over time to reflect changes in local biophysical conditions, as well as demographic, cultural, and economic trends.

3. Methods

This project adapts existing methodologies [13,39,44,6] to calculate the storm hazards vulnerability for each of 42 communities located in the NEORSD. Five sociodemographic variables taken from U.S. Census data are used to inform a social indicator for each community. Five biophysical variables taken from data produced by the NEORSD and Federal Emergency Management Association (FEMA) inform an environmental indicator. The social and environmental indicators are combined to form a composite storm hazards vulnerability index (SHVI).

Following examples from the literature [13,31,44,6], rather than using simple percentages or whole numbers, each variable is standardized as the ratio of the value for that variable in a given community to the maximum value for that variable in the study area. The result is an index for each variable that ranges from 0.00 to 1.00, where higher values indicate higher vulnerability.

The values for the five sociodemographic variables are averaged to calculate the value of the social indicator for each community and then scores are ranked from high (most vulnerable) to low (least vulnerable). The same process is followed for the environmental indicator. The values for the social indicator and environmental indicator are then averaged to compute the SHVI score for each community. Following Cutter (2000), [17], Koks et al. [31], and Wu et al. [44], weights are not attached to the variables. As with the social and environmental indicators, SHVI scores are ranked relative to each other.

For example, the percentage of people living below the poverty threshold in each community is divided by the maximum percentage of households in poverty in the study area, then scores are ranked from high (most vulnerable) to low (least vulnerable). The scores are averaged with the four other sociodemographic variables and then ranked from high (most vulnerable) to low (least vulnerable) per community to compute the social indicator. A similar process is followed for the environmental indicator. Scores from the social and environmental indicators are averaged to determine the composite SHVI score for each community.

3.1. Social indicator

The social indicator is calculated using 2010 U.S. Census data for the following five variables: (1) gender; (2) ethnicity; (3) age; (4) home ownership; and (5) income, as outlined in Table 1. While additional variables could be included, those selected have proven to be useful in existing studies and offer an initial metric for analysis in this case [13,22,40,45,6].

In some studies, principal component analysis has been employed to select the most appropriate measures of social vulnerability among census data [14]. Others have eschewed the use of statistical procedures and instead sought measures based on existing data or that are most appropriate for a given population or location [44,6]. Indicator selection for this study adapts the latter methodology to look at storm hazards in the NEORSD. Table 1 explains how each of the five sociodemographic variables (gender, ethnicity, age, home ownership, and income) is operationalized and contributes to social vulnerability.

3.2. Environmental indicator

In an effort to capture the unique environmental factors that influence vulnerability of northeast Ohio communities, existing NEORSD data on stormwater management and FEMA data for land per community in the 100 year flood zone (area that depict floods that have a 1 in 100 chance of occurring in a given year) is used.

Geographic Information System (GIS) data from the NEORSD Stormwater Inventory and Inspection (SII) project identifies existing flood, erosion, debris, and water quality hazards in residential

Table 2
Environmental vulnerability measures.
Sources: NEORSD, 2014 [37] and FEMA, 2016 [24].

Data source	Measure
FEMA	Acreage within the 100 year flood zone
NEORSD	Flooding hazards
	Erosion hazards
	Debris hazards
	Water quality hazards

watersheds and quantifies potential risks to assets (residences, businesses, utilities, and transportation routes) throughout the study area (outlined below in Table 2).

The SII project focuses on the inspection of open stream channels, culverted streams, transportation crossings, and major structures located within the Sewer District's stormwater management program. All inspections are conducted using android tablets, equipped with online ArcGIS Collector software. Each of the systems noted above is observed for hazards based on the severity of the findings with a score of 1 (minimal) to 5 (severe). Only hazards with a score of 4 or 5 are included in this data set [37]. The number of hazards per community is calculated, with larger numbers representing greater vulnerability.

Special Flood Hazard Area (SFHA) data from FEMA's Flood Insurance Rate Maps (FIRM) (2016) is used to identify and quantify the amount of land per community located in the 100 year flood zone per community. SFHA are defined as "the area that will be inundated by the flood event having a 1% chance of being equaled or exceeded in any given year." Higher quantities of land in the flood zone indicate higher vulnerability.

3.3. Storm hazards vulnerability index (SHVI)

The composite SHVI score for each community represents the arithmetic mean of the scores of the social and environmental indicators. Composite SHVI scores are ranked against all other communities in the study area to reveal overall vulnerability from most vulnerable to least vulnerable. While vulnerability associated with each variable can be considered independently, the aggregate of all variables offers a more complete perspective on storm hazards vulnerability.

Index scores are divided into quintiles and GIS maps are created using ArcGIS to show the spatial variation of both social and environmental vulnerability, as well as the composite SHVI. Numerical values for all communities are displayed in Appendix A. Maps for the social and environmental indicators and the composite SHVI are shown in the Results section (Figs. 2–4). A model of the storm hazards vulnerability index is shown below in Fig. 1.

4. Results

4.1. Social vulnerability

The highest concentration of socially vulnerable communities are located in Cleveland City and the eastern inner ring suburbs (see Fig. 2). These communities were predominantly built between 1900 and the 1930s. Growth in these areas accelerated dramatically in the years following World War II, but has slowed since. The inner ring suburbs are now 45 – 100+ years old, and as suggested by the Northeast Ohio First Suburbs Consortium [36], a government-led advocacy organization focused on revitalizing these communities, "many have begun to experience that which had been exclusively central city challenges," such as aging infrastructure, out-migration of jobs and retail outlets, and lack of economic opportunities.

The community with the highest social vulnerability ranking is East Cleveland. This is not a surprise, given that, among the 42 communities in this study, it has the highest percentage of residents living below the poverty threshold (42.10%), the third highest percentage of minority residents (95.40%), third lowest owner-occupied housing rate (35.20%), and seventh highest percentage of females (54.90%). Among the rest of the top 5 most socially vulnerable cities, Warrensville Heights, Maple Heights, North Randall, and Cleveland City all rank in the top 10 for percentage of residents living below the poverty threshold and percentage of minority population. Geographically, each of these communities is located in an eastern inner ring suburb, either adjacent to Cleveland, or one of the other most socially vulnerable municipalities.

4.2. Environmental vulnerability

Unlike the social vulnerability indicator, communities identified as environmentally vulnerable are predominantly located to the south and southwest of Cleveland, including Cleveland City itself. The position of these communities correlates geographically with the Cuyahoga River Valley and areas within the Rocky River watershed, rather than the socioeconomic pattern delineated by the inner-ring suburbs. The one exception is Pepper Pike, which is located in a far eastern exurb. This community is ranked among the most environmentally vulnerable due to consistently high scores across measures. For example, it ranks fifth highest in debris hazards, third highest in erosion hazards, third highest in water quality hazards, and twelfth in structural hazards, out of the 42 communities in the study area.

The biggest determinant of environmental vulnerability correlates to acreage per community located within the 100 year flood zone. Overall acreage per community in the 100 year flood zone in this study ranges from 0 acres to 2034 acres, with Cleveland City ranking as the highest. Communities with the second and third highest number of acres in the 100 year flood zone are also the second and third most environmentally vulnerable communities in this study – Independence and Strongsville. Contributing to these high vulnerability scores, Cleveland and Independence rank first or second for 4 of the 5 environmental measures overall.

4.3. Storm hazards vulnerability index

Overall storm hazards vulnerability correlates more closely with the environmental indicator than the social indicator, especially among the most vulnerable communities. For example, the top 4 most environmentally vulnerable communities (Cleveland, Independence, Strongsville, Pepper Pike) also have the highest aggregate storm hazards vulnerability rankings. Seven of the top 10 are among the 10 highest ranked for storm hazards vulnerability (Cleveland, Independence, Strongsville, Pepper Pike, Olmsted Falls, Parma, Garfield

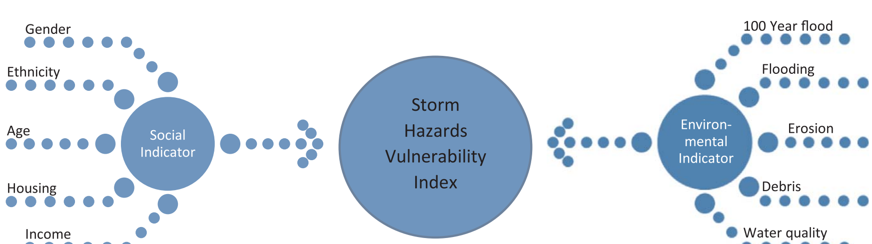

Fig. 1. Storm Hazards Vulnerability Index.

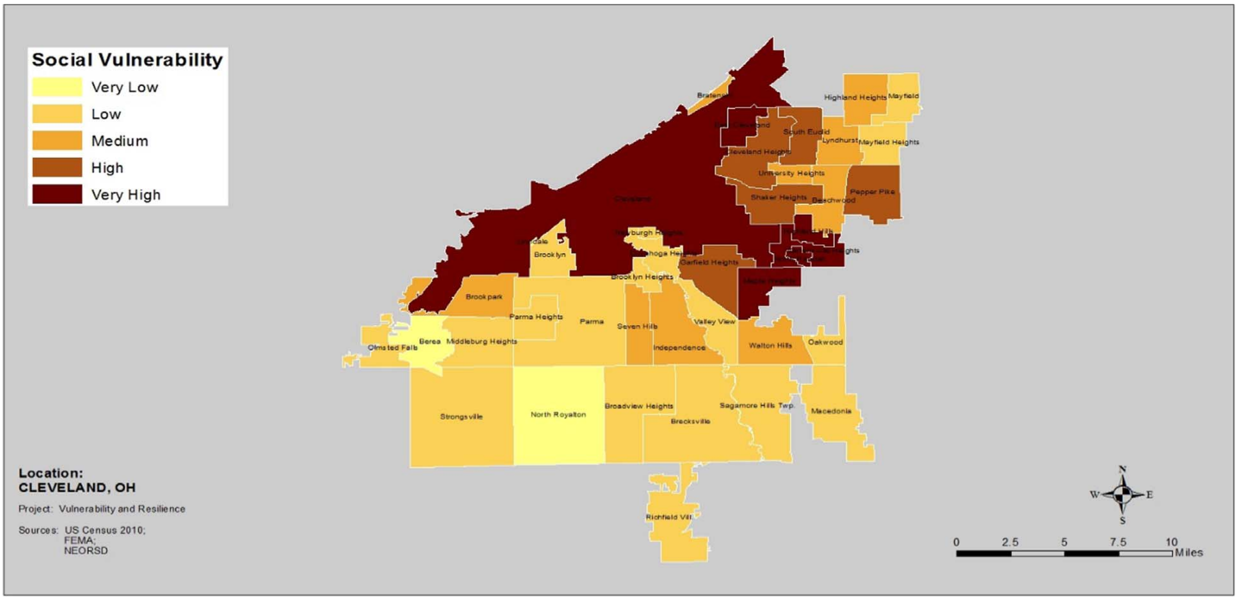

Fig. 2. Social vulnerability of NE Ohio communities.

Heights). Conversely, the single most socially vulnerable community (East Cleveland) only has the tenth highest storm hazards vulnerability score. Overall, 5 of the top 10 most socially vulnerable communities are among the 10 highest ranked for storm hazards vulnerability (East Cleveland, Warrensville Heights, Maple Heights, Cleveland, Garfield Heights).

Geographically, the most vulnerable communities to storm hazards are distributed somewhat evenly across the study area. Of the top 10 most vulnerable, 5 are considered "new suburbs" and are thus located along the inner-ring of Cleveland City (Garfield Heights, Maple Heights, Parma, Warrensville Heights, East Cleveland). Seven of the top 10 are located within the Cuyahoga River watershed. Several outliers exist as well, such as Olmsted Falls on the far western end of the study area, and Pepper Pike on the far eastern end.

5. Discussion

While easy to consider certain measures individually (e.g., household income) the goal of this analysis is to compile multiple variables in order to paint a more complete picture of risk and vulnerability to coastal storm hazards. Further analysis could possibly find that some of the communities identified as most vulnerable in this study offer the best quality of life according to other standards, such as quality of public schools, low crime rates, home affordability, etc. It is important to keep in mind that this analysis only considers trends reflecting social and environmental vulnerability to coastal storm hazards.

It is also important to note that the social measures chosen: age, gender, income, ethnicity, and home ownership especially speak to vulnerabilities directly associated with natural hazards, not political or societal hazards. Likewise, the environmental measures are associated with storm-related hazards of critical importance to citizens of northeast Ohio, and may not be as appropriate for similar studies focused on other natural hazards, or in other regions.

Interestingly, the most environmentally vulnerable places do not consistently intersect spatially with the most socially vulnerable

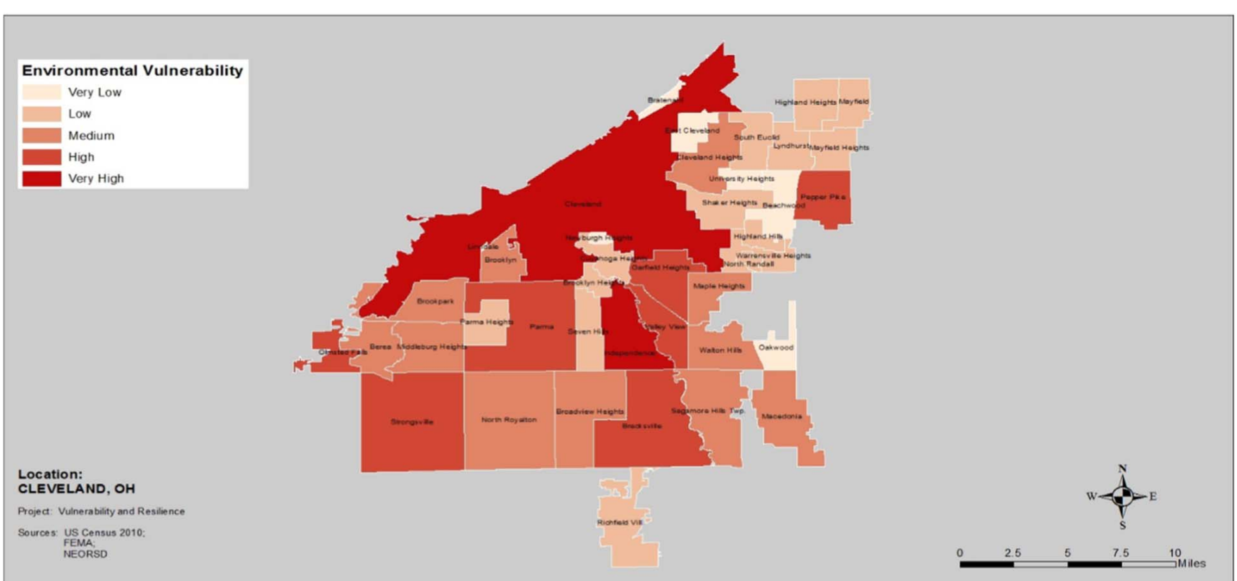

Fig. 3. Environmental vulnerability of NE Ohio communities.

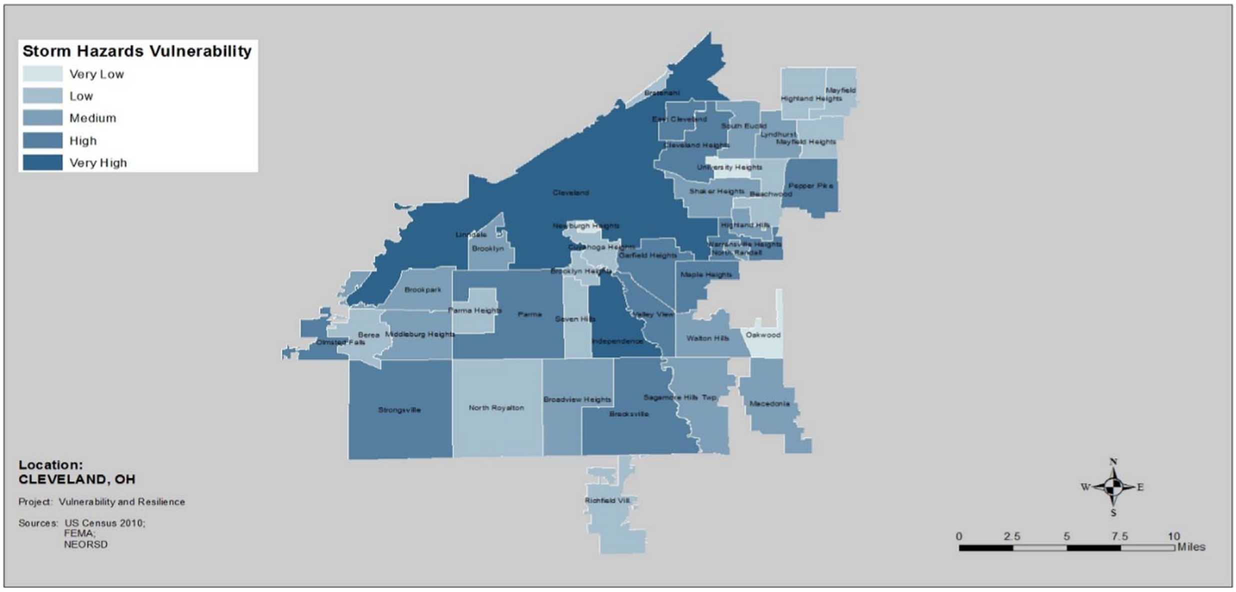

Fig. 4. Storm hazards vulnerability index.

communities. The most influential factor for environmental vulnerability is proximity to flood zones, namely those of the Cuyahoga River and the Rocky River. For social vulnerability, the percentage of residents living below the poverty threshold and percentage of minority population are the most impactful variables. In northeast Ohio, patterns of neighborhood development in close proximity to waterways do not necessarily correlate with household income or ethnicity. Thus, employing one of the indicators without the others would skew the study results substantially.

A similarly uneven distribution among social groups and hazardous locations was observed by Cutter and Emrich [16] while investigating the social vulnerability of residents living along he hurricane coasts. Chakraborty et al. [6] also found that environmental risk and social vulnerability can be quite different when determining hurricane evacuation strategies in Hillsborough County, FL. Others have found that there can be spatial differences between physical and social attributes and their combined impact on place vulnerability [13,4,44,8]. Conversely, in some instances the relationship between social vulnerability and environmental hazard are suggested to not be spatially random, and in fact, can be highly clustered geographically [33].

Although storm hazards vulnerability correlates more closely with the environmental indicator in this study overall, there are several communities of relatively low environmental vulnerability that are ranked high for overall vulnerability. Moreover, among the most environmentally vulnerable communities, there is an uneven level of social vulnerability. This is an important finding because it reflects the likely "social costs" of hazards in northeast Ohio. This also supports research from Cutter et al. [13] who found similar patterns in Georgetown County, SC. As suggested by the Cutter et al. study ([13] pg. 733):

> "While economic losses would be great for residents in areas delineated in high-risk biophysical hazard zones, their recovery will be facilitated by greater wealth and access to resources. On the other hand, it would take only a moderate hazards event to disrupt the livelihoods and well-being of the majority of [county] residents and retard their longer term recovery from disaster."

When put into action as policy or mitigation actions, vulnerability, similar to risk as viewed by Cutter et al. ([13], pg. 717), can either be "reduced through good mitigation policy, or amplified by poor or nonexistent mitigation policies and practices. The hazard potential interacts with the underlying social fabric of the place to create the social vulnerability." This suggests that, while social measures are important for identifying at-risk populations, biophysical factors also play a large role in risk determination. This further supports a dual focus on the geographical patterns of both social and environmental vulnerability as outlined in this study, and should be instructive for policymakers and practitioners in the region.

Similar approaches to addressing dual threats of social vulnerability and scaled environmental risk reduction have been suggested to be successful in other studies. An example can be seen in Chen et al. [7] integration of social vulnerability and disaster risk mitigation with sustainable development approaches in the Yangtze region of China. Blaikie et al. (pg. 4) [3] also tackles this issue and suggests that "The crucial point about understanding why disasters happen is that it is not only natural events that cause them. They are also the product of social, political and economic environments…" Related approaches to understanding the biophysical and social patterns of vulnerability in a given population has been widely adopted by vulnerability scholars ([29–32,4,6,8]; [44]) and can offer insights into disaster risk reduction and emergency management decision making.

6. Conclusion

The heaviest 1% of precipitation events are predicted to increase in the Great Lakes region in the coming decades [19], and with this increase may come more severe and frequent storm hazards. This trend could significantly increase the vulnerability of at-risk populations to flooding, erosion, and combined sewer overflow caused by storm events. Results from this study indicate that the most environmentally vulnerable communities are not always home to the most socially vulnerable populations. In northeast Ohio, storm hazards vulnerability is impacted more by biophysical factors than social variables, especially among the most vulnerable communities. Often times, these communities are located within the 100 year flood zone of major rivers, especially the Cuyahoga River and the Rocky River.

While computer models can predict regional precipitation frequency estimates for northeast Ohio, it is more difficult to predict social vulnerability trends. Which communities will be able to build their adaptive capacity to climate-induced storm hazards and which will not? What sociodemographic trends will emerge that create the greatest potential for loss among different populations? These questions need to be answered by practitioners and policy makers in order to design programming to support at-risk communities and help build resilience to growing threats.

This paper attempts to support such efforts by focusing on the social and environmental vulnerability of communities located along one stretch of Ohio's north coast. This project thus holds the potential to inform investment (financial, technical, and human) in stormwater and emergency management planning and hazards mitigation actions in local communities, at the county level, and on a regional scale within the greater NEORSD. If productive, this approach could be valuable to decision makers tasked with managing stormwater utilities and planning for coastal storm hazards across the Great Lakes states.

Several limitations constrain this project's findings. The first concerns the breadth of variables included in the analysis. While variables were chosen because of their appropriateness for the study area or inclusion in the existing literature, they do not tell the entire story of vulnerability in northeast Ohio. Values for each of the variables were not weighted, potentially impacting the order in which communities are ranked for social and environmental vulnerability, as well as the SHVI. Another limitation concerns the highly focused view on vulnerability to storm hazards, rather than all natural hazards. Lastly, while this project produces a storm hazards vulnerability index that ranks communities in teams of vulnerability, it does not offer recommendations on how to build adaptive capacity in at-risk communities nor suggest specific policy responses.

More comprehensive analyses are needed that cast a broader net and consider vulnerability on a regional scale, for multiple and/or simultaneous hazards, as well as offer guidance on local, state, and federal actions to help build resilience among affected communities. While a helpful tool for informing decision-making, more research is needed on the social construction of vulnerability to all hazards in northeast Ohio, and specific recommendations are needed for mitigating loss.

Acknowledgements

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Appendix A. Storm hazards vulnerability rankings

Social Vulnerability	Value	Environmental Vulnerability	Value	Storm Hazards Vulnerability	Value
East Cleveland	0.8158	Cleveland	0.9245	Cleveland	0.8174
Warrensville Heights	0.7381	Independence	0.7257	Independence	0.6427
Maple Heights	0.7196	Strongsville	0.4063	Pepper Pike	0.4774
North Randall	0.7135	Pepper Pike	0.3408	Strongsville	0.4717
Cleveland	0.7104	Olmsted Falls	0.3204	Garfield Heights	0.4707
Highland Hills	0.6966	Parma	0.3185	Maple Heights	0.4526
Garfield Heights	0.6499	Garfield Heights	0.2914	Parma	0.4341
South Euclid	0.6310	Valley View	0.2815	Olmsted Falls	0.4250
Cleveland Heights	0.6306	Brecksville	0.2802	Warrensville Heights	0.4215
Shaker Heights	0.6167	Macedonia	0.2229	East Cleveland	0.4079
Pepper Pike	0.6139	Brook Park	0.2112	Brecksville	0.4070
Walton Hills	0.5950	Maple Heights	0.1855	Valley View	0.4065
Beachwood	0.5872	Cleveland Heights	0.1780	Cleveland Heights	0.4043
Bratenahl	0.5853	Broadview Heights	0.1740	Highland Hills	0.3930
University Heights	0.5725	Brooklyn	0.1693	North Randall	0.3881
Seven Hills	0.5677	Walton Hills	0.1577	Macedonia	0.3877
Lyndhurst	0.5676	Middleburg Heights	0.1573	Brook Park	0.3845
Highland Heights	0.5641	North Royalton	0.1379	Walton Hills	0.3764
Independence	0.5597	Sagamore Hills Twp.	0.1351	Broadview Heights	0.3615
Brook Park	0.5579	Berea	0.1328	Brooklyn	0.3588
Brooklyn Heights	0.5549	Lyndhurst	0.1085	Middleburg Heights	0.3496
Macedonia	0.5525	Brooklyn Heights	0.1057	Shaker Heights	0.3461
Newburgh Heights	0.5522	Warrensville Heights	0.1049	South Euclid	0.3438
Parma	0.5498	Highland Hills	0.0894	Sagamore Hills Twp.	0.3385
Broadview Heights	0.5489	Parma Heights	0.0778	Lyndhurst	0.3381
Brooklyn	0.5484	Mayfield Heights	0.0777	Brooklyn Heights	0.3303
Richfield Village	0.5445	Shaker Heights	0.0755	Berea	0.3267
Middleburg Heights	0.5420	Cuyahoga Heights	0.0732	North Royalton	0.3171
Sagamore Hills Twp.	0.5419	Mayfiled Village	0.0702	Seven Hills	0.3135
Mayfield Heights	0.5411	North Randall	0.0626	Mayfield Heights	0.3094
Oakwood	0.5404	Seven Hills	0.0592	Bratenahl	0.3085
Strongsville	0.5372	South Euclid	0.0566	Parma Heights	0.3067
Parma Heights	0.5356	Richfield Village	0.0484	Highland Heights	0.3061
Brecksville	0.5338	Highland Heights	0.0482	Cuyahoga Heights	0.3013
Valley View	0.5315	Bratenahl	0.0317	Mayfiled Village	0.3003
Mayfiled Village	0.5303	Oakwood	0.0048	Richfield Village	0.2964
Olmsted Falls	0.5295	Beachwood	0.0035	Beachwood	0.2953
Cuyahoga Heights	0.5293	Newburgh Heights	0.0032	University Heights	0.2863
Berea	0.5206	Linndale	0.0001	Newburgh Heights	0.2777

Linndale	0.5028	East Cleveland	0.0000	Oakwood	0.2726
North Royalton	0.4963	University Heights	0.0000	Linndale	0.2514

Source: U.S. Census, 2010 [41]; NEORSD, 2014 [37]; FEMA, 2016 [24].

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