Social Vulnerability to Climate Variability Hazards: A Review of the Literature

Final Report to Oxfam America

By

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Introduction

There is a rich multidisciplinary tradition that examines risk, hazards and disasters. To understand and appreciate the literature, a few key concepts require definitions. First is the concept of *hazards*. Hazards are threats that have the potential to harm people (and the things they value) and places. *Risk* is the likelihood of incurring harm, or the probability that some type of injury or loss would result from the hazard event. *Disasters* are singular larger scale events that overwhelm the local capacity to effectively respond to and recover from an event (NRC 2006). Hazards and disasters have many origins, but we normally view them as caused by the interaction between society and natural systems (e.g. hurricanes), between society and technology (e.g. chemical spills), or within society itself (e.g. civil strife). Oftentimes, the origins become blurred and we see situations where natural events (earthquakes or tsunamis) trigger the large-scale displacement of people across national borders, resulting in humanitarian crises. In other instances a natural event (such as drought) also is a driving force behind population displacements, but when coupled with civil or ethnic unrest and conflicts, a complex humanitarian crisis results where material assistance to those in need is often compromised by the civil conflict (NRC 2007).

In looking at climate variability and climate change as particular stressors, we can further differentiate hazards into two primary classes. Sudden onset hazards appear rapidly such as flooding or hurricanes, but last for a short time period ranging from hours to weeks. Chronic hazards are very slow onset events that are barely perceptible by society such as drought or sea level rise. They affect populations incrementally and it is not until some tipping point is reached that they transcend into disasters. The distinction between sudden onset and chronic hazards is significant in terms of perception and policy—the public and policy makers can see the flood or hurricane and anticipate the necessary response to reduce the impact on people and places. With the chronic events, it is more difficult because the immediate impacts are less clear and it is often hard to distinguish between "just a little dry spell" and a full-blown drought; or to anticipate what the climate might be like in the next century and how that would influence changes in sea level and coastal inundation.

Finally, there is considerable interest in the concept of *vulnerability*, for which there are many definitions in the research literature, derived from differing conceptual models and frameworks. From the perspective of this review, vulnerability is the susceptibility of a given population, system, or place to harm from exposure to the hazard and directly affects the ability to prepare for, respond to, and recover from hazards and disasters. *Social vulnerability* explicitly focuses on those demographic and socioeconomic factors that increase or attenuate the impacts of hazard events on local populations

(Tierney et al. 2001; Heinz Center 2002), in other words who is at risk and the degree to which they can be harmed. *Resilience,* often embedded within the vulnerability construct, speaks to the capacity of the population, system, or place to buffer or adapt to changing hazard exposures. Within the climate change community, resilience is used along with adaptation to gauge how society responds to this threat source (see Cutter et al. 2008 for an overview).

The purpose of this literature review is to present the recent (primarily 2000-2009) peer- reviewed literature on social vulnerability and hazards and its application to climate variability hazards. From the perspective of natural hazards research, those hazards most relevant to climate change variability include flooding, drought, hurricanes and coastal storms, and sea level rise. The review has four main sections: 1) conceptual models and theoretical frameworks for understanding vulnerability with specific applications of those models and frameworks; 2) vulnerability assessments; 3) measuring vulnerability and constructing indices; and 4) social vulnerability metrics and mapping. To facilitate the narrative, we provide the literature cited at the end of each section, but also include a complete bibliography at the end of the report, arranged alphabetically. This is not an exhaustive review of all the literature, rather we selected those studies that are most relevant in understanding the evolution, measurement, and application of social vulnerability and its relationship to those hazards associated with climate variability including sudden onset (hurricanes and flooding) and chronic events (drought and sea level rise).

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1. Conceptual Frameworks on Vulnerability to Hazards and Disasters

Evolution of Major Theoretical Models

Beginning in the 1940s, there was considerable research and policy interest in understanding the human occupancy of hazard zones, the range of societal adjustments available for reducing the impact, and the social acceptance or at least tolerance of the risks associated with placing human lives and livelihoods in harm's way. Derived from the pioneering work of Gilbert F. White and his students, the risk/hazards paradigm was born. Working at the interface between social and environmental systems, the risk/hazards approach sought to understand who lived in hazardous areas and the drivers of the nation's increasing vulnerability to losses from natural hazards (White and Haas 1975). This natural event exposure-based approach prevailed for three decades until researchers began to question the validity of such a natural event centric focus. Arguing that increasing vulnerability to hazards and disasters worldwide was a product of political and economic struggles that intensified the vulnerability and ultimately the hazard's impact, O'Keefe et al.'s (1976) seminal paper, "Taking the Naturalness out of Natural Disasters" refocused attention on the human drivers of vulnerability. This political ecology perspective made the role of human agency explicit by attributing the drivers of vulnerability on the social, political, and economic pressures imposed on individuals, which constrained their responses and ability to cope with disasters. Because such forces are not experienced equally, the political ecology approach is more human-centric and examines who is most vulnerable and why. This conceptual framework is most prevalent in the environment and development literature (Zimmerer and Bassett 2003; Forsyth 2004; Peet and Watts 2004; Walton et al. 2008).

The next theoretical advancement occurred with the *At Risk* volume (Blaikie et al. 1994; Wisner et al. 2004), especially their development of the pressure and release model. This human-centric approach tracks the progression of vulnerability from root causes to dynamic pressures to unsafe conditions, which then interact with natural events. The model fails to address the role of proximity to the source of the threat and the interaction between the social and natural systems in the production of the hazard in the first place. It is most valuable for descriptive analyses rather than empirical testing.

The next conceptual development occurred with the hazard-of-place approach to vulnerability that is a hybrid of the risk/hazard and political ecology perspectives. First formulated in 1996 (Cutter 1996) the model describes the place-based interaction between biophysical vulnerability (exposure) and social vulnerability in an overall determination of the differential social burdens of hazards and how this relationship changes over time and across space. The major critique of this approach is its failure to examine the root causes of the social vulnerability and the failure to include the larger contexts within which such vulnerability exists. However, this approach is the most amenable to empirical testing and the use of geo-spatial techniques.

Lastly, the vulnerability/sustainability framework proposed by Turner et al. (2003a), provides an alternative conceptualization of vulnerability to global change by locating local vulnerabilities within the larger contexts that influence processes often operating at regional to global scales. This model does not clearly differentiate between exposure and sensitivity (social vulnerability) and it does not clearly specify where vulnerability begins and ends. It is more useful for qualitative assessments than empirically based analyses.

The majority of the research from the mid-1990s to the present focused on the conceptual models with relatively few examples of how such models operate in real-world contexts. There is relatively little direct application of the vulnerability/sustainability framework and the hazards-of-place models beyond the authoring teams or their students. However, the central tenet of these approaches appears quite prominently in the literature (Eakin and Luers 2006). It is also worth noting (as shown below) that much of the work of the human dimensions of global change community is derivative from hazards and disasters research, a subfield that many of the researchers trained in before channeling their interests into climate change.

Applications

These theoretical frameworks have been around long enough that there is now a body of work on the application of such conceptual models in understanding vulnerability to various hazards. The most frequently cited theoretical model is the pressure and release model (Blaikie et al. 1994), where it has been operationalized to examine natural hazards like flooding (Mustafa 1998) and typhoons (Gaillard et al. 2007), as well as complex pandemics such as HIV/AIDS (Tsasis and Nirupuma 2008). Mustafa (1998) applies the pressure and release model to central Pakistan examining how things like poverty and lack of political participation and representation when combined with increased flood hazards serve to further increase the vulnerability of residents. In a similar vein of research, (Gaillard et al. 2007) argue that the impact of the 2004 tropical depressions and typhoons on the Philippines' eastern coast was so devastating not due to the actual hazards, but rather was rooted in the underlying social, political, and economic conditions that further contributed to people's vulnerability. Unlike the previous two studies, research has also applied the pressure and release framework to slow onset hazards like disease. Tsasis and Nirupuma (2008) examine how vulnerability to HIV/AIDS relates to the root causes of the transmission, which is a function of unequal access to resources and power and high rates of poverty in some areas. By understanding the root causes and determining the level of HIV/AIDS preparedness in populations, the implementation of targeted and more effective mitigation measures helps reduce the spread of the disease.

The hazards-of-place approach (Cutter 1996) is more prevalent in U.S.-focused analyses of hazard vulnerability. Most of this research incorporates multi-hazards or multiple stressors along with population information at specific spatial scales such as county (Clark et al. 1998; Cutter et al. 2000; Wu et al. 2002; Azar and Rain 2007); or metropolitan level (Montz and Tobin 2003; Rashed et al. 2007). The contribution of these applications is the detailed delineations of hazard exposures and their relationship to population sensitivities, at scales that are meaningful for local to regional interventions or mitigation. International applications of the hazards-of-place approach include a study of multihazards in New Zealand (Montz 2000), India (O'Brien et al. 2004), Barbados and St. Vincent (Boruff and Cutter 2007) and Europe (Kumpulainen 2006). More recently, the hazards-of-place approach has seen improvements in the measurement of social vulnerability (see Section 4). The hazards-of-place model, extended to examine place-based community resilience to natural hazards (Cutter et al. 2008), is another enhancement.

The vulnerability/sustainability framework (Turner et al. 2003a) is still relatively new, so there is less documentation of its application in the literature at present. There were some initial case studies (Turner et al. 2003b). In addition, variants on the framework for modeling socio-ecological systems examined climate change risks in different regions--Mexico (Eakin 2005), Australia (Sposito 2005), Norway (Tyler et al. 2007), Ghana (Westerhoff and Smit 2009) and in the Canadian Arctic (Ford and Smit 2004; Ford et al. 2006a, b). Giannecchini et al. (2007) also used the social-ecological systems approach to look at land cover change and socioeconomic factors in villages in rural South Africa.

Conceptual Advances in Vulnerability Research: Climate Change and Variability

There is considerable research activity in the area of vulnerability to climate change (Adger 2006), much of it focused on conceptualizations of vulnerability and its relationship to adaptation. The other themes that appear are sustainable livelihoods and vulnerability to poverty, and the vulnerability and resilience of social-ecological systems. Many of the studies are simple conceptual diagrams useful for framing the issue of vulnerability to climate change at macro (global) scales (Füssel 2007a; Heltberg et al. 2009; Ionescu et al. 2009). Others focus explicitly on adaptation (Kelly and Adger 2000; Smit et al. 2000; Brooks 2003; Downing and Patwardhan 2004; Adger et al. 2005; Brooks et al. 2005; Füssell and Klein 2006; Füssell 2007b; Smit and Wandel 2005; Yamin et al. 2005).

The most innovative advancement is the vulnerability scoping diagram (Polsky et al. 2007) which provides a framework for meta-analyses of hazard-specific vulnerability assessments which contain dissimilar measures of exposure, sensitivity, and resilience (or adaptive capacity). It also provides a methodology for conducting such analyses (Schröter et al. 2005).

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2. Hazard Vulnerability Assessments

Hazard vulnerability assessments describe who and what is exposed to the threat (hazard identification), and the differential susceptibility (the potential for loss, injury, harm, adverse impacts on livelihoods), and impacts of that exposure. In other words, the goal is not only to identify the risk factors (who and what is vulnerable), but also the driving forces that shape vulnerability in a particular place (Hill and Cutter 2001; Birkmann 2006). These assessments are either qualitative in their approach or they are quantitative in nature providing numerical estimates of population exposures and rankings of vulnerability. They can be single hazard or multi-hazard and they can range from local place-specific analyses to more regionally based patterns.

Three distinct elements comprise hazard vulnerability assessments: exposure assessment (the identification of the risk source including magnitude, frequency of occurrence, and spatial impact); impact assessments (the consequences of a particular hazard or stressor on a population; and damage assessment (defining the direct and indirect losses (fatalities, infrastructure, economic) associated with a particular event). However, the integration of these three elements into a comprehensive vulnerability assessment for the area or region of concern is often lacking. Part of this is a function of the bifurcation of the science inputs (e.g. natural scientists provide most of the relevant data and models for exposure assessments while social scientists provide the inputs for the populations at risk) and the difficulties of working across disciplinary or knowledge boundaries.

Examples of exposure assessment include coastal vulnerability (Gornitz et al. 1994; Hammer-Klose and Thieler 2001), drought (Wilhelmi and Wilhite 2002; Alcamo et al. 2008; Kallis 2008;) and FEMA's multi-hazard assessment for the United States (FEMA 1997). Impact assessments range from single hazard applications to multi-hazard assessments. For example, specific research on extreme storms in Revere, MA (Clark et al. 1998), tsunamis along the Oregon coast (Wood et al. 2009), sea level rise in Cape May NJ (Wu 2002), and coastal erosion in the US (Boruff et al. 2005) highlight the interaction of the physical systems with the likely impacts on population characteristics. Most of these single hazard applications are conducted at local scales such as county or city scale. On the other hand, there are multi-hazard impact assessments that combine two or more hazards. These can range from locally-based county level assessments utilizing a dozen or more hazards (Cutter et al. 2000); to national studies involving a smaller subset of climate-related threats (O'Brien et al. 2004; Alcamo et al. 2008;); and to global scales (De Sherbinin et al. 2007), where the consequences of climate change are used to assess the impacts on cities. More recently, Dow and Downing (2006) provide maps displaying the drivers of climate change and the likely impacts and consequences at the global scale in their handsome and readable atlas of climate change.

The vast majority of research on hazard damage assessment tends to focus on loss estimation and modeling. Perhaps the most well known and publically available loss estimation methodology is FEMA's HAZUS product (http://www.fema.gov/plan/prevent/hazus/index.shtm), covering earthquakes, wind, and flooding. Within the financial sector, there is a multitude of loss estimation models, most of them proprietary (Kunreuther and Roth 1998; Grossi and Kunreuther 2005). There are a plethora of case studies on risk and vulnerability assessment techniques and applications compiled by NOAA's Coastal Services Center (Flax et al. 2002). Some focus only on exposure, while others take a more comprehensive view of the hazards assessment and include impact and damage assessments (http://www.csc.noaa.gov/vata/).

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3. Measuring Vulnerability

Developing a universal metric or measurement tool for vulnerability assessments across all disciplines is challenging given the ever-present definitional ambiguity along with the dynamic nature and changing scale of analysis (temporal and spatial). However, there has been a shift from more qualitative work centered on conceptual models and frameworks (see Section 1) to more quantitative or empirical measures of vulnerability that are examined in this section. Part of this shift is due to advances in vulnerability science. However, the greater impetus is the need for evidence-based and empirically derived information to support the mitigation planning pressures in the U.S. Disaster Mitigation Act of 2000 (DMA 2000), and the scientific support (as embodied in the IPCC reports) for climate change policies.

Indicators are "quantitative measures intended to represent a characteristic or a parameter of a system of interest" (Cutter et al. 2008: 7) using a single value. One of the most famous is the U.S.'s Index of Leading Economic Indicators, a composite of ten economic variables used to estimate future economic activity, which has proven quite robust in predicting economic recessions over the past fifty years. There is a rich tradition within the social and environmental sciences on the development of indicators beginning in the 1940s with economic indicators. Social indicators were more prominent in the 1960s and 1970s, followed by environmental indicators. The 1990s witnessed more emphasis on the development of indicators for environmental sustainability as well as for vulnerability (Kaly et al. 1999; Esty et al. 2005; Birkmann 2006, 2007; Polsky et al. 2007).

The use of indicators and indices to measure attributes of interest for a system continues to garner momentum in the literature. However, there are a few limitations associated with the development of and use of indicators. First, there is the challenge to reduce the complexity of an interaction within a system to a particular variable or set of variables. This has major implications for how and what is measured (Bogardi and Birkmann 2004; Barnett et al. 2008). For example, some concepts or interactions are very difficult to quantify. With hazards vulnerability this is readily apparent with issues such as social networks, trust in the government, and institutional capacity and disaster readiness, which are difficult to quantitatively measure. Additionally, data availability poses problems for both hazard and population parameters and this by itself may hinder the selection of input variables. The result is that vulnerability indices are limited in the scale of analysis (geographic unit and timeframe). There are further limitations in the comparability between various indices because each uses a different set of variables, geography, or approach to the construction of the index. Because of these problems, vulnerability indices are better cast as descriptions of existing and anticipated conditions rather than as predictive tools. In this regard, vulnerability indices can guide policy development on vulnerability reduction at national and sub-national scales, and serve as a means of measuring progress towards that specific goal (Parris and Kates 2003).

General Vulnerability Indices

During the past ten years, a number of indices related to vulnerability, sustainability, and quality of life gained prominence in the literature. Among them are the Environmental Vulnerability Index (Kaly et al. 1999; SOPAC 2005), Environmental Sustainability Index (Esty et al. 2005), Human Development Index (UNDP 1990; 2005; Burd-Sharps et al. 2008, 2009), and Human Well-being Index (Prescott-Allen 2001). Most of these efforts are cross-national comparisons, with little focus on variations at the sub-national level. In other words, a single value is used to characterize the entire country, even though, in reality, we know that there is considerable variability within that country in terms of the exposure, susceptibility, and impact.

The Environmental Vulnerability Index (EVI) developed by the South Pacific Applied Geoscience Commission (SOPAC) was one of the earliest efforts and examines vulnerability to environmental change (Kaly et al. 1999 and SOPAC 2005). The scale of analysis is at the country level with the emphasis on Small Island Developing States (SIDS). The EVI excludes the human systems, so is more like an exposure assessment rather than an integrated vulnerability assessment. The EVI uses 50 biophysical or natural environment 50 indicators grouped into three sub-indices (hazards; resistance; damage) and then applies these to the following policy relevant issues or threats: climate change, biodiversity, water, agriculture and fisheries, human health, desertification, and exposure to natural disasters (http://www.vulnerabilityindex.net/).

The Environmental Sustainability Index assesses the sustainability of 146 nations based on five core components: environmental systems, environmental stresses, human vulnerability to environmental stresses, social and institutional capacity, and global stewardship (Esty et al. 2005). The index uses 76 variables (or data sets) reduced to 21 sub-indices to create an overall sustainability score by summing each sub-index and then taking the average. Country rankings provide useful information on the relative level of sustainability, but an examination of the sub-indices (especially over a number of years) provides valuable policy information on improvements in meeting sustainability goals. Further, Esty et al. (2005) stress that there is inevitably some degree of uncertainty associated with the ESI construction due to data quality and availability, measurement error, and missing data. Additional information on environmental sustainability and vulnerability indices including data sets and methodologies is available at http://sedac.ciesin.columbia.edu/es/compendium.html.

The Human Development Index (HDI), a product of the United Nations Development Programme (UNDP) examines the quality of life (for 177 countries) based on three dimensions of human development: health, education and income. Four indicators reflect these dimensions of interest: life expectancy, adult literacy rate, educational enrollment, and GDP per capita. While the number of variables is small, the goal of the HDI is compare the relative levels of development and improvements in well-being among nations, and is the gold standard for assessing the human condition at the country level. More recently, the American Human Development Index (AHDI) measures the well-being among states in the US, thus providing the first downscaled version of the HDI at the US sub-national level (Burd-Sharps et al. 2008). A companion volume examines a single state (Mississippi) at the sub-state level using the same indicators (Burd-Sharps et al. 2009).

The Human Well-being Index (HWI) developed by Prescott-Allen (2001) is an alternative to the HDI. Unlike the HDI, the HWI extends its analysis to include demographic data but also includes measures of community (political rights, crime, internet users, and peace and order), and social equity (gender and income). The HWI uses a much larger pool of variables (33) in which to derive their five indicators or sub-indices for 180 countries. The five sub-indices represent health and population, wealth, community, equity, and knowledge.

The Prevalent Vulnerability Index (PVI) is a social vulnerability index that focuses on social, economic, institutional, and infrastructural capacity to recover from natural hazards or the lack thereof (Cardona 2005). Although there is not an explicit adoption of a theoretical framework, the literature cited by Cardona (2005) and the choice of indicators imply that the PVI is largely rooted in the political-ecological tradition of vulnerability science. The PVI recognizes 24 indicators ranging from the percentage of population that lives in poverty to the amount of insured infrastructure and built environment expressed as percentage of the GDP. PVI employs min-max normalization to restrict the value range of indicators between zero and one. The PVI's indicators are aggregated into three sub-indices with varying weights, and then summed to generate the final index score. The PVI for Latin America employs vulnerability-relevant indicators but suffers from methodological weaknesses when it comes to indicator aggregation and weighting (Gall 2007).

Vulnerability Indicators and Climate Variability

Research continues on the development of quantitative indicators of climate variability and adaptation to climate-related hazards at multiple scales of analysis (Leichenko and O'Brien 2002; Moss et al. 2002; O' Brien et al. 2004; Brenkert and Malone 2005; Brooks et al. 2005; Sullivan and Meigh 2005; Ericksen and Kelly 2007; Deressa et al. 2008; Torresan et al. 2008; Hahn et al. 2009). Indicators for vulnerability and adaptation to climate change and climate variability face many of the same challenges as other vulnerability indices as noted above (Leichenko and O'Brien 2002; Ericksen and Kelly 2007). The science is not as advanced in understanding vulnerability to climate variability as it is with some hazards, so the development of indicators is still in its infancy, although there is considerable research and policy interest. One of the confounding issues is how to incorporate hazard or disaster vulnerability indicators into climate change vulnerability assessments. For example, Brooks and Adger (2003) argue for the inclusion of natural disaster risks, particularly climate-related disasters in assessing vulnerability to climate change and variability. Using data on the number of fatalities and individuals affected by climate-related disasters to construct global climate risk indicators, they provide information on individuals who will be better able to adapt and deal with the long term impacts of climate change and variability, what we refer to as resilience. In an extension of that work, Brooks et al. (2005) developed a set of national level indicators that measure climate change vulnerability and adaptive capacity.

O'Brien et al. (2004) used the IPCC definition of vulnerability, which includes the elements of exposure, sensitivity, and adaptive capacity to map vulnerability of agriculture in India to both climate change and globalization at a sub-national level. Comprised of three sets of biophysical, social, and technological indicators, they used a combination of mapping techniques and local case studies to identify the high-vulnerability districts of Jhalawar, Anantapur, and Chitradurga. Like O'Brien et al. (2004), Deressa et al. (2008) also examined vulnerability to climate change and variability by local farmers based on the IPCC's definition of vulnerability. Using a combination of socioeconomic and biophysical indicators, they developed a vulnerability index and applied it to a case study of seven regions in Ethiopia.

More empirically based indices of climate change vulnerability are now appearing in the literature, the majority of the research done outside the U.S. The Livelihood Vulnerability Index developed by Hahn et al. (2009), for example, used several indicators to assess the impacts of climate change and variability among individuals residing in two districts in Mozambique. They use primary data gathered from household surveys in the study area based on the following components: socio-demographic profile, livelihood strategies, social networks, health, food, water, and natural disasters and climate variability. This index weights all indicators equally when assessing those factors that determine sensitivity and exposure to climate change impacts. Another innovative approach to assessing climate change variability employs the Dynamic International Vulnerability Assessment (DIVA) tool. Torresan et al. (2008) employ this methodology to assess vulnerability to climate change and sea level rise along the coast of Venetia, Italy. The majority of indicators that are used are biophysical encompassing dimensions like geomorphology, topography, and vegetation. Because there are so few regional vulnerability assessments of climate change in coastal environments, they perform their analysis at the regional scale, and compare it to the global scale using the same variables.

In addition to more locally oriented case studies, a number of researchers developed indices of climate vulnerability at the national level in order to compare across countries. Moss et al. (2002) developed a Vulnerability-Resilience Indicator Prototype (VRIP) model that assessed the ability of different groups to adapt and cope with climate change in 38 different countries. Indicators that reflected sensitivity and coping capacity included a combination of environmental and social factors like food, water, health, environment and economics. The proxies were scaled against global data to get the overall national baseline of vulnerability and resilience for each of the countries. Brenkert and Malone (2005) in an extension of that work applied the VRIP model to India for a more in depth analysis of climate change vulnerability. Finally, Sullivan and Meigh (2005) developed a Climate Vulnerability Index comprised of six indicators encompassing resource, access, capacity, use, environment, and geospatial dimensions. They suggest their index has applicability and comparability across various scales of analysis from small island developing nations (SIDs) to the national level. However, there is no theoretical discussion of indicator choice or the specific indicators.

Vincent's (2004) index of social vulnerability to climate change in Africa (SVA) uses the conceptual implementation of the global climate change community's alignment of social vulnerability with adaptive capacity (Adger 2006; Gallopín 2006; Klein et al. 2003). The SVA concentrates, then, on social vulnerability to climate change, particularly water availability. This causes an inherently bias towards events such as droughts and does not accomplish an all-hazards representation (Gall 2007). The framework unites concepts of social vulnerability, coping range, and adaptive capacity. SVA uses 9 indicators as a proxy for social vulnerability ranging from amount of population in poverty to the presence of household and community telephones. Though the SVA currently limits its spatial coverage to African nations, the index could be expanded geographically since all indicators are available globally (Gall 2007). To arrive at a final index score, the SVA utilizes a combination of weighted and unweighted averaging for aggregation. Though the index exhibits a basic aggregation structure, it relies heavily on expert judgment. Since little is published about the methodological choices such as the weighting scheme, and as a result, SVA appears largely subjective, driven by the author's untested choices (Gall 2007).

The Predictive Indicators of Vulnerability Index (PIV) (Adger et al. 2004) focuses on vulnerability to climate variability and climate change. The PIV rests on the conceptual framework that risk (outcome) is a function of both biophysical and social vulnerability. The PIV's goal is to identify driving factors of social vulnerability and adaptive capacity (Adger et al. 2004). The PIV consults hazard fatalities to conclude on driving vulnerability factors. The PIV aggregates climate-related mortality from the EM-DAT database per decade from 1971 to 2000, and then standardizes hazard mortality by population size. The PIV subsequently reduced a collection of 45 social vulnerability variables to a final set of eleven indicators based on correlations with decadal hazard mortality. To arrive at a final PIV score, the authors simply average the eleven indicators of social vulnerability without imposing weights (Adger et al. 2004). While the PIV's aggregation structure is simple, its approach to normalizing indicators differs significantly from most indices. The PIV normalizes indicators by grouping them into quantiles and assigns scores ranging from one to five to each quantile. It adjusts for the direction of an indicator by equating the top quintile of a vulnerability-increasing indicator with a score of five whereas the top quantile of a vulnerability-reducing indicator receives a score of one. Thus, the higher the aggregated PIV score, the smaller a country's adaptive capacity to climate change and the greater its vulnerability. The Index of Predictive Indicators of Vulnerability (PIV) mimics development-oriented indices such as the Human Development Index (HDI) rather than social vulnerability.

While there is considerable research and policy interest in the development of vulnerability indicators and indices, especially in the arena of climate change, general agreement on measuring vulnerability (data, variables, and index construction) remains elusive.

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4. Social Vulnerability Metrics and Mapping Techniques

Social vulnerability describes those characteristics of the population that influence the capacity of the community to prepare for, respond to, and recover from hazards and disasters. Social vulnerability interacts with natural processes and the built environment to redistribute the risks and impacts of natural hazards and in this way creates the social burdens of hazards (Cutter et al. 2003). Social vulnerability helps to explain why some communities experience the hazard differently, even though they experience the same level of flooding or storm surge inundation. Understanding the differential impact of hazards as a product of the social vulnerability of a place, rather than exposure, is a critical element in formulating comprehensive mitigation plans (Morrow 2008). Unlike biophysical vulnerability or other exposure indicators, social vulnerability is present, independent of the hazard type or threat source. In other words, social vulnerability is a pre-existing condition or an inherent property of existing communities, irrespective of the natural hazard of interest.

Race, Class, and Gender and other Correlates of Social Vulnerability

Within the social science and disasters literature, there is a rich tradition of research focused on those social factors that increase or decrease the impact of specific natural hazard events on the local population. Some broad indicators appear repeatedly in social vulnerability analyses, although it is possible to choose different proxies or variables to represent them. Those characteristics most often found in the literature include socioeconomic status (wealth or poverty); age; special needs populations; gender; and finally, race and ethnicity (Tierney et al. 2001; Heinz Center 2002; National Research Council 2006; Bates and Swan 2007) (Table 1).

Socioeconomic status influences the ability of individuals and communities to absorb the losses from hazards (Peacock et al. 2000; Masozera et al. 2007). In general, people living in poverty are more vulnerable than the wealthy to hazard impacts (Fothergill and Peek 2004). Poor people have less money to spend on preventative measures, emergency supplies, and recovery efforts. Although the monetary value of the economic and material losses of the wealthy may be greater, the losses sustained by the poor are far more devastating in relative terms. Poor people are more likely to live in substandard housing, which can be a major disadvantage when disasters occur (Long 2007), and during disasters, are less likely to have access to critical resources and lifelines, such as communications and transportation. Some research suggests that working class families tend to experience long-lasting impacts from disasters (Dash and Morrow 2007).

The confluence of race and class (socioeconomic status) has a long history of producing social inequalities (Füssell 2007; Germany 2007). Nowhere were these inequalities than in the differential impact of and response to Hurricane Katrina (Cutter et al. 2006; Elliott and Pais 2006; Logan 2006; Pastor et al. 2006; Elder et al. 2007; Brunsma et al. 2007; Potter 2007). Many scholars refer to Hurricane Katrina as an "unnatural disaster" (Dyson 2006; Hartman and Squires 2006; Laska and Morrow 2006) inferring that the impacts associated with it were more related to the underlying socioeconomic inequalities within the affected population rather than the hurricane's intensity. In the United States, racial and ethnic minorities are more vulnerable to hazards because minorities are more likely to live in poverty (Peacock et al. 2000). Discrimination also plays a major role in increasing the vulnerability of racial and ethnic minorities (Fothergill et al. 1999; Bolin 2006). In particular, real estate discrimination may confine minorities to certain hazard-prone areas or hinder minorities in obtaining policies with more-reliable insurance companies (Peacock and Girard 1997). Ethnic communities are often geographically and economically isolated from jobs, services and institutions. Where minorities are immigrants from non-English-speaking countries, language barriers can greatly increase vulnerability to a disaster and recovery (Peguero 2006; Leong et al. 2007a,b; Trujillo-Pagan 2007).

Table 1 Selected Population Characteristics influencing Social Vulnerability

Concept or Characteristic	Proxy Variable	Effect on Social Vulnerability
Socioeconomic status	% poverty Per capita income	Increases High decreases; low increases)
Gender	% female headed households	Increases
Race and/or ethnicity	% African Americans % Hispanic	Increases Increases
Age	% elderly % under 18	Increases Increases
Housing tenure (ownership)	% renters % homeowners	Increases Decreases
Employment	% unemployed	Increases
Occupation	% agricultural workers % low skilled service jobs	Increases Increases
Family Structure	% Single parent households Large families	Increases Increases
Education	% Less than high school	Increases
Population growth	Rapid growth	Increases
Access to medical services	Higher density of medical establishments and services	Decreases
Special needs populations	Homeless, tourists, transients, nursing home residents	Increase
Social dependence	% social security recipients	Increase

Gender also affects social vulnerability (Enarson and Morrow 1998; Enarson et al. 2006; Enarson 2007). Women are more vulnerable than men are to disasters, mainly because women— especially single mothers — are more likely to live in poverty (Bianchi and Spain 1996). Women often suffer the impacts of a disaster disproportionately. For example, women are more likely than men are to hold low-status jobs in the service industry, which often disappear after a disaster strikes (Morrow 2008). Women are also more vulnerable to disasters because of their roles as mothers and caregivers: when disaster is about to strike, their ability to seek safety becomes restricted by their responsibilities to the very young and the very old, both of whom require help and supervision.

Both the young and the elderly may be unable to respond to disasters without outside support (Ngo 2001; Heinz Center 2002; Anderson 2005; Phillips and Hewett 2005; Kar 2009; Smith et al. 2009). Children who lack adequate family support are at a major disadvantage for disaster response (Phillips and Hewett 2005; Fothergill 2004). Disruptions created by a disaster can have significant psychological and physical impacts on children (Kar 2009). Generally, the elderly are more likely to lack the necessary physical and economic resources to respond effectively to a disaster. They are more likely to suffer health problems and experience a slower recovery (Ngo 2001). The elderly also tend to be more reluctant to evacuate their homes in a disaster. In addition to the physical difficulties imposed by evacuation, the elderly become distressed at the prospect of leaving their own homes and living even on a temporary basis, in a group setting (Gladwin and Peacock 1997).

People living with mental or physical disabilities are less able to respond effectively to disasters and require additional assistance in preparing for and recovering from disasters (McGuire et al. 2007). Emergency managers need to target areas with high concentrations of disabled people, particularly in group-living quarters, for early evacuation and other preparatory measures (Morrow 2008).

It is important to note from the discussion above that the proportion of residents characterized by these broad categories is important, but also how each factor or variable interacts to produce socially vulnerable populations. Selecting a single variable (e.g. race, gender, or poverty) does not adequately capture communities described as African American female-headed households below the poverty level, because not all African Americans are in poverty; not all female-headed households are African American; and not all people in poverty are females or female-headed households. It is often the intersection of gender, race, class, and family circumstances that most influence the social burdens from natural hazards.

The Social Vulnerability Index

While the theoretical underpinnings of vulnerability science progressed over the past two decades, advancements in methods for measuring vulnerability have lagged. While there is significant policy interest in such efforts, there is less agreement on the appropriate methods for creating social vulnerability indices. The methodological development of social vulnerability indices are focused around three major decisions: 1) the scale of the index; 2) the explicit proxies (or variables) included in the index; and 3) the method of aggregation (Adger et al. 2004; Gall 2007; Barnett et al. 2008). Variations in the development of the index inevitably produce different outcomes.

In 2000, Cutter et al. operationalized the Hazards-of-Place model to reveal the vulnerability of populations living inside hazard zones for Georgetown County, South Carolina. To quantify social vulnerability, nine indicators were chosen deductively, based on *a priori* knowledge from the existing literature. These included total population and total housing units (i.e. proxy of people/ structures at risk); number of females, number of nonwhite residents, number of people under age 18, and number of people over age 65; mean house value (i.e. proxy for wealth, resilience); and number of mobile homes (i.e. proxy level of structural vulnerability). Indicators were collected for block groups using 1990 US Census Statistics. Rather than using simple percentages to represent indicators, each social variable was standardized by determining a ratio of that variable in each census block to the total value of that variable for the entire county to create a comparative proportion for each variable in each block. To produce an aggregate value for social vulnerability, standardized values were summed for each block. This score was then combined with the aggregate values for biophysical vulnerability (derived from frequency of hazard occurrence) using a GIS. Lacking the reliable theoretical or statistical evidence needed to assign weights, all indicators had the same relative importance (equal weight) within the GIS.

Chakraborty et al. (2005) used those methods developed by Cutter et al. (2000) to develop the Social Vulnerability for Evacuation Assistance Index (SVEAI) for block groups in Hillsborough County Florida. SVEAI used ten indicators, similar to those chosen by Cutter et al. (2000) with some minor changes to reflect those populations that may have special evacuations needs (i.e. disabled) and those who have differential access to evacuation resources inside their home (i.e. no telephone or vehicle).

Rather than simply summing the standardized variables, values were averaged yielding aggregate vulnerability normalized between zero and one. In further contrast from Cutter et al.'s (2000) metric, Chakraborty et al. presented four alternative approaches for grouping the variables to calculate social vulnerability for evacuation and for examining the spatial distribution of each approach within the study area. These characteristics are listed below, along with the number of variables associated with each approach: Approach 1: Population and structure (three variables); Approach 2: Differential access to resources (three variables); Approach 3: Special evacuation needs (four variables); and Approach 4: All three characteristics (all 10 variables). Each approach addresses a specific dimension of evacuation assistance need that can be examined and visualized independently, a process that recognizes the different issues that local emergency managers face in developing evacuation plans. Using the methods of Cutter et al. 2000, SVEAI was combined with a geophysical risk index (hurricane risk and flooding). The resultant values indicate overall evacuation assistance need.

In 2003, Cutter et al. developed the Social Vulnerability Index (SoVI). Based on the social dimensions of the Pressure and Release and Hazards-of-Place models (See Conceptual Frameworks, Section 1), SoVI is a multidimensional, scale dependent, spatially reliant algorithm for quantifying the relative socio-economic and demographic quality of a place as a means of understanding vulnerability. Using an inductive factor analytic approach, 42 socioeconomic variables (derived from US Census and County Data Books) reduced to 11 statistically independent factors, which accounted for about 76 percent of the variance at the county level for the entire United States. These factors were aggregated using a simple additive model to compute a summary score (i.e. the SoVI score) (Cutter et al. 2003). Again, no *a priori* weights were assigned during any point of aggregation. Those factors that contribute to the overall score often are different for each county, underscoring the interactive nature of social vulnerability—some components increase vulnerability while others reduce or moderate the SoVI score. SoVI attempted to uncover places having an uneven capacity for preparedness and response; places where resources might be used most effectively to reduce the pre-existing vulnerability). Unlike previous indices, SoVI is designed as a stand-alone indicator. This is concurrent with the accepted theoretical understanding that social vulnerability is independent of hazard type. Zones of differential exposure to any or all hazards combine with SoVI to create place vulnerability (for example see Borden et al. 2007; Burton and Cutter 2008; Wood et al. 2009). Though Cutter et al.'s SoVI (2003) was applied to all counties in the U.S., sensitivity testing suggests that the developed methods are both scalable and transportable throughout the U.S. (Schmidtlein et al. 2008) and other developed countries (Boruff and Cutter 2007).

From these seminal works come many variations in the development of social vulnerability metrics. Rygel et al. (2006) employ similar methods to those published by Cutter et al. (2003) the main deviation being the assignment of weights for aggregation, based on a ranking of the factors. Cox et al. (2007) apply a weighting schema based on the percent variance explained by each factor. Other metrics suggest the use of weights based on *a priori* comprehension of differential hazards risks and the potential for damage (Montz and Evans 2001; Myers et al. 2008).

A common critique of comparative statistical research, particularly those focused on national level analyses, is that it fails to capture the sub-national spatial and social differentiation of vulnerability and local conditions that mediate the capacity to adapt. Such macro scale analyses though, easily sacrifice detail for common patterns and potentially fail to detect the heterogeneity of vulnerability at a subscale level (Eyles and Furgal 2002; Adger et al. 2004; Barnett et al. 2008). In contrast, sub-national level indices capture sufficient detail useful for exploring intervention tools to ameliorate adverse vulnerability. The drawback of micro level studies, however, is that a high level of local detail limits the chance for generalizations and application in other regions (Eyles and Furgal 2002). These critiques are important to consider, because social vulnerability is place-sensitive, so the selection of the places (or units of analysis) for comparisons is important.

Social Vulnerability Maps

Social vulnerability as a comparative metric means little without a method of visualization. As a utility for identifying and locating sensitive populations, vulnerability maps allow for the estimation of anticipated community needs at differing levels of disaster response (Morrow 1999). The literature explicitly discussing vulnerability mapping is relatively sparse, yet most assessments provide a map depicting the geographic variability in social vulnerability (Clark 1998; Cutter et al. 2000; Wu et al. 2002; Vincent 2004; Cardona 2005; Chakraborty et al. 2005; Rygel et al. 2006; Borden et al. 2007; Boruff and Cutter 2007; Cox et al. 2007; Wood et al. 2007, 2009; Burton and Cutter 2008; Frazier et al. 2008; Lein 2008; Ebert et al. 2009;). Using vulnerability maps as planning tools, emergency managers can address the root causes of vulnerability, which will inherently change from place to place. At the local scale, planners and managers can look beyond geographical exposure to understand how unique social and political patterns facilitate the attenuation of risk (Frazier et al. 2008; Yarnal 2007). The concentration of high-risk areas can be highlighted in communities or states so that emergency management plans can be customized and disaster relief distributed based on need as determined by the social vulnerability.

Adherence to basic cartographic design and principles is evident in the outputs from social vulnerability indices. Choropleth mapping, a method by which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed, is widely used to depict the "saturation" of vulnerability in a given area. In the examples cited above, vulnerability is a single standardized value or score, which is classified using objective schema, such as standard deviations or quantiles (Cutter et al. 2003; Chakraborty et al. 2005; Rygel et al. 2006). Mapping using a geographic information system (GIS) allows for the ease of data editing, analysis, transport, storage, and visualization (DeMers 2005).

Social Vulnerability in the Context of Climate Change

In recent years, vulnerability assessment has become a noteworthy subject in the field of applied global change (McCarthy et al. 2001). The acknowledgement of a probable increase in the frequency and intensity of hazard events such as hurricane storm surge, flooding, and the potential exacerbation caused by sea level rise has yielded an increased interest in pre-hazard planning and emergency preparedness for climate related hazards (Wu et al. 2002; Adger et al. 2004; Rygel et al. 2006; Frazier et al. 2008). Most of these studies focus on the physical dimensions of climate hazards (e.g. large scale exposure) (Adger et al. 2004; Brooks et al. 2005; Torresan 2008) answering more the "What, Where and When" of climate hazards, rather than the "Who and Why". Earlier assessments of the human dimensions of climate impacts focused more on specific impacts in developing countries, such as food scarcity (Bohle et al., 1994). SoVI and variants of it now are beginning to appear in the literature to quantify local-scale social vulnerability to climate variability impacts. These studies utilize the SoVI methodology and examine the social vulnerability to specific climate variability hazards among them coastal erosion (Boruff et al. 2005), coastal inundation and storm surge (Rygel et al. 2006; Frazier et al. 2008), hurricanes (Myers et al. 2008), and flooding (Azar and Rain 2007; Zahran et al. 2008; Fekete 2009). However, Cutter et al.'s SoVI (2003) has yet to be used to assess the cumulative impact of climate variability hazards (floods, hurricanes, drought, sea level rise), despite its inherent utility in describing the geographical differences in impacts.

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5. Summary

The U.S. Disaster Mitigation Act of 2000 (DMA 2000) requires local governments to submit multi-hazard mitigation plans as a condition for future disaster relief and mitigation grant funding. These plans require updates every three years. The requirements for the content of hazard mitigation plans are prescribed in the U.S. Code of Federal Regulations Title 44, Part 201, Section 6 and a requirement for a hazard vulnerability assessment including descriptions of the type, location, and extent of relevant hazards, and a risk-based characterization of hazard vulnerability. The hazard vulnerability assessment must include descriptions of the buildings and infrastructure in hazard prone areas, estimated dollar losses, and information regarding land use and development trends. With no standardized methodology, the county hazard vulnerability assessments vary widely across the U.S.

The Hazards-of-Place Model (HOP) of vulnerability, provides a place-based overview of both the physical event parameters (and their potential impacts) and the underlying socio-economic and demographic characteristics of the population residing within the hazard zone. Because the hazards-of-place model combines the biophysical vulnerability (physical characteristics of hazards and environment) and social vulnerability to determine an overall place vulnerability it lends itself well to the identification of at risk and vulnerable populations identified within DMA 2000. Knowledge of the social, economic, demographic, and housing characteristics that influence a community's ability to respond to, cope with, recover from, and adapt to environmental hazards is key in the formulation of policy advocacy that can focus on two main components of hazard risk and vulnerability reduction. The first component supports policies aimed at structural mitigation or the reduction adverse effects to property by using protective measures such as leeves, building codes and code enforcement, and other "built environment" measures. Policy opportunities and interventions can be identified through the biophysical vulnerability assessment portion of the HOP model to address questions on the effectiveness of mitigation for communities or different segments of the population. Second, non-structural mitigation measures focus on reducing the impacts of disasters through the betterment of those segments of society that are adversely impacted or at a high risk of impact from disaster events. Non-structural mitigation measures and policy development priorities can be identified through the social vulnerability assessment portion of the HOP model and answer questions related to who will be impacted, and how will these people be able to respond and rebound from the event.

Numerous state and county level hazard assessments have utilized the HOP model to determine both the physical threat of hazards and the social impacts of these threats. Specifically, the states of California, Colorado, and South Carolina have all employed the HOP model for the identification of at risk and vulnerable populations and have had mitigation plans approved as DMA compliant by FEMA. All of these mitigation plans utilize the HOP model to identify both the physical characteristics of hazard events, and the underlying social makeup of specific places.

The science of vulnerability is in its nascent state compared to many of the other scientific fields and sub-fields. Progress towards a comprehensive, empirical understanding of hazard vulnerability inputs and processes, especially related to hazard events and outcomes, has grown in breadth and depth within the last 10-15 years. Add to this new knowledge a growing understanding of the drivers and dynamics of global environmental change - and more specifically of climate change impacts and climate related hazard events - and one quickly realizes that the questions of who, what, when, and where are no longer simply parts of a "theoretical" construct. A unique method for identifying places based not only on particular sets of socio-economic and demographic characteristics but also on the range of potential impacts from hazard events becomes available through the utilization of the human-environment place-based approach for characterizing and understanding potential impacts from natural hazards.

A place based approach, such as the hazards-of-place model supports the identification, analysis, and visualization of both the physical system and the human dimension of the hazard zone. In comparison, many other metrics, measures, theoretical constructs, and indices, provide a narrower view of vulnerability or the hazard events. While there are a myriad of approaches to understanding vulnerability including the underlying root causes, and pressures (Section 1), measuring vulnerability and conducting empirically-based hazard assessments is more difficult (Section 2 and 3). The dynamic inter-relationships between disaster agents and the affected population (Section 4) is rapidly becoming a focal for politicians, planners, emergency managers, as well as the general population. The need for evidence-based science to support policy decisions is more crucial now than ever before. Thus, the development of a robust vulnerability metric, providing insight to both physical parameters and socio-demographic characteristics of hazard events that can be combined with structural mitigation measures or through non-structural actions, such as changes in beliefs, attitudes, decision-making, and other social dimensions. This literature review provides a baseline from which a comprehensive understanding of vulnerability science can be rooted. While it is not comprehensive inventory of all peer reviewed literature on the subject, it does include the seminal works within the field of vulnerability science and presents the main theories, concepts, and applications related identifying, quantifying, analyzing, and displaying social vulnerability to climate change hazards.

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