Journal of Homeland Security and Emergency Management

Volume 8, *Issue* 1 | 2011 | *Article* 3

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Recommended Citation:
Flanagan, Barry E.; Gregory, Edward W.; Hallisey, Elaine J.; Heitgerd, Janet L.; and Lewis, Brian (2011) "A Social Vulnerability Index for Disaster Management," *Journal of Homeland Security and Emergency Management*: Vol. 8: Iss. 1, Article 3.
DOI: 10.2202/1547-7355.1792
Available at: http://www.bepress.com/jhsem/vol8/iss1/3

A Social Vulnerability Index for Disaster Management

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Abstract

Social vulnerability refers to the socioeconomic and demographic factors that affect the resilience of communities. Studies have shown that in disaster events the socially vulnerable are more likely to be adversely affected, i.e. they are less likely to recover and more likely to die. Effectively addressing social vulnerability decreases both human suffering and the economic loss related to providing social services and public assistance after a disaster. This paper describes the development of a social vulnerability index (SVI), from 15 census variables at the census tract level, for use in emergency management. It also examines the potential value of the SVI by exploring the impact of Hurricane Katrina on local populations.

KEYWORDS: social vulnerability, Hurricane Katrina

Author Notes: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Agency for Toxic Substances and Disease Registry.

Introduction

For most of the twentieth century, disaster management focused on the physical world, emphasizing infrastructure and technology. The concept of social vulnerability within the disaster management context was introduced in the 1970s when researchers recognized that vulnerability also involves socioeconomic factors that affect community resilience (Juntunen 2005). This paper describes the development of a social vulnerability index (SVI) for use in disaster management and examines its potential value by exploring the impact of Hurricane Katrina on local populations for illustration.

Background and Rationale

All regions of the United States have experienced disasters, both natural and anthropogenic. The hazards that precipitate these disasters will continue to occur in the future. Hazards may be large scale, such as hurricanes, forest fires, and earthquakes, or they may be relatively localized in extent, such as tornadoes, mudslides, or chemical spills. Although hazard events may be relatively benign, they may also culminate in disaster—severe physical injuries, emotional distress, loss of life, and substantial property damage—to the point of destroying entire communities. In both the short- and long-term future, disasters can have devastating economic, health, and social consequences for affected areas and their inhabitants.

Disaster management research and practice often refer to a formula of the following type:

$$\textit{Risk} = \textit{Hazard} * (\textit{Vulnerability} - \textit{Resources})$$

where *Risk* is the likelihood or expectation of loss; *Hazard* is a condition posing the threat of harm; *Vulnerability* is the extent to which persons or things are likely to be affected; and *Resources* are those assets in place that will diminish the effects of hazards (Dwyer et al. 2004; UCLA Center for Public Health and Disasters 2006).

Yet disaster management often only encompasses the physical hazard component. The social vulnerability component is usually ignored. Furthermore, the various disciplines approach the concept of vulnerability from different perspectives (Alwang et al. 2001). Disaster planning research, for instance, has often focused on infrastructure vulnerability, neglecting social vulnerability when considering the vulnerability component. The Federal Emergency Management Agency (FEMA), under contract with the National Institute of Building Sciences, has long provided HAZUS-MH software for use in disaster management to "map and display hazard data and the results of damage and economic loss estimates for buildings and infrastructure" (FEMA 2009a). A widely used and valuable tool, HAZUS-MH also enables users to estimate the effects of earthquakes, hurricane winds, and floods on populations in general. Until the release of the most recent version, HAZUS-MH 1.4, however, the software did not identify socially vulnerable populations. The current version now includes a component to address selected social issues, such as estimates of shelter requirements and displaced households, in disaster management (FEMA 2009b). Exploring the manner in which hazards may affect the population at large is vital, but understanding how and where particularly socially vulnerable communities may be affected can help allocate resources more effectively during the disaster cycle phases of mitigation, preparedness, response, and recovery (Figure 1).

This paper, therefore, addresses an important subcomponent of the disaster management risk equation—social vulnerability—with the goal of improving all phases of the disaster cycle.

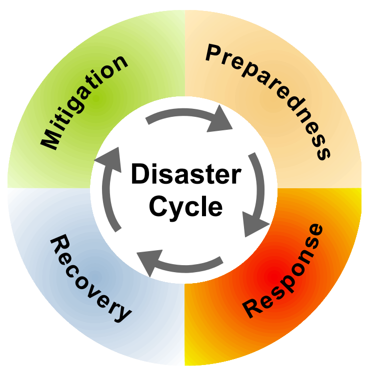

Figure 1. The disaster cycle.

Vulnerability to hazards is influenced by many factors, including age or income, the strength of social networks, and neighborhood characteristics.[1] The hazards and vulnerability literature reveals that categories of people living in a disaster-stricken area are not affected equally. For example, evidence indicates that the poor are more vulnerable at all stages—before, during, and after—of a catastrophic event. The findings are similar for racial and ethnic minorities;

[1] We focus on population groups and their overall vulnerability relative to other groups. We must avoid the ecological fallacy, i.e. making inferences or assumptions about individuals based upon characteristics of population groups. An individual's demographic characteristics per se do not cause him or her to be more vulnerable. Nothing is inherent in one's race, ethnicity, income, or education level that precludes an appropriate response in an emergency. All people are made up of a constellation of characteristics that enable them to assist in some situations but require assistance in others. None should be viewed merely as a so-called victim group or a so-called rescue group.

children, elders, or disabled people; and residents of certain types of housing, particularly high-rise apartments or mobile homes. Furthermore, such vulnerability factors often occur in combination (Morrow 1999). Population characteristics "are an important indicator of everything from evacuation compliance during an event to successful long-term recovery after one" with the socially vulnerable "more likely to die in a disaster event and less likely to recover after one" (Juntunen 2005).

The most vulnerable people are likely those whose needs are not sufficiently considered in the planning of local response and relief organizations. During emergencies, for example, real-time evacuation information is not generally provided to people with limited English proficiency, the hearing and visually impaired, and other special needs groups (U.S. Department of Transportation 2006). Many low-income people in New Orleans were stranded in the wake of Hurricane Katrina because they had no personal transportation and public authorities did not provide emergency mass transit.

In mitigating and planning for emergencies, state, local, and tribal officials must identify socially vulnerable communities to provide those residents increased assistance over the course of a disaster. Although local authorities are in the best position to identify vulnerable communities, such agencies are commonly underfunded, understaffed, and stretched thin by ongoing health and social service responsibilities. State agencies, on the other hand, even if sufficiently staffed and funded, may lack the systems in place to allocate resources as needed (APHA 2006; USGAO 2006). Municipalities should establish voluntary registration programs for the disabled, frail, or transportation disadvantaged (USGAO 2006; Town of Davie, FL 2007). A voluntary registration program is an important tool for emergency response planning but such a measure may overlook individuals who are less likely to register. While considering this important issue of social justice, state and local officials must also consider cost savings when planning for emergencies. Effective mitigation and preparation decreases both human and economic loss related to providing social services and public assistance after a disaster. Increasing recognition of the importance of identifying vulnerable populations has increased a demand for tools to do so, as evidenced in the current version of HAZUS-MH.

The Centers for Disease Control and Prevention, National Center for Environmental Health, Office of Terrorism Preparedness and Emergency Response (OTPER) collaborated with the Agency for Toxic Substances and Disease Registry's Geospatial Research, Analysis, and Services Program to produce a social vulnerability index designed to assist OTPER-funded state partners in all phases of the disaster cycle. The index will help state, local, and tribal disaster management officials identify the locations of their most vulnerable populations. This work builds on research that examines vulnerability as a social condition or a measure of the resilience of population groups when confronted by disaster (Cutter et al. 2003).

Data and Methods

Data

The domains that form the basis of the SVI are 1) socioeconomic status, 2) household composition and disability, 3) minority status and language, and 4) housing and transportation. The data are from the 2000 U.S. Census of Population and Housing at the census tract level (see Appendix A for detailed definitions of the variables). When determining the location of vulnerable population groups, the use of a geographic scale sufficient to discern demographic differences is important. Previous public health and demographic studies have used counties, census tracts, or census block groups (Aronson et al. 2007). We constructed the index at census tract level because tracts are commonly used to collect and analyze data for policy and planning in government and public health (Krieger 2006). Census tracts, small subdivisions of counties, are designed to be demographically homogeneous. They generally have between 1,500 and 8,000 people, with an optimum size of 4,000 people (U.S. Census Bureau 2009a). The mapping of these data reveals geographic patterns of potential population vulnerability to disaster that can be used in mitigation, preparedness, response, and recovery (Morrow 1999).

1) Socioeconomic Status (comprising income, poverty, employment, and education variables): Economically disadvantaged populations are disproportionately affected by disasters. The poor are less likely to have the income or assets needed to prepare for a possible disaster or to recover after a disaster (Morrow 1999; Cutter et al. 2003). Although the monetary value of their property may be less than that of other households, it likely represents a larger proportion of total household assets. For these households, lost property is proportionately more expensive to replace, especially without homeowner's or renter's insurance (Tierney 2006). Moreover, unemployed persons do not have employee benefits plans that provide income and health cost assistance in the event of personal injury or death (Brodie et al. 2006). High-income populations, on the other hand, may suffer higher household losses in absolute terms, yet find their overall position mitigated by insurance policies, financial investments, and stable employment (Bolin and Stanford 1998; Tierney 2006).

The relationship between education and vulnerability to disaster is not well understood, although education is associated with both income and poverty. People with higher levels of education are likelier to have access to and act upon varied hazard information from preparation to recovery (Tierney 2006). For people with less education, the practical and bureaucratic hurdles to cope with and recover from disaster prove increasingly difficult to surmount (Morrow 1999).

2) Household Composition/Disability (comprising age, single parenting, and disability variables): Household composition is defined here to include dependent children less than 18 years of age, persons aged 65 years and older, and single-parent households. Also included are people with disabilities. People in any of these categories are likelier to require financial support, transportation, medical care, or assistance with ordinary daily activities during disasters.

Children and elders are the most vulnerable groups in disaster events (Ngo 2001; Cutter et al. 2003:251). Children, especially in the youngest age groups, cannot protect themselves during a disaster because they lack the necessary resources, knowledge, or life experiences to effectively cope with the situation. Perhaps because parental responsibility for children is assumed, children are rarely incorporated into disaster-scenario exercises (Martin et al. 2006). Thus, local authorities are not adequately prepared to provide specific goods or services for children (Morrow 1999; Madrid et al. 2006).

Elders living alone and people of any age having physical, sensory, or cognitive challenges are also likely to be more vulnerable to disasters (Eidson et al. 1990; Schmidlin and King 1995; Morrow 1999; Peek-Asa et al. 2003; White et al. 2006; McGuire et al. 2007; Rosenkoetter et al. 2007). Many older or disabled people have special needs that require the assistance of others. Family members or neighbors who would ordinarily look in on an elder, or a caretaker responsible for the welfare of a disabled person, might be less able to do so during a crisis or may find the magnitude of the task beyond their capability.

The number of traditional households of two parents and children has decreased in the United States (U.S. Census Bureau 2000a). In addition to the usually lower socioeconomic status of single-parent households, such households are especially vulnerable in a disaster because all daily caretaker responsibility falls to the one parent.

3) Minority Status/Language (comprising race, ethnicity, and English-language proficiency variables): The social and economic marginalization of certain racial and ethnic groups, including real estate discrimination, has rendered these populations more vulnerable at all stages of disaster (Morrow 1999; Cutter et al. 2003). African Americans; Native Americans; and populations of Asian, Pacific Islander, or Hispanic origin are correlated with higher vulnerability rates (Cutter et al. 2003; Elliot and Pais 2006). In recent decades, the numbers of persons immigrating to the United States from Latin America and Asia have substantially increased (Passel and Suro 2005; U.S. Census Bureau 2009b). Many immigrants are not fluent in English, and literacy rates for some groups are lower. To the degree that immigrants have limited English proficiency, disaster communication is made increasingly difficult. This difficulty is especially true in communities whose first language is neither English nor Spanish and for whom translators and accurate translations of advisories may be scarce. Immigrants are likelier to rely on relatives and local social networks (i.e., friends and neighbors) for information (Morrow 1999; Bolin 2006; Peguaro 2006);

4) Housing/Transportation (comprising housing structure, crowding, and vehicle access variables): Housing quality is an important factor in evaluating disaster vulnerability. It is closely tied to personal wealth; that is, poor people often live in more poorly constructed houses or mobile homes that are especially vulnerable to strong storms or earthquakes (Eidson et al. 1990; Morrow 1999; Peek-Asa et al. 2003; Daley et al. 2005; De Souza 2004; Tierney 2006).

Mobile homes are not designed to withstand severe weather or flooding and typically do not have basements (Donner 2007). They are frequently found outside of metropolitan areas and, therefore, may not be readily accessible by interstate highways or public transportation. Also, because mobile homes are often clustered in communities, their overall vulnerability is increased.

Multi-unit housing in densely populated urban areas also poses a heightened risk for tenants (Cutter et al. 2003). Population densities of cities are much higher than those of suburban or rural areas. People living in high-rise apartments are particularly vulnerable to overcrowding when funneled into a limited number of exit stairwells. Furthermore, large numbers of people exiting in the street can make safe and orderly evacuation of everyone difficult and dangerous. Crowding within housing units exacerbates these difficulties (Tierney 2006).

Rates of automobile ownership are generally lower in urban areas, especially among inner city poor populations (Pucher and Renne 2004). Thus, transportation out of an evacuation zone is problematic for people who do not have access to a vehicle (Morrow 1997). For some people, fuel costs may prevent vehicle use (Brodie et al. 2006). Paradoxically, lower urban auto-ownership rates do not necessarily translate into easy evacuation for people with vehicles because the high-population densities of cities can cause severe traffic congestion on interstate highways and other major roads.

Populations residing in group quarters such as college dormitories, farm workers' dormitories, psychiatric institutions, and prisons also present special concerns during evacuation (Vogt 1990; Quarantelli 1980). Residents of nursing homes and long-term care facilities are especially vulnerable because of their special and timely needs and because of understaffing in these institutions in emergencies. Moreover, many institutions can be unprepared to quickly remove their entire staff and residents under conditions that require specialized vehicles.

Methods

To construct the SVI, each of the 15 census variables, except per capita income, was ranked from highest to lowest across all census tracts in the United States with a non-zero population (N = 65,081). Per capita income was ranked from lowest to highest because, unlike the other variables, a higher value indicates lesser vulnerability. A percentile rank was then calculated for each census tract over each of these variables. A percentile rank is defined as the proportion of scores in a distribution that a specific score is greater than or equal to.[2] Percentile ranks were calculated by using the formula

Percentile Rank = (Rank-1) / (N-1)

where N = the total number of data points, and all sequences of ties are assigned the smallest of the corresponding ranks.

In addition, a tract-level percentile rank was calculated for each of the four domains based on an across-the-board sum of the percentile ranks of the variables comprising that domain. Finally, an overall percentile rank for each tract was calculated as the sum of the domain percentile rankings. This process of percentile ranking—for all variables, for each domain, and for an overall SVI—was then repeated for the individual states.

In a second approach to identifying social vulnerability, we provide a count, or flag, of the number of individual variables with percentile ranks of 90 or higher for each of the four domains and for the tract overall. Although the SVI and total flag counts are similar indicators and are strongly correlated (r = 0.58), some census tracts with high SVI have few total flags or vice versa. The total flags variable may be used to identify tracts that have vulnerable populations due to a high percentile in at least one demographic variable, yet their overall social vulnerability scores are masked because of averaging with low percentiles in other demographic variables. Thus, SVI values and flag counts were calculated for each of the 15 variables, for the four domains, and for the overall results, altogether totaling 40 measures for each census tract.[3]

[2] As an example, if a grade of 95 on an examination were greater than or equal to the grades of 86% of the students taking the exam, the percentile rank of that grade would be 86.
[3] To download and view the SVI data, visit
ftp://ftp.cdc.gov/pub/ATSDR/census-svi/SVI_Database/

Case Study

The social vulnerability index can be used in all phases of the disaster cycle from mitigation and preparedness through response and recovery. In this section, we demonstrate the potential value of the SVI for the response and recovery phases by using Hurricane Katrina's impact on New Orleans as an example. According to Cutter and Finch, the lower Mississippi Valley, in which New Orleans is located, is a region of high social vulnerability and would be expected to demonstrate high sensitivity to hazards and a limited ability to respond, cope, and recover from such a disaster (Cutter and Finch 2008).

Katrina made landfall in southeast Louisiana on August 29, 2005, as a Category 3 hurricane. The storm surge caused flooding along the U.S. Gulf Coast in the states of Mississippi and Louisiana. With much of New Orleans below sea level, the surge also caused catastrophic levee breaches resulting in massive destruction and loss of life. Houses were lifted off their foundations by the force of flowing water, and much of the area was reduced to scattered rubble. The flooding affected an estimated 77% of the population of Orleans Parish and nearly all the residents of St. Bernard Parish (Gabe et al. 2005). The Louisiana Department of Health and Hospitals reports 1,464 fatalities in the state due to Hurricane Katrina (Louisiana DHH 2006).

A recent study of Katrina-related flood deaths, which used a traditional approach, focused on the relationship between the physical hazards of the down flow of levee breaches, water velocity and depth, and the general population vulnerability, i.e., people in proximity to the hazard (Jonkman et al. 2009). The study defined the exposed population as the original population minus the evacuated and sheltered fractions of the population.

The highest death rates among the exposed population, primarily by drowning, occurred in areas that experienced both high-velocity down flow of severe levee breaches and high water depths. Although the authors recognized that evacuation rates were probably different for the various communities and subpopulations, they assumed equal evacuation and sheltering rates because pre-storm evacuation and shelter data are unavailable. The researchers recommended investigating spatial differences in pre-storm evacuation and shelter rates if these data become available. They noted that, among the nursing homes in the flooded areas, 21 homes were evacuated before Katrina made landfall, whereas 36 were not.

The overall race- and sex-specific proportions of deaths were consistent with the pre-Katrina population distribution of the affected area (Brunkard et al. 2008; Jonkman et al. 2009). However, Jonkman et al. stated that their analysis of mortality rates at the parish level would have benefited from a more detailed statistical analysis at the "neighborhood level." Brunkard et al. did conduct a stratified analysis that evaluated the effect of race within age groups. They found that age masked the effect of race in most age groups and determined that older black male residents had a higher mortality rate than whites relative to their population distribution.

Although discrepancy existed on race-specific mortality rates, the age-specific mortality rate was clear cut. The majority of Katrina fatalities in Orleans, St. Bernard, and Jeffersion Parishes were elderly people with almost half older than 75 years of age. Given that only 6% of the pre-Katrina residents in the affected area were older than age 75, the elderly were especially vulnerable to this catastrophic event (Brunkard et al. 2008). Therefore, the elderly, the most vulnerable subpopulation in the Katrina event, were identified and used to evaluate the SVI. The elderly are represented with the census variable "population aged 65 or older."

Application

To visualize deaths in the flood zone in conjunction with the state-based elderly population component of the SVI, we first delineated areas flooded to greater than 2 feet as estimated by the National Oceanic and Atmospheric Administration (NOAA). The 2-foot threshold was chosen from data classed in two-foot increments (i.e. 0 to 2 feet, > 2 feet to 4 feet, etc.), because a mortality function for flood zones with rapidly rising waters shows initial flood mortality occurring above 1 meter (Jonkman et al. 2009). We overlaid the flood zone boundaries on a tract-level map of the elderly SVI value. A third map layer displayed tract areas within the delineated flood zone that have significantly high or low rates of death from Katrina-related drowning (Figure 2). We chose to examine drowning fatalities because most of the Louisiana deaths were from drowning and because the drowning deaths were probably due to the physical impacts of the flooding.

Death records were obtained from the Louisiana Office of Public Health and include data collected by the Hurricane Katrina Disaster Mortuary Operational Response Team (DMORT) and death certificates from Louisiana vital statistics. The death data were geocoded and then aggregated to census tract level. Levee breach locations were compiled based on materials published in *The Times-Picayune* and the Jonkman et al. paper (Swenson 2009; Jonkman et al. 2009).

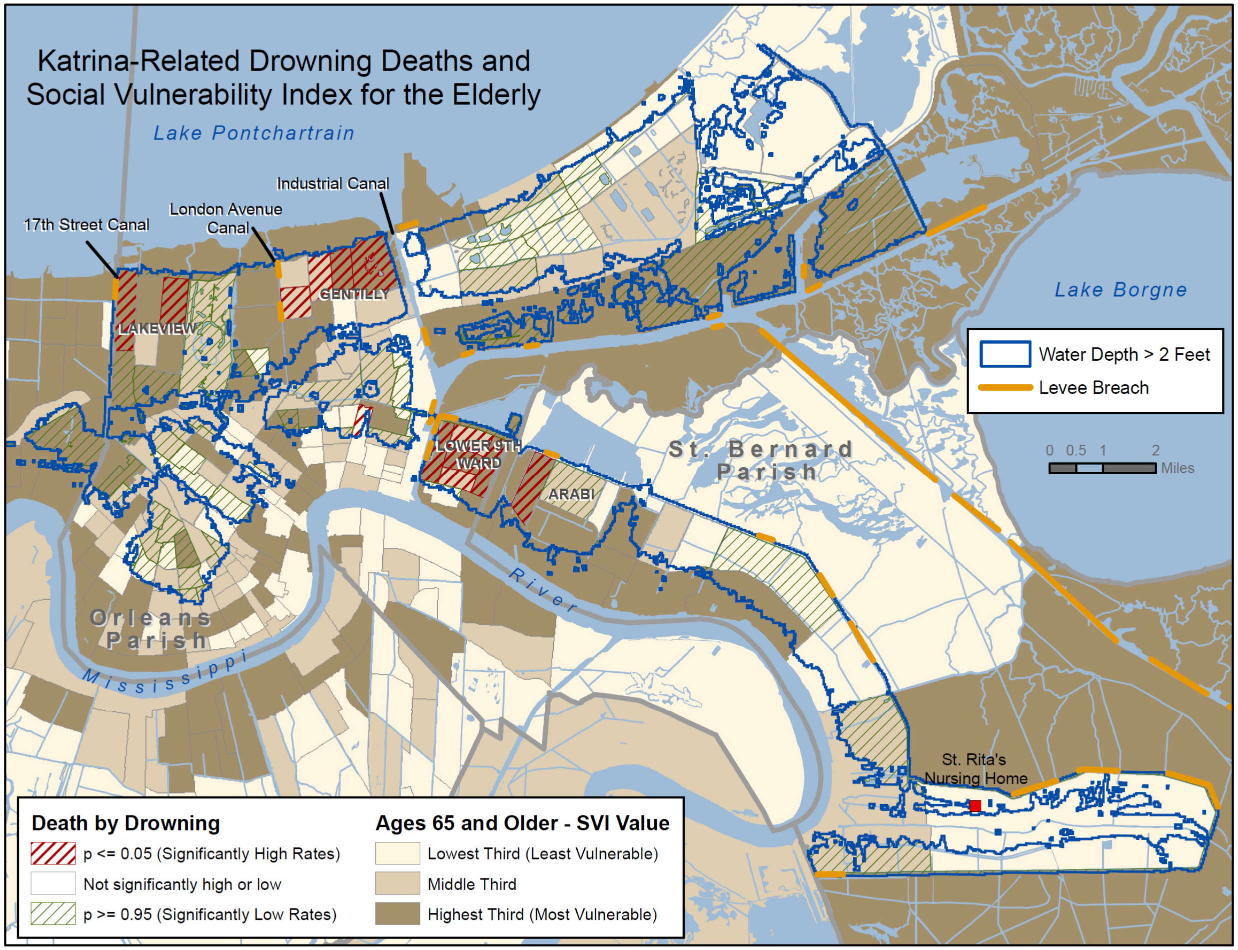

Figure 2. Overlay of Katrina-related drowning deaths and the elderly social vulnerability index (SVI) value, i.e., percentile rankings for population older than age 65 years. Data sources: NOAA 2006, Louisiana Department of Health and Hospitals 2006, Swenson 2009, Jonkman et al. 2009, and U.S. Census Bureau 2000b.

Because the numbers of drowning deaths were statistically rare events, the Poisson distribution was used to determine the probabilities and statistical significance of the observed number of deaths (Cromley and McLafferty 2002). Pre-storm evacuation data were unavailable, so our estimates for the exposed population were based on an area proportion algorithm. The 2000 census population for each tract was multiplied by the geographic area, or proportion, of each tract within the flood zone. In terms of deaths, the map demonstrates the findings of the Jonkman et al. paper; the tracts with the highest proportion of deaths to exposed population are near levee breaches at the 17th Street Canal, the London Avenue Canal, the IHNC/Industrial Canal, and the Lower Ninth Ward. Regarding the SVI value for the elderly, of the 15 tracts with a statistically significant higher number of deaths than expected, eight are located within the most vulnerable category of elderly residents, i.e., the highest third. With the exception of one tract in the lowest elderly SVI value category, the remaining tracts are in the middle SVI category. We cannot say with certainty that an association between tract-level elderly SVI value and mortality exists in this example because we do not have all the data required to do a complete quantitative analysis. However, we do know the elderly were disproportionately affected, and we can use the elderly component of the SVI to identify where to focus future emergency preparedness and response activities.

In addition, data have shown that many of the elderly died in nursing homes and hospitals that did not evacuate. Census numbers incorporate data from nursing homes, but these data are sometimes masked by the surrounding population. For instance, more than 30 residents of St. Rita's nursing home in St. Bernard Parish died in the flooding (Schleifstein 2009), but the tract that includes the nursing home indicates a low elderly SVI. For this reason, examining not only census tract-level data but also data on facilities, such as nursing homes, that house vulnerable populations would be beneficial.

Population displacement due to Hurricane Katrina is another important consideration. The Congressional Research Service estimates that about half of the persons displaced by Katrina lived in New Orleans. The socioeconomic characteristics of the area indicate that many people were poor, African-American, elderly, or young children (Gabe et al. 2005). To explore the recovery phase of the disaster cycle, we mapped mail delivery data, which serve as one indicator of recovery: the return of residents to the affected area. Mail delivery data were mapped by census tract and overlaid with the Louisiana SVI value for the socioeconomic domain, a combined measure of income, poverty, employment, and education (Figure 3). Examining scatterplots for each of the four domains indicated an association between mail delivery and both the socioeconomic and household structure domains, hence the choice of the socioeconomic domain for the mapped example.

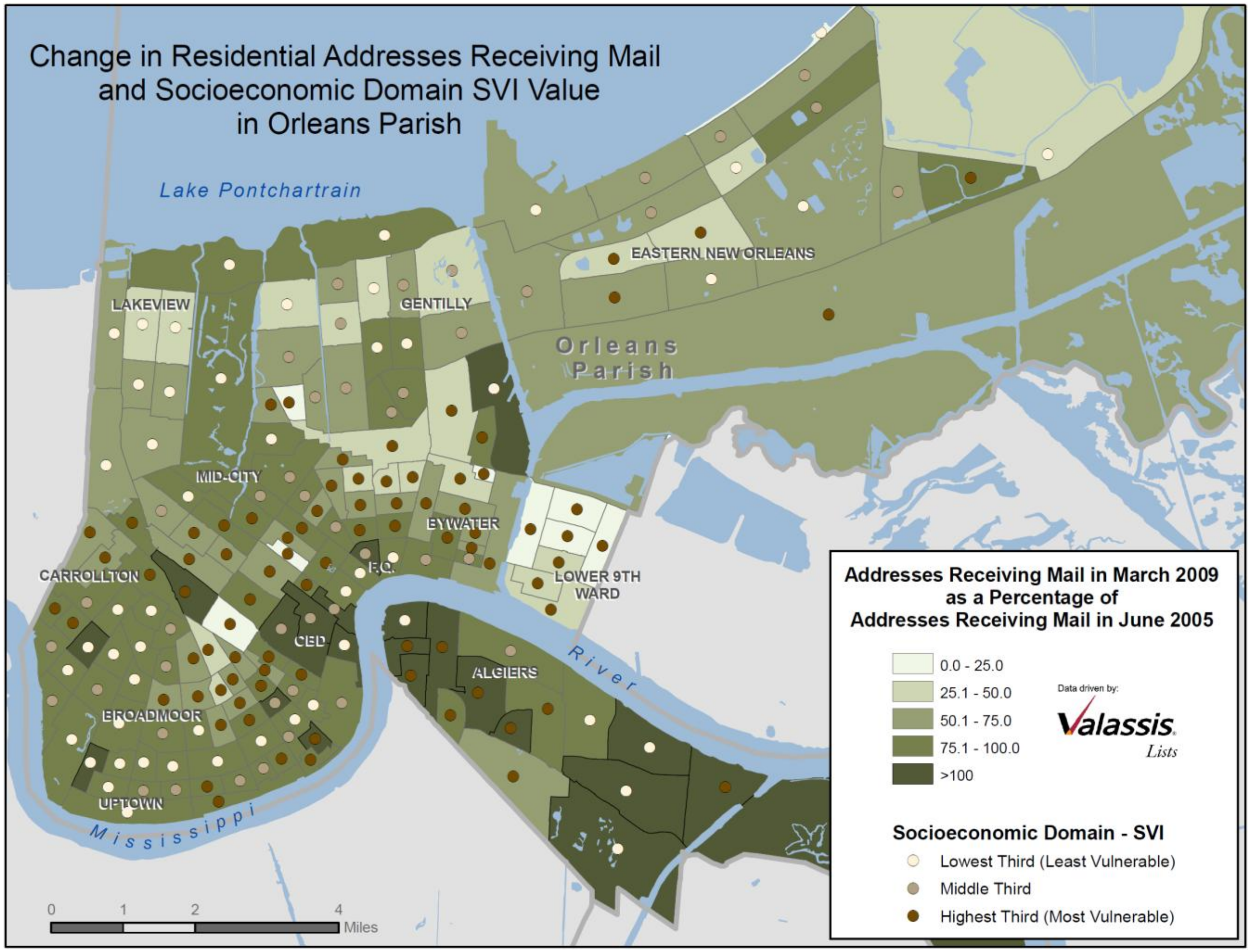

Figure 3. Overlay of the socioeconomic domain social vulnerability index (SVI) value on mail delivery data for Orleans Parish. Data sources: Valassis Lists 2009 and U.S. Census Bureau 2000b.

The map shows addresses that are actively receiving mail as of March 2009 as a percentage of addresses that received mail in June 2005. The New Orleans business district (CBD) and the main tourist centers, such as the French Quarter (F.Q.), experienced limited damage compared with many residential neighborhoods (GNOCDC 2009). This result is reflected in the map, which indicates current mail delivery of near or even greater than 100% of pre-Katrina delivery levels. Local leaders strongly supported the recovery of the central business district and the tourist areas. In addition, the socioeconomic characteristics of the residents of these areas, as shown in the SVI value, range from the least vulnerable to the middle third of vulnerability. In contrast, areas that were heavily damaged in the flooding, such as Lakeview and Gentilly, at the southern end of Lake Pontchartrain, and the Lower Ninth Ward, just north of the Mississippi River, have mail delivery rates less than half of pre-Katrina rates, regardless of SVI value. However, the Lower Ninth Ward, with tracts in the most vulnerable socioeconomic category, has mail delivery less than 25% of the pre-Katrina rates; recovery is slow or nonexistent. In addition, areas in the flood zone that were not as heavily affected in terms of severity of flooding and mortality are slower to recover where the SVI value is in the highest third. For instance, the tracts to the northwest of Bywater, as well as the tracts near Broadmoor, show lower rates of mail delivery with higher SVI value. So, as would be expected, the heavily damaged areas have been slow to recover no matter the demographic characteristics. However, areas that have socioeconomically vulnerable populations are also slow to recover even without heavy flood damage and those areas that experienced heavy damage and have socioeconomic vulnerable populations are the slowest to recover.

Another phenomenon observed during the recovery phase was a 47% increase in the general mortality rate from January to June 2006 for the greater New Orleans area, which includes Orleans, Jefferson, Plaquemines, Saint Bernard, Saint Charles, Saint James, Saint John the Baptist, Saint Tammany, Tangipahoa, and Washington parishes (Stephens et al. 2007). The monthly mortality rate for this time period averaged 91.4 deaths per 100,000 persons, compared with a monthly average of 62.2 deaths per 100,000 for the years 2002–2004. A severe compromise of the public health system in the months after the storm, along with substandard living conditions, caused the increased mortality rate. The study’s researchers identified the socially vulnerable—women, children, the elderly, and people with disabilities—as those most negatively affected.

Finally, as seen in multiple phases of the disaster cycle, the inhabitants of the Lower Ninth Ward, relative to other Louisiana tracts, are vulnerable to disasters for several reasons. Essentially, this population is very poor and minority, unemployment is very high, and the percentage of high school completion is low. Furthermore, the percentages of single-parent households and residents with disabilities are high. Crowding within units is high, and access to vehicles is very low. Thus, the overall social vulnerability of the Lower Ninth Ward is a key indicator of the community's susceptibility to disaster.

The next step to understanding geographic variation in recovery is to perform quantitative analysis of the data. Initial regression analysis, not shown here, indicates that both the Katrina-related drowning probabilities and the SVI household composition domain are statistically significant and together explain 33% of the variance in the mail delivery data. To properly specify the model, a near term effort will be to examine the possible contribution of other explanatory variables. For example, landuse type may affect recovery. In addition, the degree of infrastructure rebound, such as proximity to operational schools, daycare, and medical facilities, may be a suitable factor to examine with regards to population return. For our own purposes, it is important to note that both visual and initial quantitative analyses support our contention that SVI components are critical factors in Katrina recovery.

This case study demonstrates the potential predictive power of the SVI. The SVI can provide state, local, and tribal disaster management personnel information to target for intervention those tracts that may be socially vulnerable before, during, and after a hazard event.

Summary and Future Strategies for the SVI

State, local, and tribal agencies are most knowledgeable about the people in their communities. The social vulnerability index is designed to aid them in their efforts to ensure the safety and well-being of their residents. The components of the SVI can assist state and local personnel concerned with all phases of the disaster cycle. Knowing the location of socially vulnerable communities, planners can more effectively target and support community-based efforts to mitigate and prepare for disaster events. Responders can plan more efficient evacuation of those people who might need transportation or special assistance, such as those without vehicles, the elderly, or residents who do not speak English well. Local governments can identify neighborhoods that may need additional human services support in the recovery phase or as a mitigating measure to prevent the need for the costs associated with post-response support. The Katrina case study illustrated how the SVI can be used as part of the risk equation in the response and recovery phases. The elderly were particularly vulnerable during this event. Moreover, areas that are slower to recover include those that were heavily flooded and those with socioeconomically vulnerable populations. Future case studies will explore how the SVI can be used as part of the equation in the preparedness and mitigation phases to aid in targeting disaster management interventions.

A unique toolkit consisting of SVI data along with a simple mapping application was initially distributed to 24 state and local public health departments for review and feedback. The toolkit, which is flexible and easy to understand, provides readily accessible data, including the following for each tract, or "community," in the United States: 1) an SVI value for each of the 15 census variables, 2) an SVI value for each of the four overarching domains, 3) an overall SVI, and 4) flags representing a percentile rank of 90 or higher for each of the 15 variables, for each of the four overarching domains, and for the total number of flags for each tract. Toolkit user feedback and the identification of useful data and applications are enabling the evolution of the SVI. For example, users suggested the calculation of state-based indices, in addition to national-level indices, for more meaningful within-state comparisons. State-based indices have been calculated and will be included with the next version of the SVI package. Users also requested raw census data for each of the variables, e.g., the total number of persons in poverty in each tract, for targeted interventions. Raw census data will also be added to the SVI toolkit. Additional socioeconomic variables recommended for use in various vulnerability indexes, such as living alone, may be added to the SVI variable set. We may also include in the toolkit map layers such as nursing homes, hospitals, schools, and other facilities that house socially vulnerable populations. In addition, custom mapping tools will be included, such as a tool to estimate population numbers within study areas that cut across census tracts or tools that return facility counts for neighborhoods.

The SVI is flexible, for use in different phases of the disaster cycle and for different event types, depending on how best the readily accessible components fit the user's needs. Although the researchers in a recent study on heat vulnerability did not use the SVI, they did incorporate variables of social vulnerability, such as age, poverty, income, education, race and ethnicity, and living alone, with health data, vegetation cover, household air conditioning data, and climate data (a combination of vulnerability, resource, and hazard data) to identify areas for intervention and further investigation (Reid et al. 2009). Future studies could employ components of the SVI to do similar modeling, combining SVI data with other data to more completely specify explanatory variables in risk models for understanding and predicting disaster event outcomes.

Nevertheless, using the SVI has some limitations. One limitation is the rapidly changing composition of some small-area populations in the intercensal years. For instance, the present index uses year 2000 census data. Between that census and 2005, when Katrina struck, much public housing in New Orleans underwent major renovation, including demolition of many older multi-unit structures and their replacement with one- or two-household structures. Many people in these developments were at least temporarily relocated, so that the 2000 census data for those tracts were inaccurate by 2005. Similarly, the addition of new subdivisions in suburban counties can quickly produce a significant population increase. The Census Bureau's American Community Survey, which will be fully implemented by the year 2010, will provide annual population, housing, and socioeconomic data at several geographic levels, so that more frequent adjustments of the index will be possible.

The use of census data only is also a limitation of the SVI calculations. The census counts people where they live, not necessarily where they work or play. As mentioned above, however, we hope to address this limitation by considering the incorporation of other vulnerable facilities, such as hospital and school locations, into the SVI toolkit.

Finally, users should recall that the SVI is only one component of a larger equation that also includes the hazard itself, vulnerability of the physical infrastructure, and community assets or other resources that may help to reduce the effects of the hazard. The SVI is intended to spatially identify socially vulnerable populations, to help more completely understand the risk of hazards to these populations, and to aid in mitigating, preparing for, responding to, and recovering from that risk.

Appendix A

U.S. Census 2000 Variable Definitions

Variable	2000 Census Table Variable(s)	Additional Description	Domain
Percent individuals below poverty	P88	Individuals below poverty="under .50" + ".50 to .74" + ".75 to .99." Percent of persons below federally defined poverty line, a threshold that varies by the size and age composition of the household. Denominator is total population where poverty status is checked.	Socioeconomic Status
Percent civilian unemployed	P43	Based on total population 16+. Civilian persons unemployed divided by total civilian population. Unemployed persons actively seeking work.	
Per capita Income in 1999	P82	The mean income computed for every person in the census tract.	
Percent persons with no high school diploma	P37	Percent of persons 25 years of age and older, with less than a 12th grade education (including individuals with 12 grades but no diploma).	
Percent persons 65 years of age or older	P8		Household Composition/Disability
Percent persons 17 years of age or younger	P8		
Percent persons more than 5 years old with a disability	P42	Percent of civilian population not in an institution who are 5 years of age and older with a disability.	

Percent male or female householder, no spouse present, with children under 18	P10	"Other family: male householder, no wife present, with own children under 18 years" + "Other family: female householder, no husband present, with own children under 18 years"	
Percent minority	P6 & P7	Total of the following: "black or African American alone" + "American Indian and Alaska Native alone" + "Asian alone" + "Native Hawaiian and other Pacific Islander alone" + "some other race alone" + "two or more races" + "Hispanic or Latino – white alone."	Minority Status/Language
Percent persons 5 years of age or older who speak English less than "well"	P19	For all age groups and all languages—the total of persons who speak English "not well" or "not at all."	↓
Percent multi-unit structure	H30	Percent housing units with 10 or more units in structure.	Housing/Transportation
Percent mobile homes	H30	Percent housing units that are mobile homes.	↓
Crowding	H49	At household level, more people than rooms. Percent total occupied housing units (i.e., households) with more than one person per room.	
No vehicle available	H44	Percent households with no vehicle available.	
Percent of persons in group quarters	P9	Percent of persons who are in institutionalized group quarters (e.g., correctional institutions, nursing homes) and non-institutionalized group quarters (e.g., college dormitories, military quarters).	

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