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Measuring Resilience and Vulnerability in U.S. Counties

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INTRODUCTION

This paper summarizes work completed as part of the Missouri Transect Project Community Team's *Integrating Responses to Climate Change within a Regional Resilience Framework.* The goal was to create a series of county level indexes to measure resilience and vulnerability relative to other counties in the U.S. The eventual aim is to provide communities with the capacity and tools to prepare resilience plans that can respond to a range of natural and human-made threats, include climate change.

METHODOLOGY

Prior papers have provided a review of the literature surrounding the concepts of resilience and vulnerability and described the methodological process and progress.[3] This paper presents a final set of indexes and variables designed to measure county resilience and vulnerability along social, infrastructure, economic, and environmental dimensions.

For each dimension of resilience and vulnerability, a range of variables were identified and assembled, with values calculated or assigned at the county level using a variety of reputable data sources. These values were scaled and aggregated into indexes of resilience and vulnerability. For each index, counties were allocated to one of four quadrants according to their relative high or low resilience and vulnerability.

Variables were selected that represented important facets of resilience and vulnerability based on an extensive review of the literature[4], although inevitably constrained by the availability of data across all counties in the U.S., and by the need to minimize correlation among variables.[5] Some variables were clearly associated with either resilience or vulnerability; others were classified as describing resilience or vulnerability based on their direction. For variables where a larger value was a positive characteristic

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[3] Miller and Dabson (2015); Miller, Johnson and Dabson (2015)

[4] For a detailed review of prior work in this area, see Dabson (2015); Miller and Dabson (2015)

[5] Variables correlated with a correlation coefficient above 0.70 were not included in the same index. One exception was within the economic index, where the measures of economic diversity and employment in natural resource sectors were correlated above this threshold; both were still included, because of their importance in understanding economic resilience and vulnerability.

(e.g. higher educational attainment), they were included in the resilience index; for variables where a larger value was a negative characteristic (e.g. poverty rates), they were included in the vulnerability index.

Variables were scaled using a minimum-maximum rescaling method. All values were re-coded into a scale ranging from zero (the lowest value) to one (the highest value) following the formula below. However, in order to minimize the influence of extreme values, the minimum and maximum values were capped at a value of three standard deviations from the mean. Values more than three standard deviations above the mean were re-coded with a scaled value of 1. Values more than three standard deviations below the mean were re-coded with a scaled value of 0.

$$normalized(x_i) = \frac{x_i - X_{\min}}{X_{\max} - X_{\min}}$$

Where:

x_i =individual value for variable x

X_{min}=minimum value of X across all counties, or value representing 3 standard deviations below the mean, whichever value is larger

X_{max}=maximum value of X across all counties, or value representing 3 standard deviations above the mean, whichever value is smaller

For distance-based measures (such as the distance to hospitals with an emergency room), rather than use the minimum-maximum values of all counties, counties were grouped based on the Core Base Statistical Area (CBSA)[6] status as central or outlying, as designated by the U.S. Census Bureau. Indicators were then rescaled using the range of values within their group. This method prevented the influence of densely areas to affect the values of rural or outlying counties.

Appendix 1 provides a detailed discussion of the impacts of capping the minimum and maximum values, and compares this technique with the alternative method of using standardized (z) scores.

The set of normalized values for each dimension was averaged, resulting in four separate indexes for both resilience and vulnerability, a total of eight. Averaging, as opposed to summing, assured that all indexes fell within a range of zero to one, although it is possible that extremely high values for any particular variable may be “neutralized” by extremely low values for another. It is important, therefore, to review the impact of individual variables for any given county when evaluating its resilience and vulnerabilities.

A matrix of resilience and vulnerability was created for the set of indexes for each dimension. Counties were assigned to one of four quadrants based on the average resilience and vulnerability score relative to the median value across all counties. Counties above the median value were labeled “high resilience” or “high vulnerability,” while counties below the median value were labeled “low resilience” or “low vulnerability.” The comparison of values for resilience and vulnerability, then, place the county in one of four quadrants, illustrated in Figure 1[7].

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[6] A metropolitan area contains a core urban area of 50,000 or more population, and a micropolitan area contains an urban core of at least 10,000 (but less than 50,000) population. Each metropolitan or micropolitan area consists of one or more counties and includes the counties containing the core urban area (central counties), as well as any adjacent counties that have a high degree of social and economic integration (as measured by commuting to work) with the urban core (outlying counties).

[7] Adapted from the University of Notre Dame Global Adaptation Index. See Detailed Methodology Report, December 2013. http://gain.org/

Figure 1: Resilience and Vulnerability Quadrants

THE SOCIAL DIMENSION

SOCIAL RESILIENCE

Measures of social resilience were identified that capture concepts of place attachment, a well-educated population, civic engagement within the community, citizen health, and the capacity of the community to engage and serve the needs of its citizens, as shown in Table 1. Several studies have included these concepts in the creating of vulnerability and disaster resilience indicators.[8]

Table 1. Social Resilience Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
Place attachment	Percentage of population living in same county as one year prior	U.S. Census Bureau, American Community Survey, 2009-2013
Place attachment	Percentage of housing units that are owner occupied	U.S. Census Bureau, American Community Survey, 2009-2013
Highly educated population	Percentage of population with a BS degree or higher	U.S. Census Bureau, American Community Survey, 2009-2013
Civic engagement	Voter participation rate	U.S. Census Bureau, American Community Survey, 2009-2013, and *theguardian.com*, 2012
Social capital	Number of 501(c)(3) organizations per capita	Internal Revenue Service, April 2015, and U.S. Census Bureau, 2010
Social capital	Number of associations per 10,000 population	U.S. Census Bureau, County Business Patterns, 2013, and U.S. Census Bureau, 2010
Healthy population	Life expectancy	Institute of Health Metrics and Evaluation, 2014

- The percentage of the population living in the same county as one year prior and the percentage of housing units that are owner occupied were included as measures of place attachment. Areas where residents feel a stronger connection to place are more likely to rebound quickly after a disaster.
- Measures of civic engagement and social capital are based on research at Penn State University compiling a "Social Capital Index" for U.S. counties. The relationship between social capital in a community and a community's ability to respond to unforeseen emergencies is documented in prior literature.[9]
- Voter participate rates for the 2012 Presidential election were calculated by retrieving a dataset of total votes cast for Presidential candidates, and dividing that by the total citizen voting age population as reported by the U.S. Census Bureau. Because not all eligible voters are registered voters, the values may be systematically lower than actual participation rates.
- The rate of 501(c)(3) organizations per capita was used to represent the nonprofit capacity of the community. These were identified from Internal Revenue Service data with the number of organizations calculated on a per capita basis for each county, based on the decennial Census population count in 2010.
- The number of associations per capita provides a measure of social cohesiveness within a community. Current NAICS codes were selected that matched, as closely as possible, the original SIC

[8] For example, Cutter et al 2010, Renschler et al 2010, and Rupasingha and Goetz 2008
[9] Rupasingha and Goetz 2008

codes utilized in the construction of the Social Capital Index by researchers at Penn State University. The measure of associations included the following industry categories: bowling centers, civic and social associations, physical fitness facilities, public golf courses, religious organizations, membership sports and recreation clubs, political organizations, professional organizations, business associations, labor organizations and membership organizations not elsewhere classified.

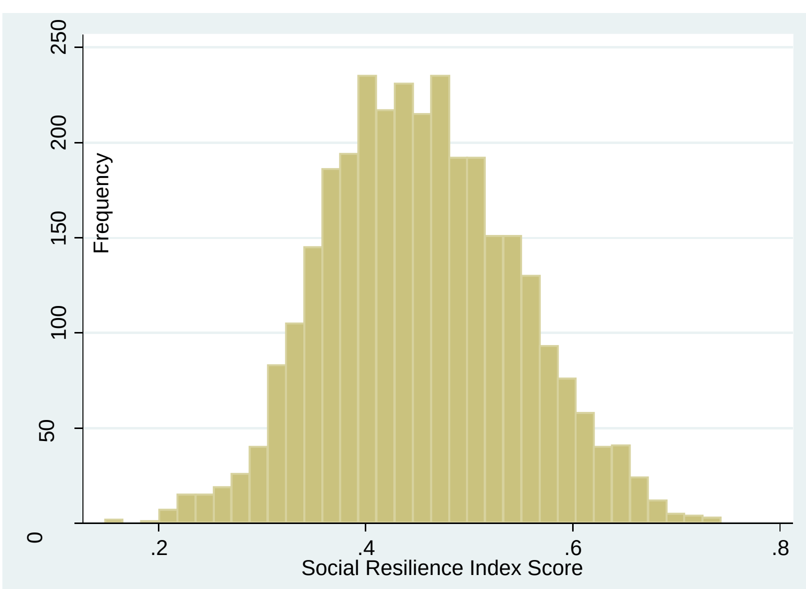
- Life expectancy was included as a proxy for population health. Life expectancy figures are provided separately for males and females, and an overall life expectancy measure for each county was constructed based on the gender distribution of each county's population using 2010 decennial Census data.

Descriptive statistics for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 2.

Table 2. Social Resilience Index: Descriptive Statistics

Measure	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
% population living in same county	3,143	93.4	93.9	3.0	56.3	99.8	0.58	0.62
% households owner occupied	3,143	59.2	60.3	9.3	0	86.3	0.51	0.53
% populations with BS degree or higher	3,143	19.8	17.6	8.8	3.2	74.4	0.38	0.33
Voter participation rate	3,113	56.1	56.8	12.4	0.3	107.0	0.51	0.51
Life expectancy	3,142	77.2	77.4	2.2	68.5	83.3	0.51	0.53
501(c)3 organizations per capita	3,143	404.4	355.1	320.0	0	13077.6	0.29	0.26
Associations per 10,000 population	3,143	14.3	13.0	7.1	0	81.5	0.40	0.37

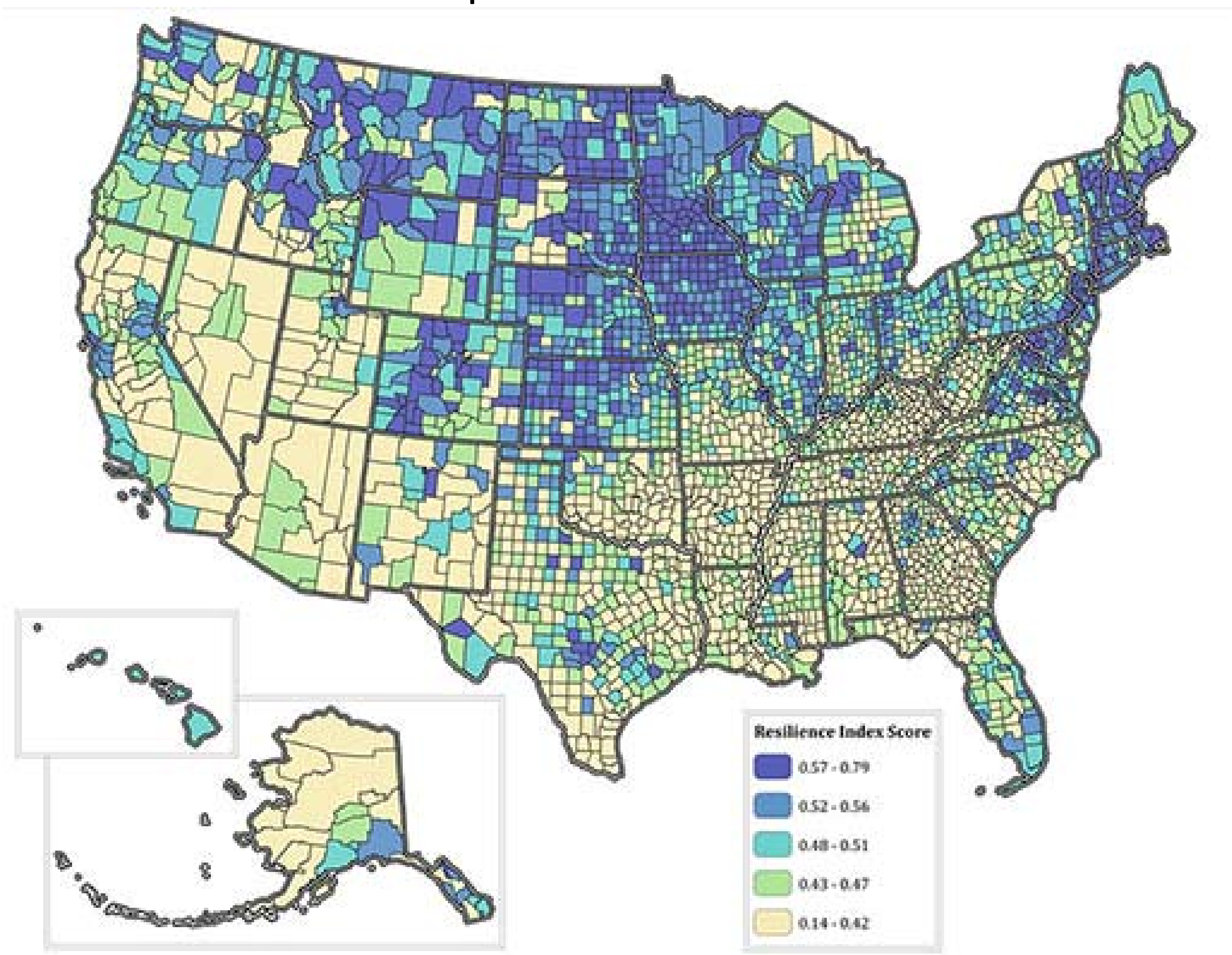
Figure 2. Distribution of Social Resilience Index Score



Non-missing values of the rescaled variables were averaged to calculate the mean resilience score for each county. The resultant index ranged from 0.15 to 0.73 with a mean value of 0.45 and a median value of 0.45. As shown in Figure 2, the distribution of the mean social resilience score across counties follows a normal distribution.

Map 1 shows the distribution of social resilience index scores, with values divided into quintiles. Counties shaded in darker colors, largely concentrated in the north central and northeastern regions of the United States, had higher mean social resilience scores, those with a light yellow shade had the lowest resilience index scores.

Map 1. Social Resilience Index



SOCIAL VULNERABILITY

Measures of social vulnerability were selected to capture particularly vulnerable and special-needs populations within the community. Also included were measures of income inequality, social erosion, and political fragmentation. Higher values on these measures may indicate a greater level of difficulty in responding to or recovering from emergency situations or disasters. Table 3 lists the variables used in the social vulnerability index.

Table 3. Social Vulnerability Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
Income inequality	County Gini index	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	County poverty rate	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	Percentage of households that are linguistically isolated	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	Percentage of population with a disability	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	Percentage of population without health insurance	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	Percentage of population age 65 and over	U.S. Census Bureau, American Community Survey, 2009-2013
Vulnerable population	Percentage of population under age 18	U.S. Census Bureau, American Community Survey, 2009-2013
Community erosion	FBI violent crime rate	U.S. Department of Justice, 2010-2012
Political fragmentation	Number of jurisdictions	U.S. Census Bureau, Census of Governments, 2012; 2013 Census Tiger/LINE Tribal Lands boundary file; National atlas, 2006 Federal Lands layer

- While the county Gini index and the county poverty rate may seem related, these are two distinct constructs. A high proportion of poor individuals within a county does not necessarily equate with a wide or uneven income distribution. Likewise, a county with a very equitable distribution of income may include a high poverty population.
- Many of these variables relating to vulnerable populations follow prior work on social vulnerability, which include sub-populations that may face particular challenges following a disaster. Data from the 2009-2013 American Community Survey was used in each case.
- Although overlapping jurisdictions might be regarded as a positive attribute in the sense of multiple resources being available to respond to a disaster, it is treated in this analysis as an indicator of vulnerability. When a multitude of jurisdictions overlap in the face of an emergency, research suggests there will be an inherent challenge to collaboration and to meeting the needs of the community.[10] The U.S. Census Bureau's Census of Governments was the primary data source for counting the number of jurisdictions, which included county governments, all incorporated places, townships, county subdivisions, special school districts, and other special districts, such as fire, police, water, and transit authorities). Also included was a tally of tribal and federal lands within the county, using Census Tiger/LINE boundary files to identify recognized American Indian, Alaska Native, and Hawaiian areas. The number of federal agencies operating within the county was

[10] Bharosa, Lee and Janssen 2010

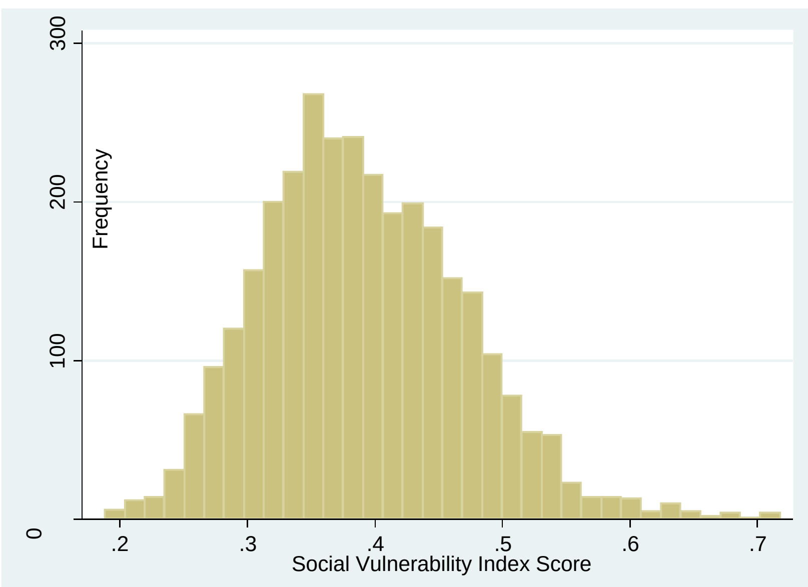
tabulated using the 2006 Federal Lands layer with a 2013 county boundary layer from the U.S. Census Bureau. Only agencies controlling at least 50,000 square meters of land were counted.

Descriptive statistics for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 4.

Table 4. Social Vulnerability Index: Descriptive Statistics

Measure	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
County Gini index	3,143	0.4	0.4	0.03	0.3	0.6	0.49	0.50
% households linguistically isolated	3,143	1.8	0.8	2.9	0	30.4	0.16	0.08
% population with a disability	3,143	15.4	15.1	4.4	3.1	32.4	0.48	0.47
% population without health insurance	3,143	15.2	14.7	5.8	2.4	65.6	0.42	0.41
% population age 65+	3,413	16.3	16.0	4.3	3.3	46.7	0.50	0.49
% population under age 18	3,143	23.1	23.1	3.5	0	41.6	0.50	0.50
Violent crime rate	2,955	257.1	202.0	207.5	0	1,989.5	0.29	0.23
County poverty rate	3,143	16.7	15.9	6.5	0.9	53.2	0.45	0.43
Number of jurisdictions	3,138	30.0	20.0	31.9	1	537	0.22	0.15

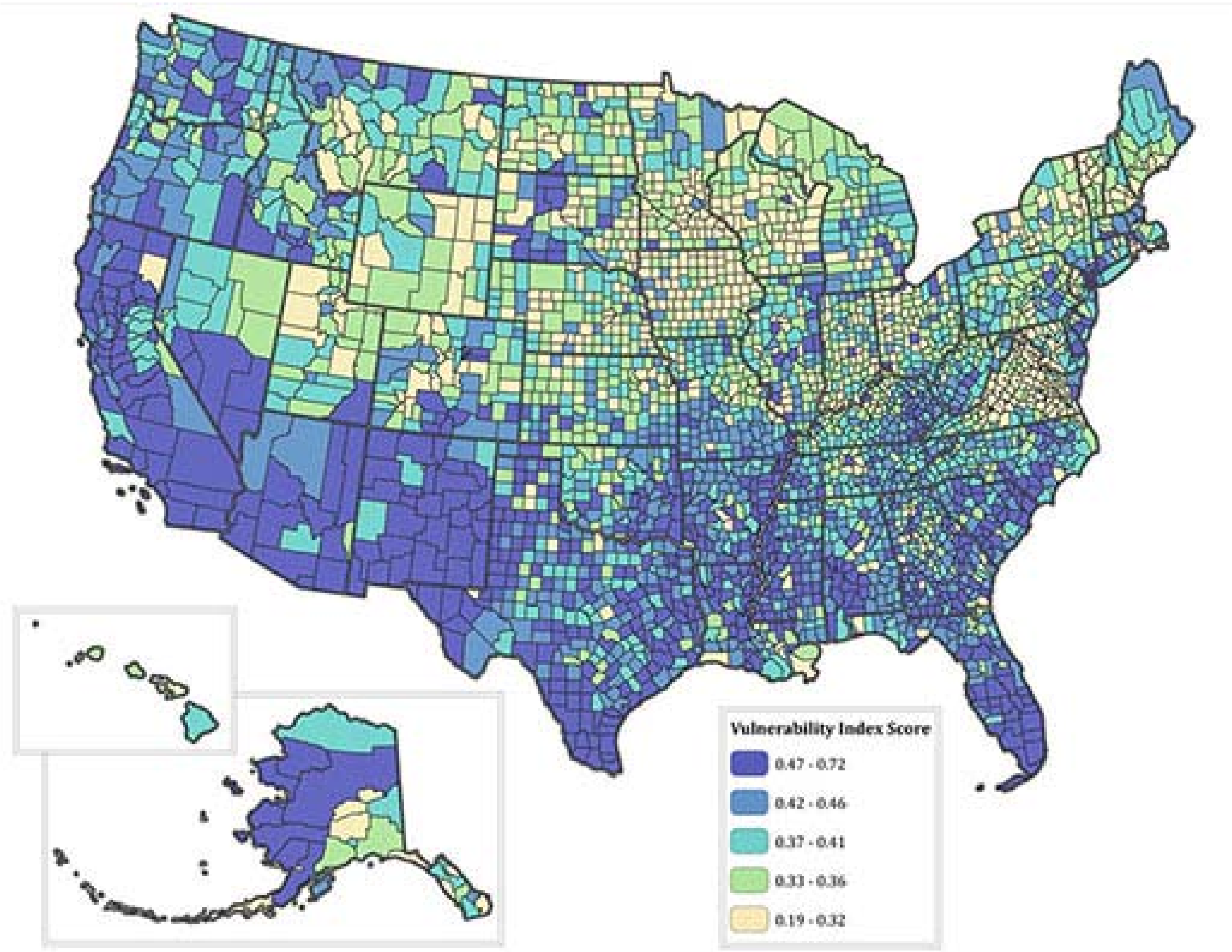
Figure 3. Distribution of Social Vulnerability Index Score



Non-missing values of the rescaled variables were averaged to calculate the mean vulnerability score for each county. The resultant index ranged from 0.19 to 0.72 with a mean value of 0.39 and a median value of 0.38. As shown in Figure 3, the distribution of the mean social vulnerability score across counties follows a normal distribution.

Map 2 shows the distribution of social vulnerability index scores, the values broken into quintiles. Counties shaded in darker colors had higher mean social vulnerability scores. The light yellow shade represents counties with the lowest vulnerability index scores.

Map 2. Social Vulnerability Index



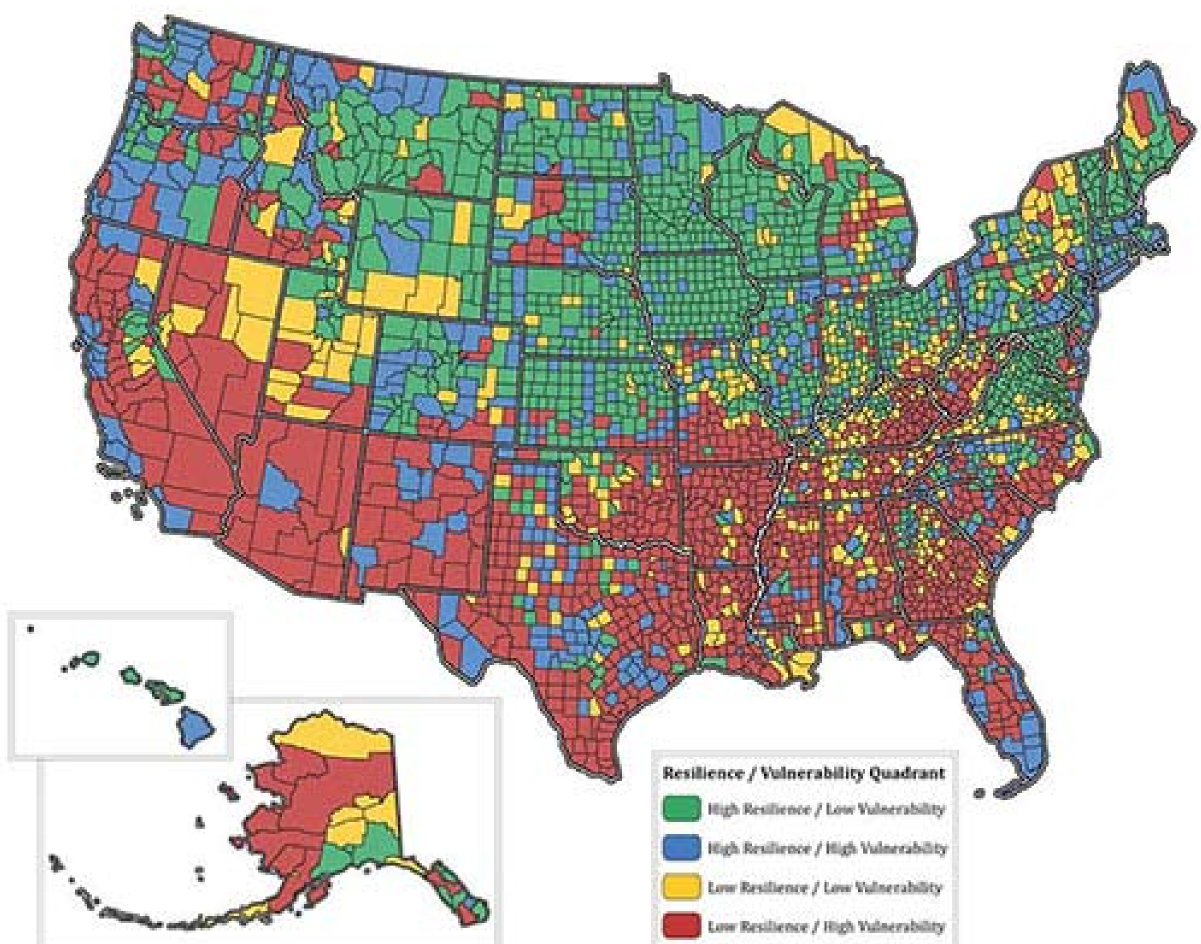
SOCIAL RESILIENCE AND VULNERABILITY

The individual social resilience and vulnerability scores for each county were compared to the median value across all counties. Counties were then placed into one of four quadrants, as shown in Table 5.

Table 5. Social Resilience and Vulnerability Quadrants		
Quadrant	**Number of U.S. Counties**	**Percent of U.S. Counties**
High Resilience / Low Vulnerability	1,085	34.5
High Resilience/ High Vulnerability	487	15.5
Low Resilience/ High Vulnerability	1,085	34.5
Low Resilience / Low Vulnerability	486	15.5
Total Counties	3,143	100.0

Map 3 shows the spatial distribution of counties across the four quadrants. Counties that fall into the Low Resilience and High Vulnerability quadrant are particularly vulnerable in terms of limited social capital and a low level of ameliorative conditions. These counties tend to be concentrated across the South, Southwest, and the Northwest.

Map 3. Social Resilience and Vulnerability Quadrants



THE ECONOMIC DIMENSION

ECONOMIC RESILIENCE

Measures of economic resilience were identified that capture the diversity of the local economy, the breadth and depth of entrepreneurship, labor force participation, and business establishment birth rate. The variables, measures, and data sources are listed in Table 6.

Table 6. Economic Resilience Index: Variables, Measures, and Data Sources		
Variable	**Measure**	**Data Source**
Economic diversity	Employment sector diversity (relative to national average)	U.S. Census Bureau, American Community Survey, 2009-2013
Entrepreneurship	Proprietors as a percentage of total nonfarm employment	Bureau of Economic Analysis, 2013
Entrepreneurship	Average nonfarm proprietor income	Bureau of Economic Analysis, 2013
Active economy	Labor force participation rate	U.S. Census Bureau, American Community Survey, 2009-2013
Economic growth	Establishment birth rate	U.S. Census Bureau, Statistics of U.S. Businesses, 2012

- Economic diversity is defined as the even distribution of jobs across economic sectors. Diverse economies are considered to be more resilient to disasters in that a single industry is not responsible for the success or failure of the entire economy. This index includes a measure of economic diversity using employment figures from the 2009-13 American Community Survey[11]. The Hachman Index method was used, defined by the following formula:

$$Hachman\ Index = \frac{1}{\Sigma\left(\left(\frac{\text{EMPCTYj}}{\text{EMPUSj}}\right) \text{x EMPCTYj}\right)}$$

  Where

  EMPCTYj is there share of the county's employment in industry j and
  EMPUSj is the share of National employment in industry j

  Economic Diversity index scores range from 0 to 1, where 1 is the most diverse (most similar to the National distribution). The Hachman Index was chosen for the calculation because it is a relative measure given that employment categories within the available data were not necessarily equal.
- Entrepreneurship is an important aspect to community resilience as entrepreneurs tend to be tied to the local area, create jobs, and are a source of innovation.[12] Two measures of entrepreneurship capture the breadth and depth of entrepreneurial activity in the county. Breadth is measured by nonfarm proprietors as a percentage of total nonfarm employment, and depth by the average income per nonfarm proprietors. Data were obtained directly from the BEA Economic Profiles table CA30.

[11] Data consist of counts and percentages of the total civilian employed population in 25 occupation categories from 2009-13 5-Year ACS Table C24010: Sex by Occupation for the Civilian Employment Population 16 Years and Older.
[12] Low, Henderson and Weiler (2005)

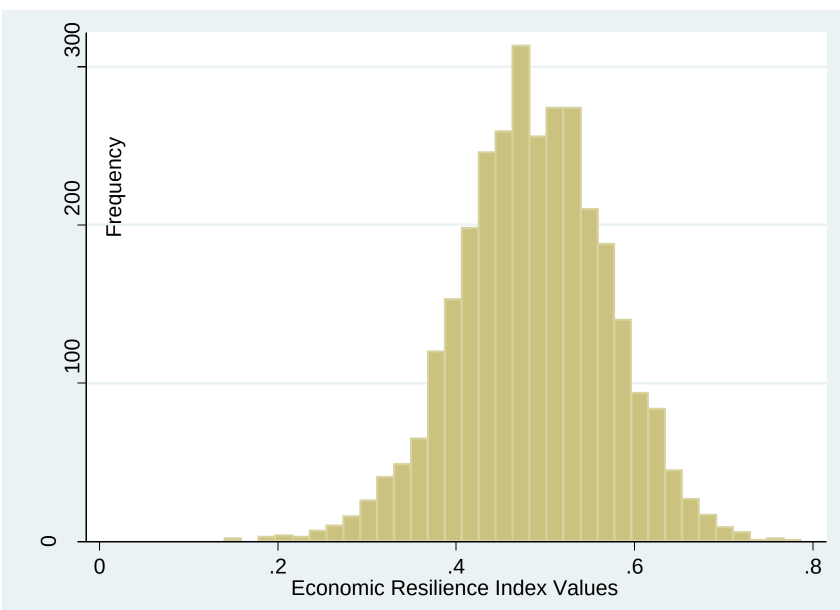
- The labor force participation rate is an indicator of the strength of the economy. In areas with limited employment opportunities, labor force participation tends to be lower as individuals drop out of the labor force.
- Economic resilience is also reflected in the rate of establishment births. Data were obtained from the U.S. Census Bureau's Statistics of U.S. Businesses (SUSB) database, measuring change between 2011 and 2012. The Census Bureau defines a birth as an establishment that "has zero employment in the first quarter of the initial year and positive employment in the first quarter of the subsequent year". Birth rates are calculated by dividing births over total establishments in the first quarter of the initial year. A county with a high establishment birth rate is assumed to exhibit strong dynamism and entrepreneurship and thus has a capacity for growth, sustainability, and overall resilience.

Descriptive statistics for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 7.

Table 7. Economic Resilience Index: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
Diversity index	3,143	0.76	0.79	0.2	0.07	0.98	0.69	0.73
Nonfarm proprietors as % of employment	3,088	27.2	25.1	11.1	2.9	80.4	0.42	0.38
Nonfarm proprietors income	3,088	22K	20K	14K	430	169K	0.34	0.30
Labor force participation rate	3,143	59.7	60.3	7.6	23.2	92.3	0.50	0.51
Establishment birth rate	3,135	85.0	81.2	29.7	0	392.9	0.48	0.47

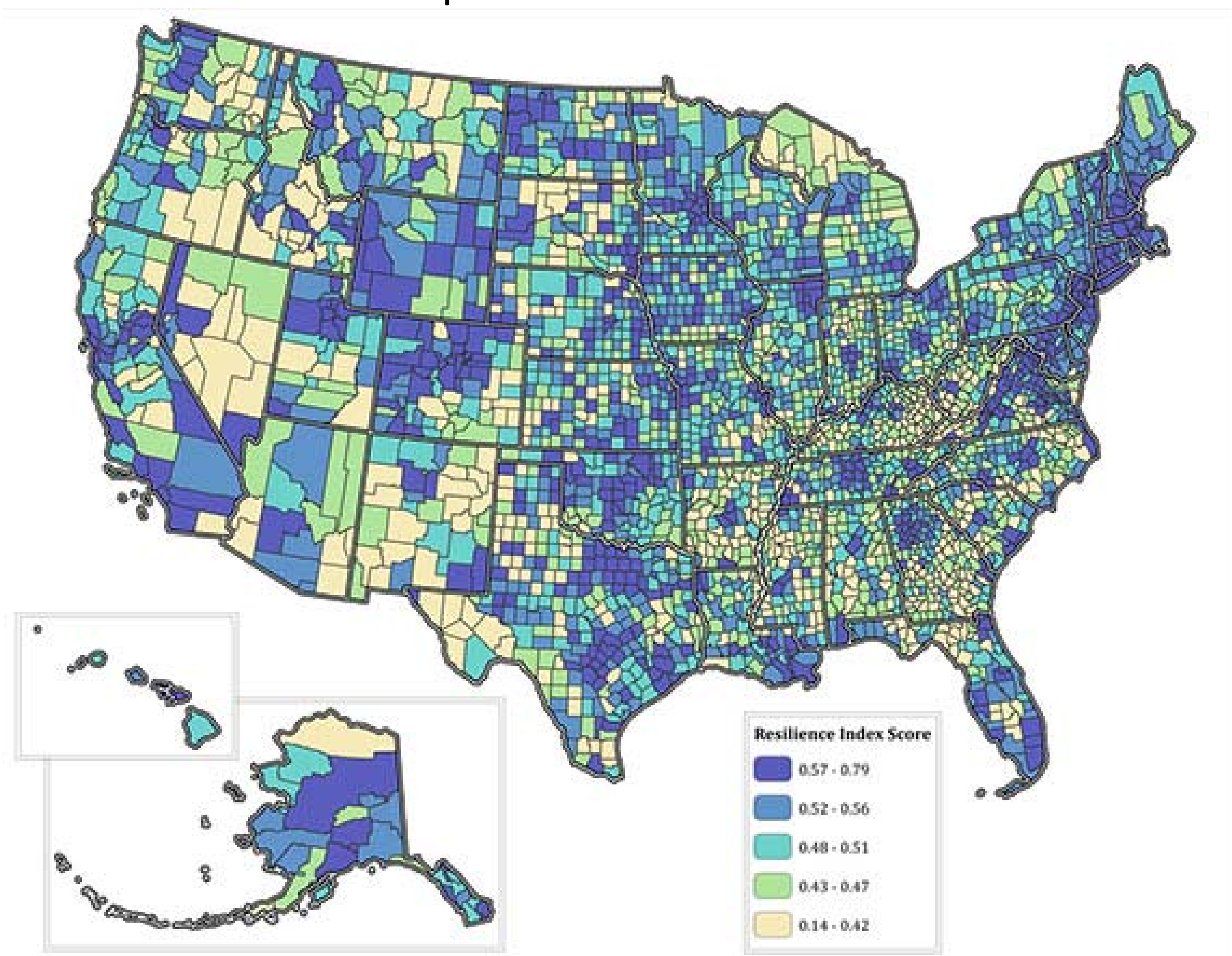
Figure 4. Distribution of Economic Resilience Index Score



Non-missing values of the rescaled variables were averaged to calculate the mean economic resilience score for each county. The resultant index ranged from 0.13 to 0.71 with a mean value of 0.36 and a median value of 0.35. As shown in Figure 4, the distribution of the mean economic resilience score across counties follows a normal distribution.

Map 4 shows the distribution of economic resilience index scores, with values divided into quintiles. Counties shaded in darker colors had higher mean economic resilience scores; while those with a light yellow shade had the lowest resilience index scores.

Map 4. Economic Resilience Index



ECONOMIC VULNERABILITY

An ailing economic will tend to much more vulnerable to a natural or economic disaster than a healthy economy. Measures of economic vulnerability include a reliance on natural resource sectors, households that are housing cost burdened, the overall county unemployment rate, and shortfalls in tax revenues that would support government operations. The variables, measures, and data sources are listed in Table 8.

Table 8. Economic Vulnerability Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
Reliance on natural resource sectors	Percentage of workers employed in agriculture, forestry, fishing, mining industries	U.S. Census Bureau, American Community Survey, 2009-2013
Economic hardship	Percentage of households spending 30% or more of total income on housing costs (mortgage/rent and utilities)	U.S. Census Bureau, American Community Survey, 2009-2013
Economic hardship	Unemployment rate	U.S. Census Bureau, American Community Survey, 2009-2013
Potential tax shortfalls	Business vacancy rate	Department of Housing and Urban Development; U.S. Postal Services (2014, Quarter 2)

- Reliance on natural resource sectors that suffer from boom and bust cycles can be devastating to a local community.[13] The Census Bureau does not disaggregate this sector further.[14]
- Households that are cost burdened are those that spend 30 percent or more of gross income on mortgage or rent and utilities. This provides a broad measure of economic hardship in a community. While low income households are often more likely to be cost burdened, moderate and middle income groups have experienced a rise in cost burdens over the past decade.[15]
- The unemployment rate was also included as a measure of economic hardship within the local area. The use of the American Community Survey five-year average estimates may mask more recent declines in unemployment rates as areas continue to rebound from the recession.
- The business vacancy rate illustrates possible gaps in employment opportunities, as well as potential tax revenue shortfalls to local economics.

[13] Cutter et al (2003)

[14] It should be noted that this measure is correlated with the economic diversity measure within the economic resilience index with a correlation coefficient of -0.7130. Even though the correlation was beyond the selected threshold of 0.7, both measures were included because of their importance in certain regions.

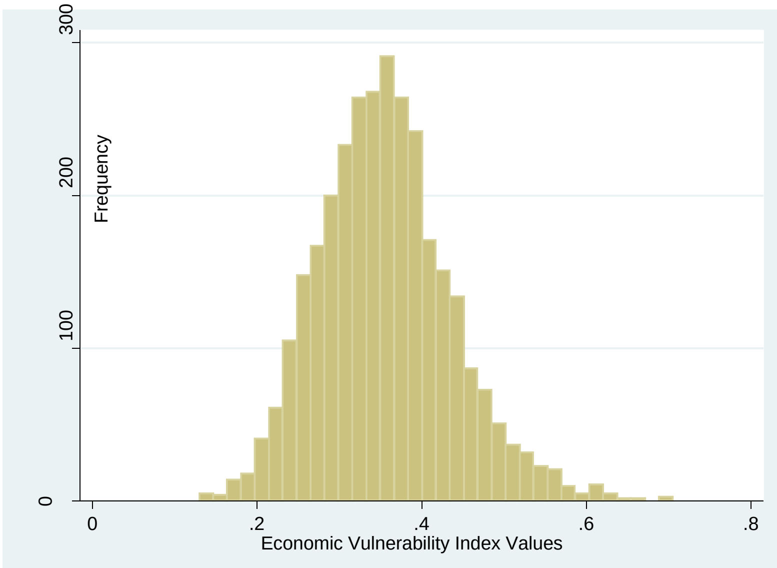
[15] McCue, Daniel 2015

Descriptive statistics for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 9.

Table 9. Economic Vulnerability Index: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
Employment in natural resource sectors	3143	6.9	4.3	7.5	0	82.9	0.23	0.15
Cost burdened households	3143	27.5	27.2	7.1	4.9	53.5	0.50	0.49
Unemployment rate	3143	9.0	8.7	3.9	0	28.8	0.35	0.34
Business vacancy rate	3123	8.7	8.9	5.6	0	41.2	0.34	0.35

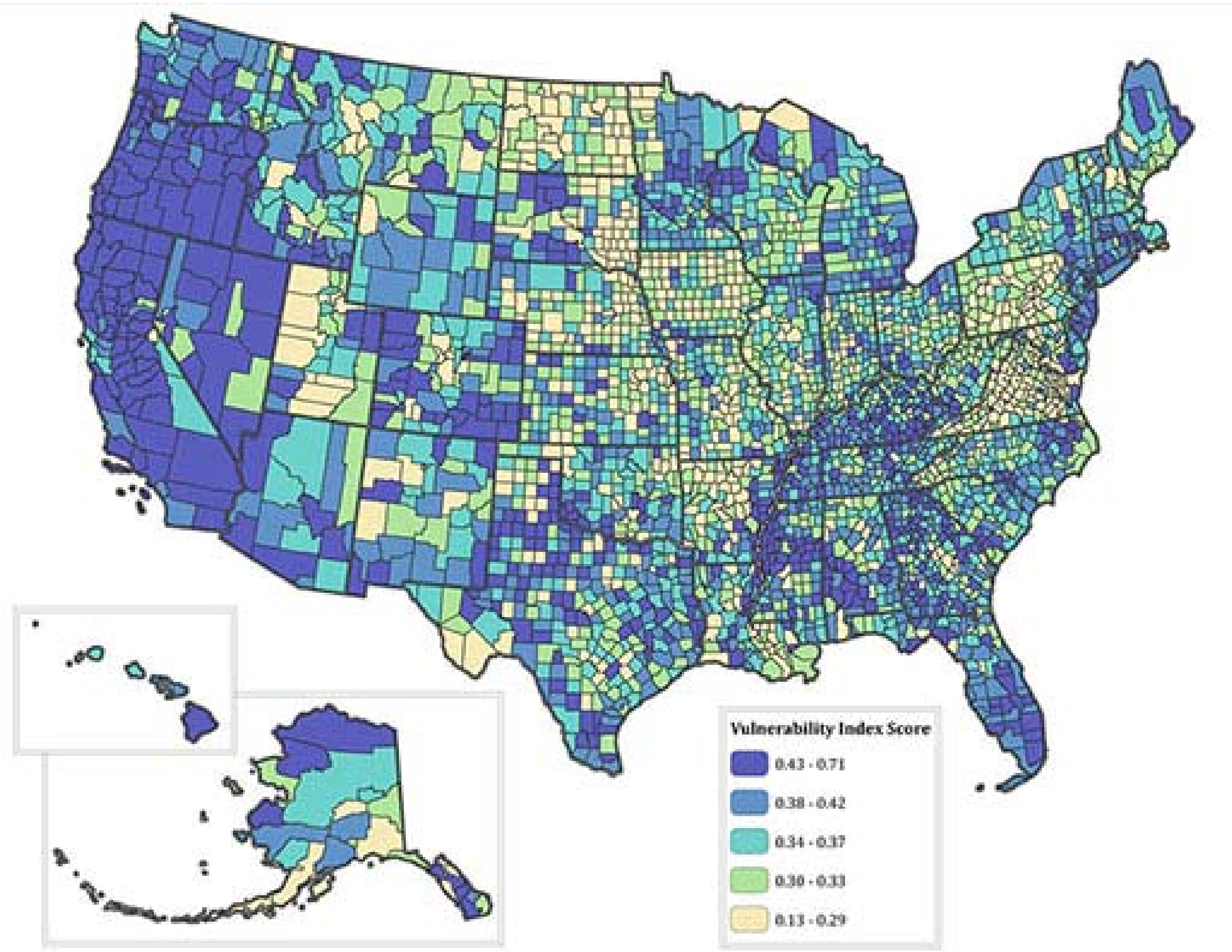
Figure 5. Distribution of Economic Vulnerability Index Score



Non-missing values of the rescaled variables were averaged to calculate the mean economic vulnerability score for each county. The resultant index ranged from 0.13 to 0.71 with a mean value of 0.36 and a median value of 0.35. As shown in Figure 5, the distribution of the mean economic vulnerability score across counties follows a normal distribution.

Map 5 shows the distribution of economic vulnerability index scores, with values divided into quintiles. Counties shaded in darker colors had higher mean economic vulnerability scores; while those with a light yellow shade represents counties had the lowest.

Map 5. Economic Vulnerability Index



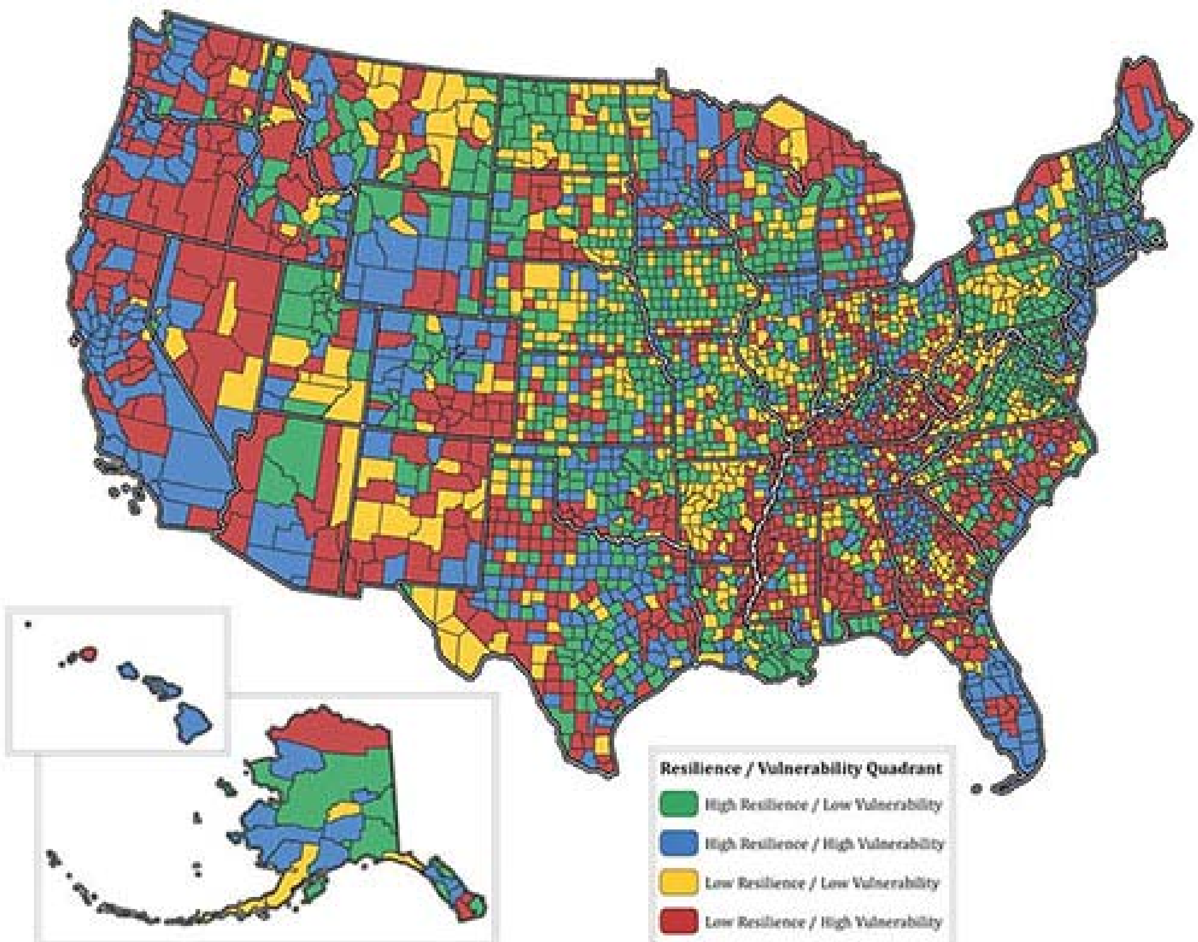
ECONOMIC RESILIENCE AND VULNERABILITY

The individual economic resilience and vulnerability scores for each county were compared to the median value across all counties. Counties were then placed into one of four quadrants, as described in Table 10.

Table 10. Economic Resilience and Vulnerability Quadrants		
Quadrant	**Number of U.S. Counties**	**Percent of U.S. Counties**
High Resilience / Low Vulnerability	899	28.6
High Resilience/ High Vulnerability	672	21.4
Low Resilience/ High Vulnerability	899	28.6
Low Resilience / Low Vulnerability	673	21.4
Total Counties	3,143	100.0

Map 6 shows the spatial distribution of counties across the four quadrants. Counties that fall into the low resilience and high vulnerability quadrant are particularly vulnerable in terms of limited economic opportunities and conditions.

Map 6. Economic Resilience and Vulnerability Quadrants



THE INFRASTRUCTURE DIMENSION

INFRASTRUCTURE RESILIENCE

Variables and measures of infrastructure resilience were identified that capture the capacity of a community to address potential disaster scenarios. These included medical capacity, adequacy of roadways in the event of a mass evacuation, the availability of potential first responders in case of emergency, local investments in policy and fire protection, and access to a grocery store.

Table 11 lists the selected variables, measures, and data sources.

Table 11. Infrastructure Resilience Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
Medical Capacity	Percentage of population within 10 miles of a hospital with an emergency room	Centers for Medicare and Medicaid Services Provides of Service File, 2014; U.S. Census Bureau, 2010.
Medical Capacity	Primary care physicians per capita	Health Resources and Services Administration, Area Health Resource File, 2013-14; U.S. Census Bureau, 2010.
Potential First Responders	Persons in emergency response occupations as a percentage of total county population	U.S. Census Bureau, American Community Survey, 2009-2013
Investment in emergency response system	Per capita expenditures on police and fire	U.S. Census Bureau, Census of Governments, County Area Expenditures, 2012
Adequacy of roadways	Lane miles of interstates, principal arterial and minor arterial roads per 1,000 population	Federal Highway Administration, Highway Performance Monitoring System, 2012; U.S. Census Bureau, 2010.
Access to food	Percentage of population within 1 mile of a grocery store	U.S. Department of Agriculture Food Access Research Atlas

- Medical capacity is measured in two ways. First, research has concluded that increased access to hospitals is associated with lower patient mortality during life-threatening events.[16] This has been calculated by determining the percentage of each county's population within a 10 mile radius of a hospital with an emergency room. To achieve this, a 10 mile buffer was applied to all active hospitals from the Centers for Medicare and Medicaid Services (CMS) June 2014 Providers of Service data file, and the population was counted by aggregating all Census Block centroids which fell within the radius. The calculated population was divided by the total county population to arrive at the final indicator value.
- A second measure of medical capacity is medical personnel per capita. A count of primary care physicians was used rather than that of all physicians so as to avoid including specialists who would not necessarily be primary responders in the face of an emergency. However, this may represent an undercount of responding medical professionals. There were 204 counties in the U.S. that had no primary care physicians, highlighting their potential vulnerability in the face of an emergency.

[16] See, for example Shen and Hsia (2012) and Nicholl et al (2007)

- Fire, police, and emergency healthcare workers are trained specifically to respond to a variety of disasters, but their capacity to be effective depends on several factors, including communication, organization, size, and resources. This index includes assessment of size and resources by measuring the relative number of first responders in each county, as well as local government investment in them. To arrive at the number of potential first responders in each county, total employment was collected across the following occupations: emergency management directors, EMTs, paramedics, first line supervisors of police and detectives, firefighters and prevention workers, firefighters, fire inspectors, police and sheriff's patrol officers, ambulance rivers, transit and railroad police, and animal control officers. The final measure reflects first responder employment as a percentage of the total population in order to reflect the potential for an adequate response in the county in the event of an emergency situation.
- Local government expenditures are included to measure the revenue dedicated to first responders. This is an important component of infrastructure resilience, as it represents the additional non-human assets available to first responders, by calculating local fire and police protection expenditures per capita.
- Other indexes employ a measure of roadways within counties to assess evacuation capacity.[17] The measure developed in this paper adds further refinement to capture more precisely the capacity of the road infrastructure to handle potential evacuation scenarios. Total lane miles were calculated (rather than total road miles), placing more weight on roads with multiple traffic lanes. A per capita calculation was used to gauge roadways that may face a heavy load of traffic in the event of an emergency or evacuation situation. Data were obtained from the Highway Performance Monitoring System for selected interstate, principal arterial and minor arterial roads.
- Food access and food security have been cited as a key resilience issue in a review of major cities by The Initiative for Competitive Inner City (ICIC).[18] The ICIC report predicts that large national chains may have more resources to recover from disruptions, as well as providing populations immediate access to food resources after an emergency. A measure of food system resilience was obtained from the USDA Food Access Research Atlas, which measures food access by estimating the total population[19] within one mile from a major supermarket or large grocery retailer.[20] Data was then presented by census tract, and aggregated to the county level.

[17] Cutter et al (2010)

[18] http://icic.org/wp-content/uploads/2016/04/ICIC_Food_systems_final_revised_post.pdf?676fce

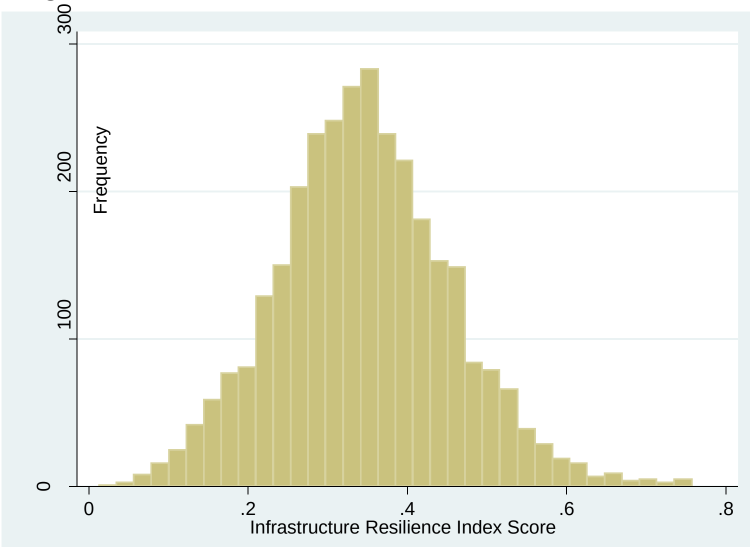
[19] Population data are based on 2010 Decennial Census figures, downcast to 500 meter grid cells. Downcasting was accomplished by area-weighting the average of block-level people or household counts at the grid-cell level. For each of the block-grid cell pieces, the share of each block's area was calculated. Then, for each of these block-grid cell pieces the share was multiplied by the population, then aggregated to the grid-cell level.

[20] Major supermarkets / large grocery stores are defined as: (1) super-centers – large stores usually 100,000 square feet or more of floor space, with a separate grocery area and general merchandise are under a single roof; (2) supermarkets – stores that are typically smaller than a supercenter and that primarily sell food and nonfood grocery products; and (3) large grocery stores – stores that sell a full range of foods and have at least $2 million in annual sales, but are not as large as supermarkets.

Descriptive statistics for each measure, and the result of the minimum-maximum re=-scaling technique are included in Table and the rescaled values, are presented below.

Table 12. Infrastructure Resilience Index: Descriptive Statistics								
Variable	**Obs.**	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**	**Mean Rescaled**	**Median Rescaled**
% population w/in 10 miles of a hospital	3,143	63.4	70.8	28.8	0	100	0.59	0.65
Primary care physicians per capita	3,143	56.4	49.3	56.4	0	741	0.31	0.27
Lane miles per 1,000 population	3,068	18.4	8.1	32.0	0	487	0.15	0.07
First responders percentage of total population	3,143	0.81	0.72	0.5	0	8.5	0.34	0.33
Per capita expenditures on police/fire	3,137	276.6	239.2	202.9	1.9	4363	0.30	0.27
Population within 1 mile of grocery store	3,143	35.0	33.7	19.5	0	100	0.38	0.37

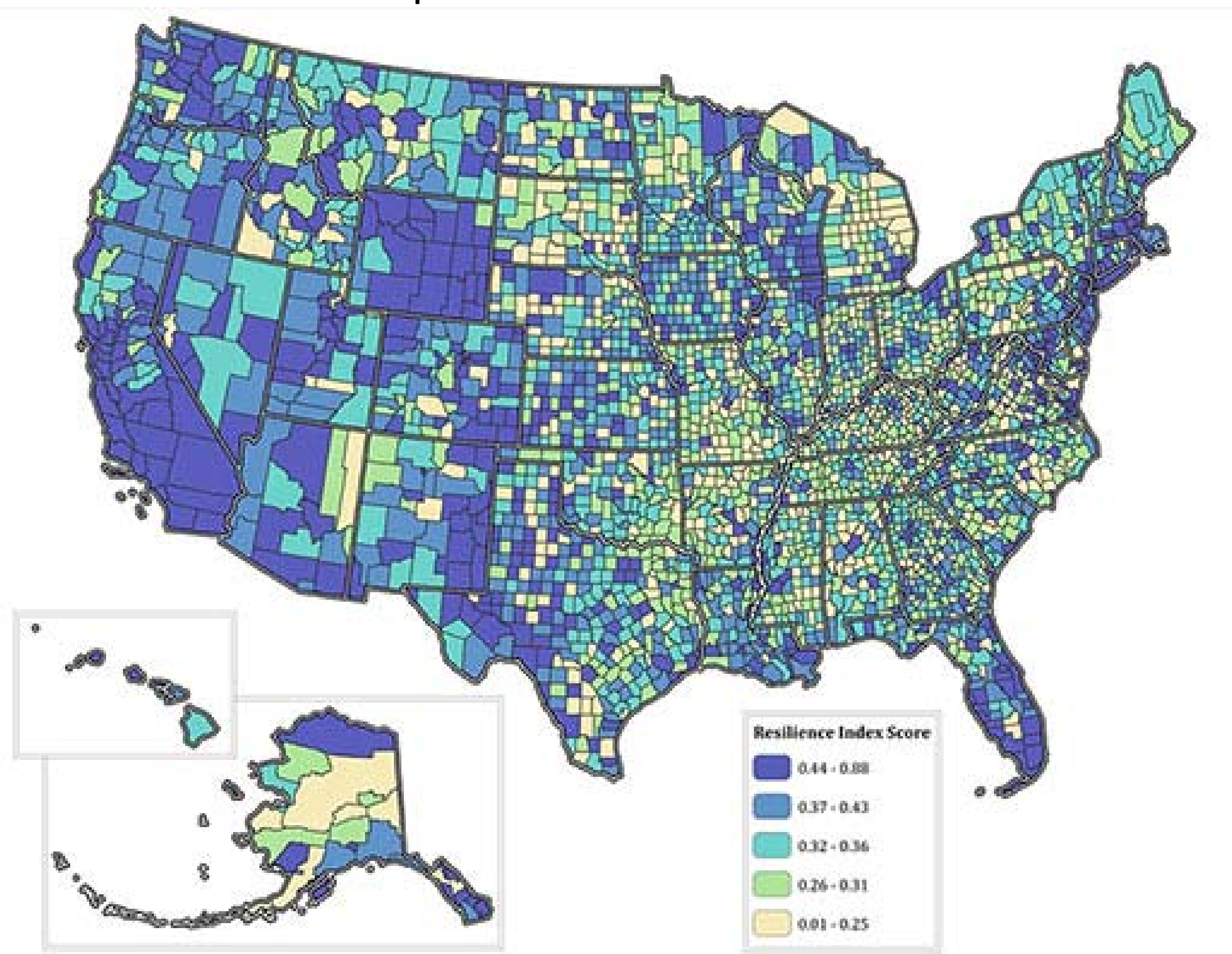
Figure 6. Distribution of Infrastructure Resilience Index Score



Non-missing values were averaged into the overall infrastructure resilience index. The index has a mean of 0.35 and a median value of 0.34, with a range from 0.01 to 0.76. As shown in Figure 6, the distribution of the infrastructure resilience score across counties follows a normal distribution.

Map 7 shows the distribution of infrastructure resilience index scores, with values divided into quintiles. Counties shaded in darker colors had higher mean infrastructure resilience scores, while those with a light yellow shade had the lowest resilience scores.

Map 7. Infrastructure Resilience Index



INFRASTRUCTURE VULNERABILITY

Measures of infrastructure vulnerability were identified that relate to at-risk infrastructure (specifically certain types of housing), evacuation challenges, high potential loss facilities, and quality of infrastructure (specifically water systems). Table 13 lists the variables, measures, and data sources for the infrastructure vulnerability index.

Table 13. Infrastructure Vulnerability Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
At risk infrastructure	Percentage of housing units that are mobile homes	U.S. Census Bureau, American Community Survey, 2009-2013
At risk infrastructure	Percentage of homes built before 1960	U.S. Census Bureau, American Community Survey, 2009-2013
Evacuation challenges	Percentage of population living in group quarters	U.S. Census Bureau, American Community Survey, 2009-2013
Evacuation challenges	Percentage of housing units with no vehicle available	U.S. Census Bureau, American Community Survey, 2009-2013
Evacuation challenges	Count of high detour or high traffic bridges	U.S. Department of Transportation, 2013 National Bridge Inventory
High potential loss facilities	Percentage of population within 5 miles of a dam	2014 National Transportation Atlas, Dams Dataset
High potential loss facilities	Percentage of population within 10 miles of a nuclear facility	U.S. Geological Survey, Structures Dataset
Infrastructure quality	Percentage of population served by water systems with at least one health-based violation	U.S. Environmental Protection Agency Safe Drinking Water Information System

- The inclusion of indicators measuring both older homes and mobile homes in disaster indicators has been established in the literature,[21] as these housing units are considered more vulnerable to disaster due to the quality of the construction. Although there is no agreement on what constitutes an “older” home, this work uses a threshold of 1960 because that represents an even 50-year cutoff from the most recent decennial Census year. Data on both older homes and mobile homes are obtained from the U.S. Census Bureau American Community Survey.
- Populations that reside in group quarters, or within households without a vehicle available face challenges in emergency situations. These populations will be difficult to evacuate, or particularly for populations in group quarters, difficult to reach in an emergency situation.
- Evacuation challenges associated with high detour or high traffic bridges were measured by using data from the U.S. Department of Transportation National Bridge Inventory to count the number of bridges in each county with an average daily traffic count of over 5,000 vehicles and a detour length greater than five miles. In addition all bridges with a detour length of over 50 miles were included to allow for those in rural counties where normal traffic is low but which would represent a significant evacuation challenge if closed. This variable was a simple count of such bridges within the county, normalized using the minimum-maximum re-scaling technique.
- The Federal Emergency Management Agency defines high potential loss facilities as those which would have a high loss or impact on the community if significantly damaged.[22] Dams and nuclear

[21] Cutter et al (2010); Cutter et al (2003)

[22] Federal Emergency Management Agency, Summary of Databases in Hazus-Multi Hazard, http://www.fema.gov/summary-databases-hazus-multi-hazard (accessed 7/16/15)

power plants are two such facility types. This index considers potential damage from these facilities by estimating the percentage of population affected should facilities be damaged. From the 2014 National Transportation Atlas, all dams 50 feet or more in height, with a normal storage capacity of 5,000 acre-feet or more, or with a maximum storage capacity of 25,000 acre-feet or more were identified.[23] A five mile radius around each dam was calculated, and the population within each radius was determined based on Census block centroids using data from the 2010 Decennial Census. The population within 5 miles of a dam was aggregated to the county level, and divided by the total population for the indicator value.

- To determine the potential impact of nuclear power plant failure, the percentage of population in each county living within 10 miles of a nuclear facility was calculated. This distance is the evacuation radius determined by the U.S. government.[24] Facility locations were acquired from the U.S. Geological Survey.
- To measure the quality of water supply infrastructure in a county, the percentage of people served by community water systems with at least one health-based violation was calculated.

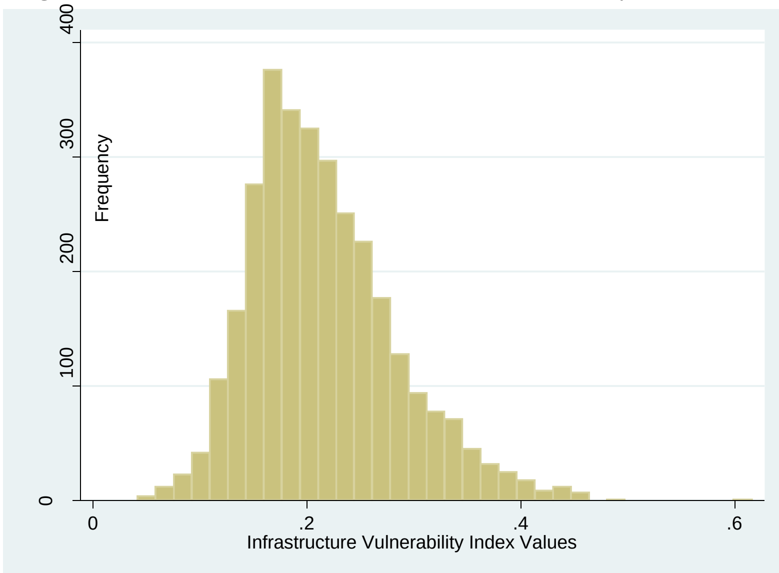
Descriptive statistics for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 14.

Table 14. Infrastructure Vulnerability Index: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
% housing units that are mobile homes	3143	13.1	11.2	9.4	0	63.5	0.32	0.27
% population in group quarters	3143	3.6	2.0	4.5	0	65.9	0.2	0.12
% housing units with no vehicle available	3143	5.4	4.8	3.7	0	67.9	0.32	0.29
% homes built before 1960	3143	31.3	28.8	15.3	1.6	76.9	0.40	0.36
High detour or high traffic bridges	3143	12.4	6	18.7	0	212	0.17	0.09
% population within 5 miles of dam	3143	15.3	4.9	20.6	0	100	0.20	0.06
% population within 10 miles nuclear facility	3143	0.8	0	5.5	0	91.4	0.03	0.00
% population served by water systems w/ violation	3082	9.2	1.1	16.8	0	100	0.09	0.01

[23] National Transportation Atlas Dams Dataset, 2014
[24] The radius likely underestimates the potential damage from a major disaster, given that wind and weather can carry contamination over larger distances. In fact, the U.S. government recommended a 50 mile evacuation zone for Americans living near the Fukushima nuclear disaster.

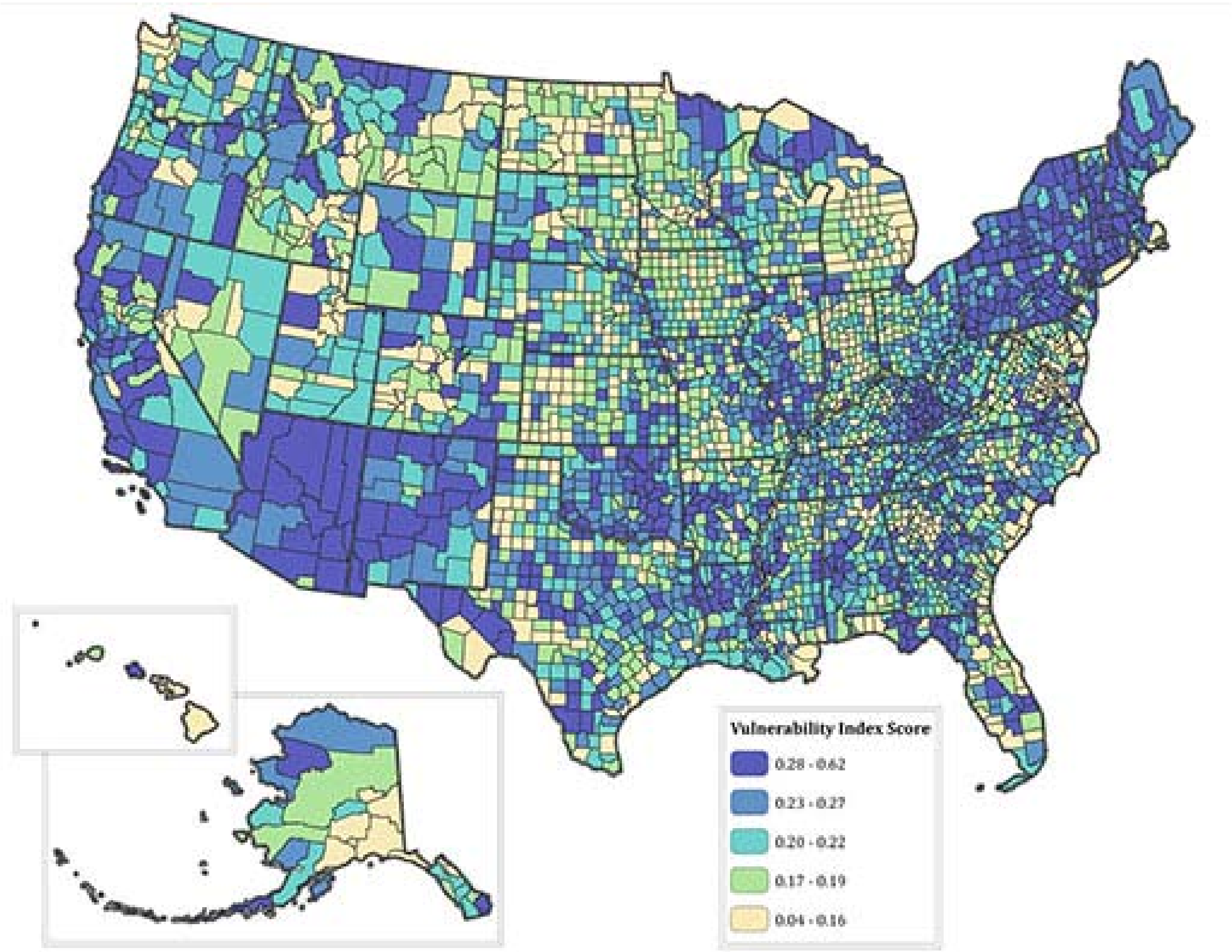
Figure 7. Distribution of Infrastructure Vulnerability Index Score



Non-missing values of the re-scaled indicators were averaged for the infrastructure vulnerability index. The index has a mean value of 0.22, a median value of 0.21, and ranges from 0.04 to 0.62. As shown in Figure 7, the distribution of the mean infrastructure vulnerability score across counties follows a normal distribution with a tail to the right.

Map 8 shows the distribution of infrastructure vulnerability index scores, with values divided in quintiles. Counties shaded in darker colors had higher mean economic vulnerability scores; while those with a pale yellow shade had the lowest vulnerability scores.

Map 8. Infrastructure Vulnerability Index



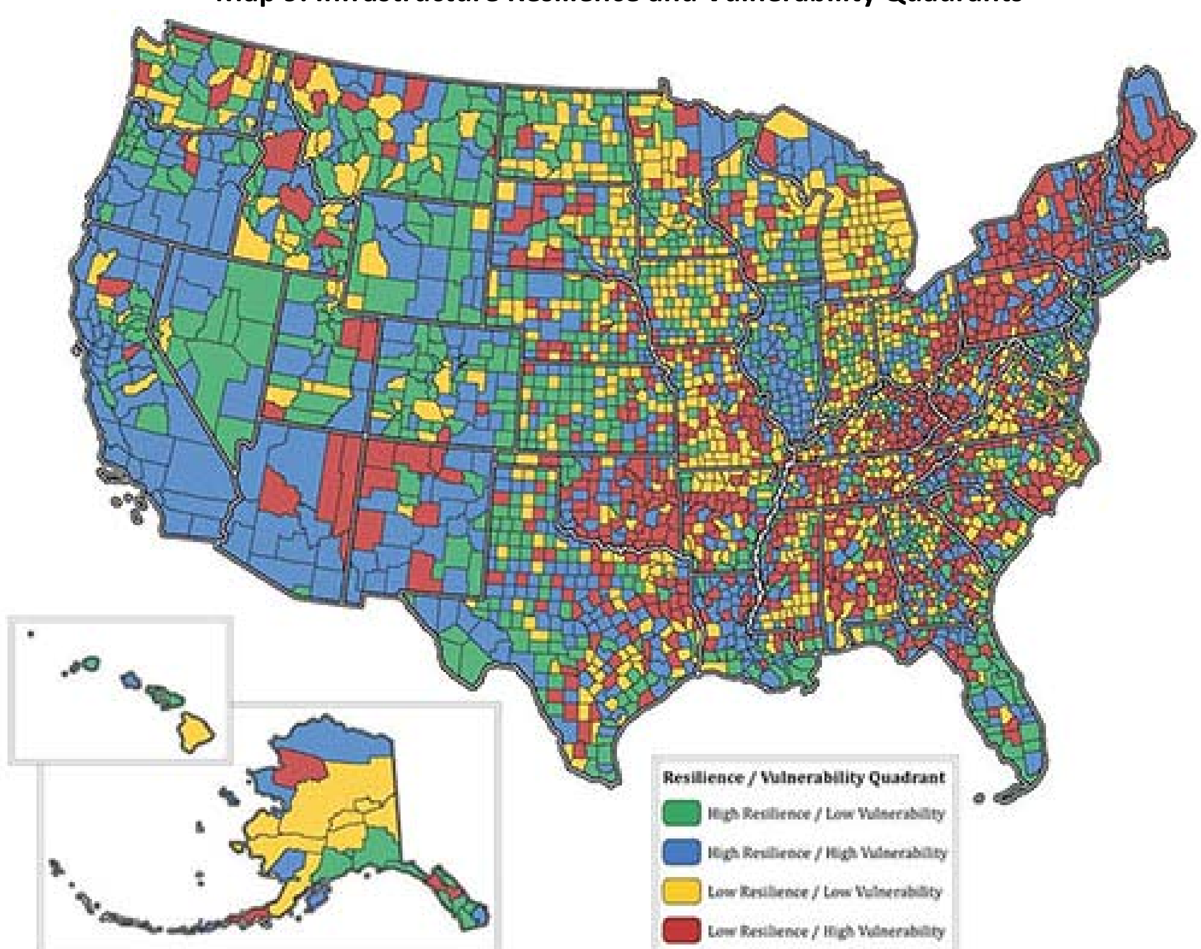
INFRASTRUCTURE RESILIENCE AND VULNERABILITY

The individual infrastructure resilience and vulnerability scores for each county were compared to the median value across all counties. Counties were placed into one of four quadrants, as described in Table 15.

Table 15. Infrastructure Resilience and Vulnerability Quadrants		
Quadrant	**Number of U.S. Counties**	**Percent of U.S. Counties**
High Resilience / Low Vulnerability	744	23.7
High Resilience/ High Vulnerability	828	26.3
Low Resilience/ High Vulnerability	744	23.7
Low Resilience / Low Vulnerability	827	26.3
Total Counties	3,143	100.0

Map 9 shows the spatial distribution of counties across the four quadrants.

Map 9. Infrastructure Resilience and Vulnerability Quadrants



THE ENVIRONMENTAL DIMENSION

ENVIRONMENTAL RESILIENCE

One composite measure of environmental resilience has been used which quantifies the diversity of climate, lithology, land cover, and landform across a county. This measure addresses resource availability and diversity, assuming that more diverse landscapes are better able to rebound from a variety of disaster scenarios. Data are from ESRI's World Ecophysiographic Diversity, 2015 dataset[25], created in partnership with the U.S. Geological Survey's Climate and Land Use Change Program and the Group on Earth Observations. The dataset consists of a 250m grid of the world, created by calculating the number of ecological facets in a 5 x 5 km square surrounding each pixel. Ecological facets are unique combinations of climate[26], lithology[27], land cover[28], and landform[29]. County-level figures represent the mean value of all grid cells within the county boundary, calculated using ESRI's zonal statistics tool.

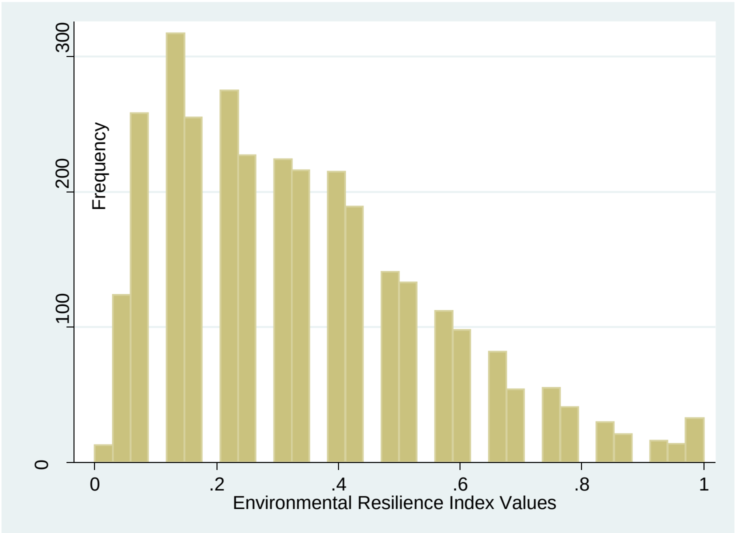
Descriptive statistics for this measure, and the result of the minimum-maximum re-scaling technique are shown in Table 16.

Table 16. Environmental Resilience Index: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
Environmental diversity	3,143	127.2	115	72.8	14	447	0.34	0.30

[25] http://www.aag.org/galleries/default-file/AAG_Global_Ecosyst_bklt72.pdf
[26] Dataset consists of a 37-category rasterization of the earth's "bioclimate" based on temperature (growing degree days) and aridity (precipitation / evapotranspiration).
[27] Dataset consists of a 16-category rasterization of the earth's surface based on the chemical, mineral, and physical properties of rock.
[28] Dataset consists of a 16-category rasterization of the earth's surface based on the major landforms (plains, mountains, hills, etc.) as defined by elevation, slope, and relief.
[29] Dataset consists of a 23-category rasterization of the earth's surface based on land cover (the physical and observable features present at the earth's surface).

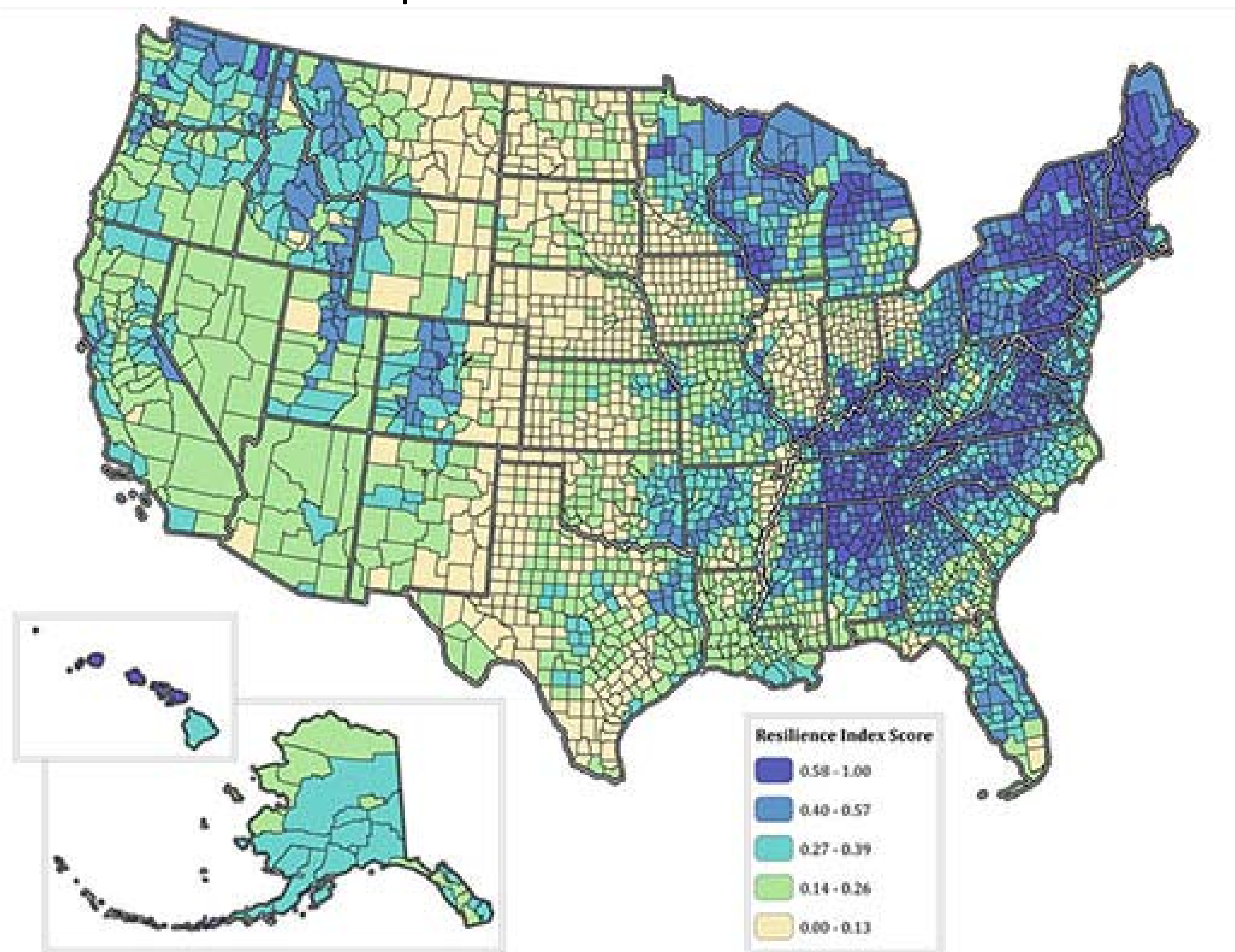
Figure 8. Distribution of Environmental Resilience Index Score



The rescaled environmental diversity variable was utilized to represent the environmental resilience index, so no averaging across multiple indicators was performed. The index ranged from 0 to 1, with a mean of 0.34 and median of 0.30. Within the index, there are many groups of counties with identical values on the diversity score, leading to the distribution shown in Figure 8.

Map 10 shows the distribution of environmental resilience index scores, with values divided into quintiles. Counties shaded in darker colors had higher mean environmental resilience scores, while those with a light yellow shade had the lowest resilience scores.

Map 10. Environmental Resilience Index



ENVIRONMENTAL VULNERABILITY

Measures of environmental vulnerability were selected to capture the range and severity of natural disaster risks faced by counties. Table 17 lists the variables, measures, and data sources used to create the environmental vulnerability index.

Table 17. Environmental Vulnerability Index: Variables, Measures, and Data Sources

Variable	Measure	Data Source
Flood risk	Percentage of population within 2 miles of a levee or within a levee zone	U.S. Army Corps of Engineers, National Levees Database, Dec. 2015
Storm severity	Number of storm events over 15 year period	National Oceanic and Atmospheric Administration, 2000-2014
Range of storm types	Diversity index of storms	National Oceanic and Atmospheric Administration, 2000-2014
Earthquake risk	Population weighted seismic hazard zone score	U.S. Geological Survey, National Seismic Hazard Maps, 2014, 2007, 1998
Drought risk	Percentage of weeks in drought	U.S. Drought Monitor, 2012-2014

- The ideal dataset for measuring flood risk would be FEMA's Flood Insurance Rate Maps (FIRMs); however, FIRMS are currently available only for about 50 percent of U.S. counties. To approximate flood risk, the percentage of population living within a leveed area or within two miles of a levee centerline was calculated. Levee data are from the U.S. Army Corps of Engineers, National Levees Database (accessed December 2015).
- Data from the National Oceanic and Atmospheric Administration's Storm Database were tabulated for the years 2000-2014. These years were chosen in order not to unduly influence the data by extreme events that occurred more than 15 years ago. The dataset is comprised of over 800,000 records, documenting all "storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce", plus additional significant weather events[30]. Storm events are listed as occurring in a county, a public forecast zone (Z) or in a County Warning Area (CWA). Events are categorized into one of 58 event types.
- The first measure calculated from the dataset was a storm frequency index. This calculation aimed to reproduce the data behind the TIME magazine "Safest Counties" report[31]. This was accomplished by selecting out all events meeting certain inclusion criteria[32]. To summarize the resulting 180,000 events, a crosswalk was developed to capture the storms from the database listed as occurring in CWAs or forecast zones, by spatially overlaying CWA and Public Forecast Zone boundaries with current county boundaries.
- The second measure was the storm variation index. This index quantifies the number of different types of storm events occurring in a county. Counties may be particularly vulnerable if

[30] Data regarding multiple severe events within a single episode are provided as separate instances. For example, a hurricane episode may result in entries for severe wind and flooding. Furthermore, additional events are recorded for each geographic area affected by the event.
[31] http://time.com/safest-counties/
[32] Records included were those which were attributed as causing over $2,000 in property or crop damage, or causing direct or indirect personal injury or death.

they have to prepare for more than one type of natural disaster. Shannon's diversity index[33] formula was calculated against the subset of data used in the storm frequency index. Storm events were recoded from 53 event types into 18 event types for this calculation. For example "Heavy Rain", "Lakeshore Flood", "Flash Flood", and "Flood" are all grouped into one "Rain / Flood" category. The formula for Shannon's diversity index (H) follows:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Where

p_i is the proportion of storms in category *i*.

- Seismic hazard risk scores provide an estimate of population-weighted average risk for a county. Data are based on the U.S. Geological Survey (USGS) National Seismic Hazard Maps, which display the maximum earthquake ground motion at a probability level of 2 percent in 50 years. The latest data versions (as of December 2015) were acquired: Lower 48 – 2014; Alaska – 2007; Hawaii – 1998. Seismic hazard risk scores were then mapped and spatially intersected with data from 2010 (POP_{CBG}). The formula used in the calculation can be expressed as:

$$Seizmic\ Hazard\ Score = \frac{\sum \mathrm{PG}_{2p50y} * \mathrm{POP}_{CB}}{\sum \mathrm{POP}_{CB}}$$

Where

PG_{2p50y} is the seismic risk score and POP_{CB} is census block population.

- Drought indicator data are based on analysis of weekly U.S. Drought Monitor shapefiles for 2012, 2013, and 2014. This USDM weekly analysis produces weekly maps of the area of the United States experiencing drought, by drought severity level (*D0 - Abnormally Dry* through *D4 - Exceptional Drought*). 156 weeks of data presented in this format were analyzed by CARES to generate the 3-year average drought statistics used here. Analysis involved intersecting census block group centroids with each of the weekly US Drought Monitor shapefiles. Data are summarized across all 156 datasets at the county level, resulting in indicator values expressing the population-weighted percentage of weeks in drought.

$$Percentage = 100 * \frac{\sum(\text{Weeks at } Dx) * \mathrm{POP}_{CBG}}{\sum 156 * \mathrm{POP}_{CBG}}$$

Where

D_x is the drought severity level and POP_{CBG} is the population of each census block group.

Finally, the percentage of weeks in drought WAS calculated by combining values for D1, D2, D3, and D4.

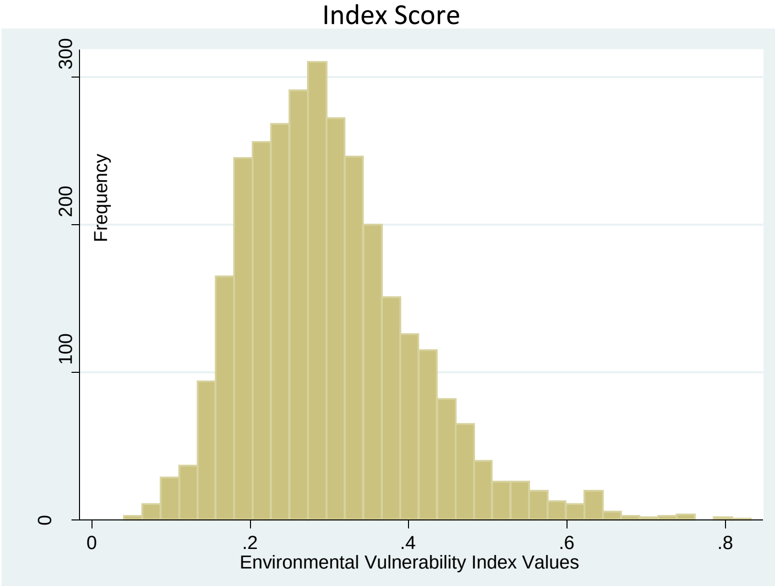
[33] Shannon's index was chosen over Simpson's index as we wanted to account for the total abundance of storms as well as their distribution.

Descriptive data for each measure, and the result of the minimum-maximum re-scaling technique are included in Table 18.

Table 18. Environmental Resilience Index: Descriptive Statistics

Variable	Obs.	Mean	Median	Std. Dev.	Min.	Max.	Mean Rescaled	Median Rescaled
% population w/in 2 miles of a levee	3143	6.4	0	16.7	0	100	0.1	0.0
Count of storm events	3133	56.7	39	60.7	1	796	0.26	0.16
Range of storm types	3133	1.0	1.0	0.3	0	1.8	0.53	0.54
Population weighted seismic hazard zone	3143	11.0	6	14.8	0	160	0.19	0.11
% of weeks in drought	3143	46.0	40.2	28.3	0	100	0.46	0.40

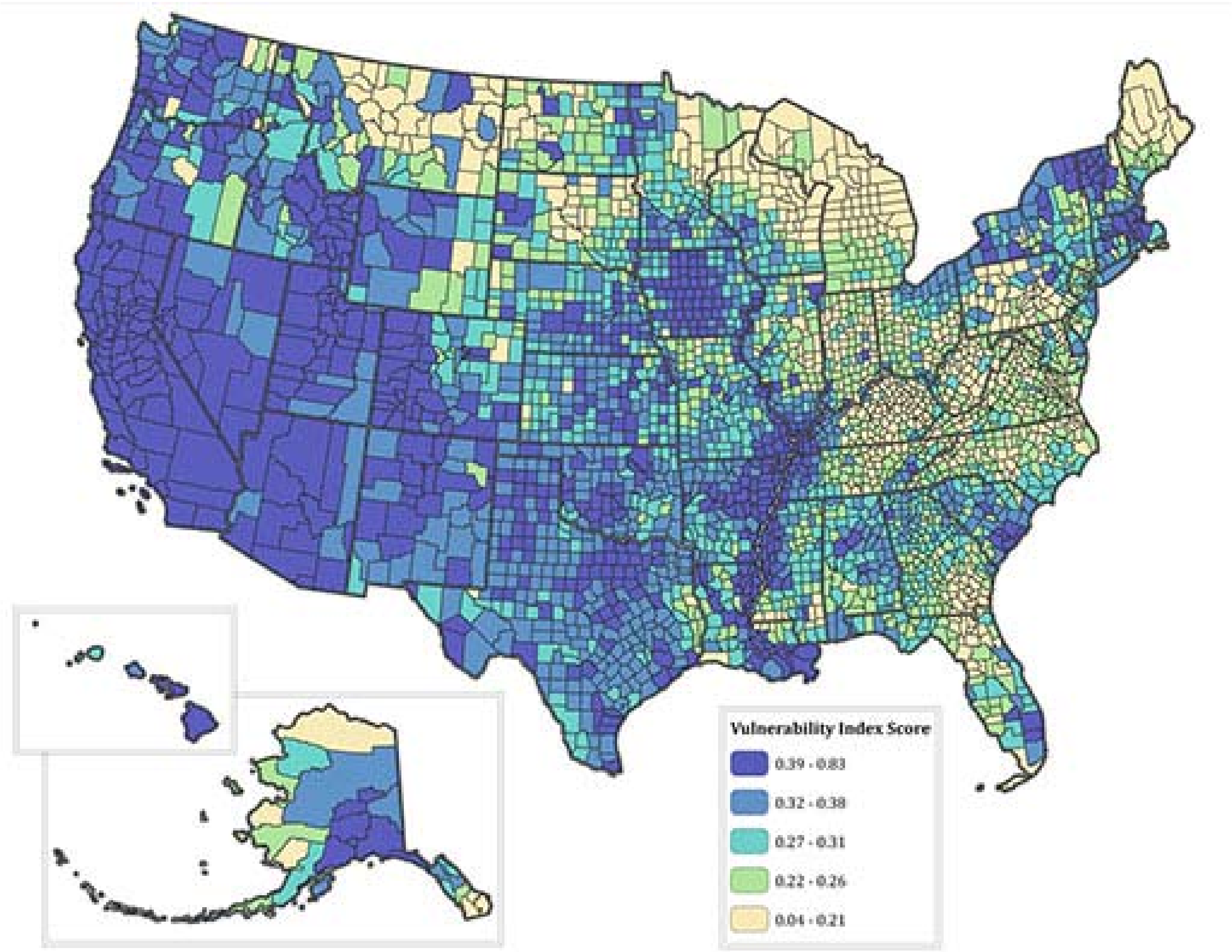
Figure 9. Distribution of Environmental Vulnerability Index Score



Non-missing values were averaged for the environmental vulnerability index. The index ranged from 0.04 to 0.83 with a mean of 0.3 and a median of 0.29, as shown in Figure 9.

Map 11 shows the distribution of environmental vulnerability index scores, with values divided into quintiles. Counties shaded in darker colors had higher mean environmental vulnerability scores, while those with a light yellow shade had the lowest vulnerability scores.

Map 11. Environmental Vulnerability Index



ENVIRONMENTAL RESILIENCE AND VULNERABILITY

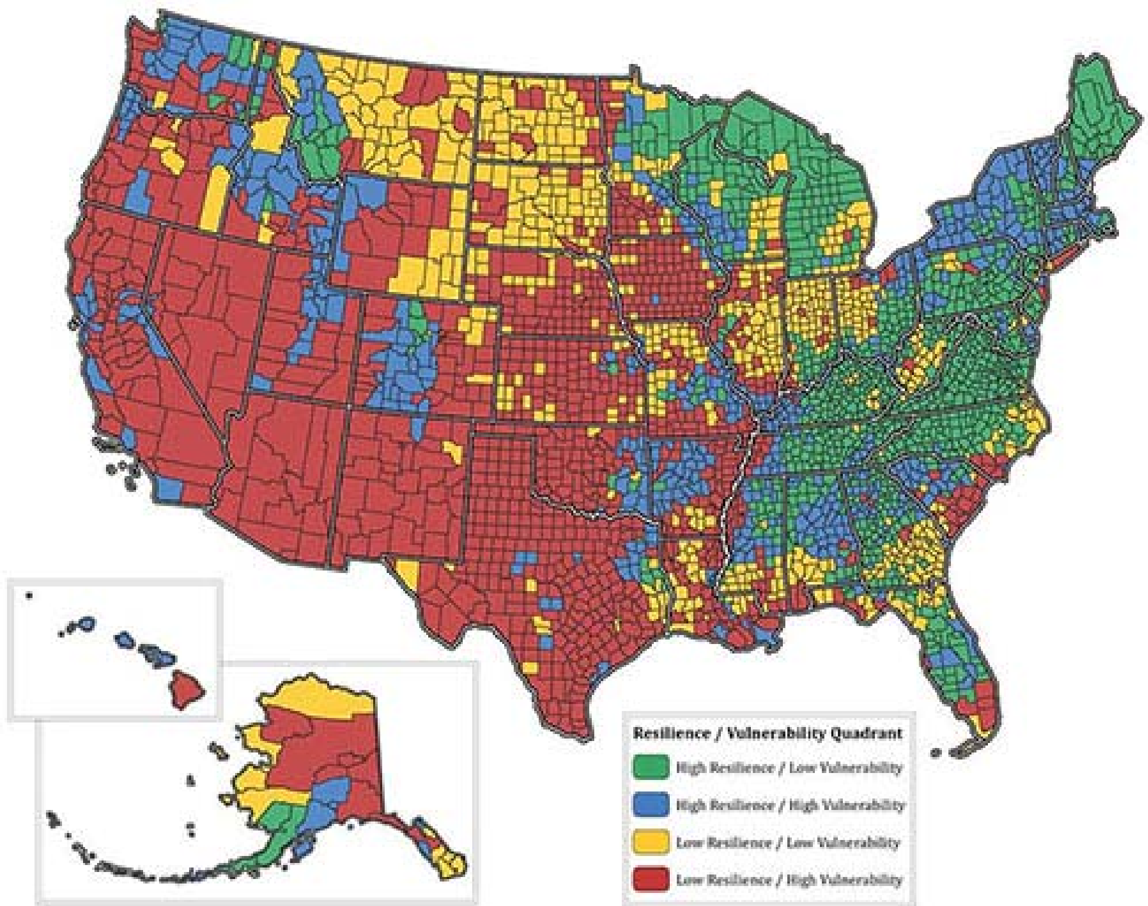
The individual environmental resilience and vulnerability scores for each county were compared to the median value across all counties. Counties were then placed into one of four quadrants, as described in Table 19.

Table 19. Environmental Resilience and Vulnerability Quadrants

Quadrant	Number of U.S. Counties	Percent of U.S. Counties
High Resilience / Low Vulnerability	904	28.8
High Resilience/ High Vulnerability	546	17.4
Low Resilience/ High Vulnerability	1,025	32.6
Low Resilience / Low Vulnerability	668	21.3
Total Counties	3,143	100.0

Map 12 shows the spatial distribution of counties across the four quadrants. Counties that fall into the Low Resilience and High Vulnerability quadrant are particularly vulnerable in terms of their relatively low diversity and susceptibility to environmental threats. These counties tend to be concentrated across the South, Southwest, and the Northwest.

Map 12. Environmental Resilience and Vulnerability Quadrants



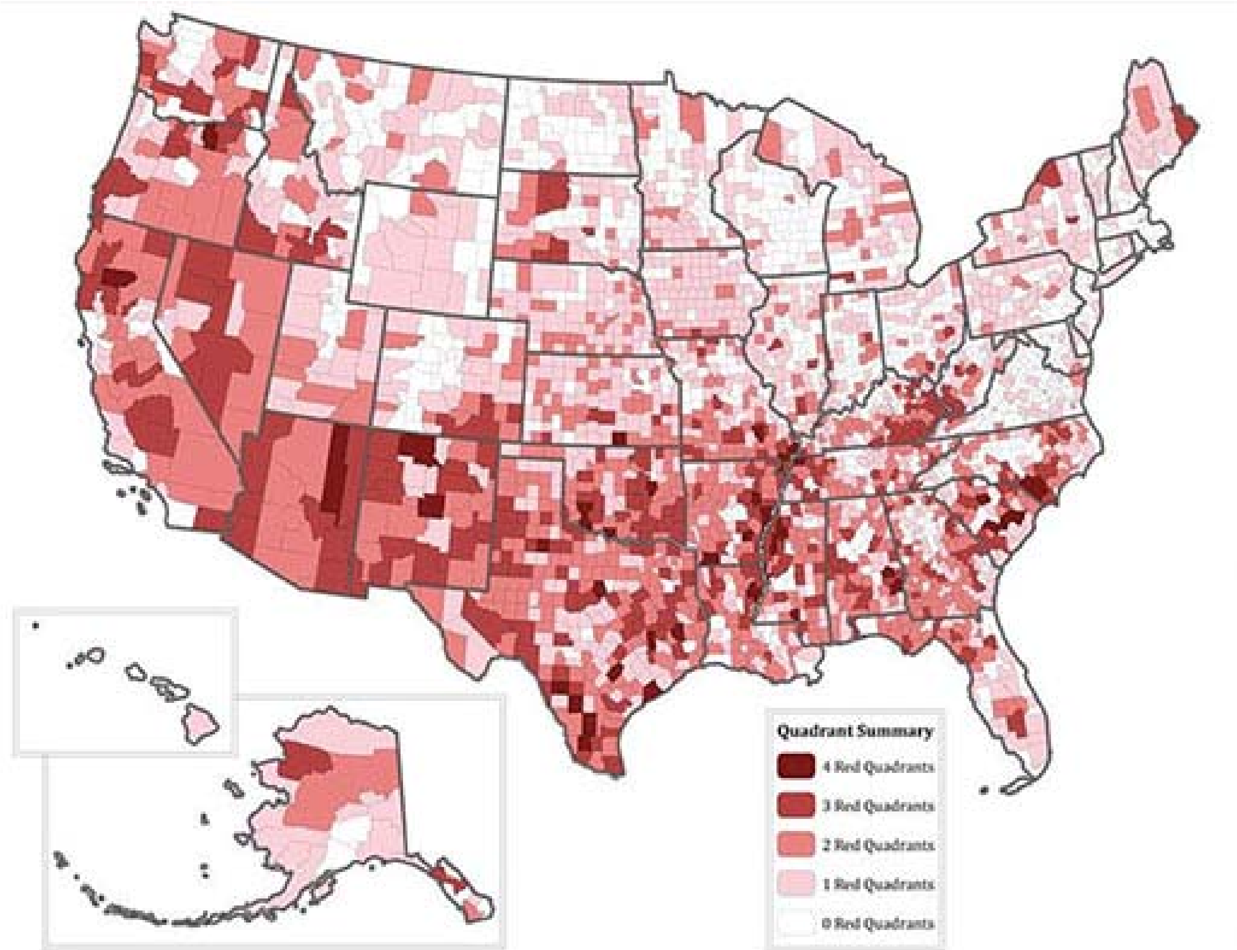
OVERALL RESILIENCE AND VULNERABILITY

Within each of the four categories, counties were divided into four quadrants based on their differences from the mean resilience and vulnerability scores. In order to identify the most vulnerable places, we compared the quadrants across all four categories. The times a county fell within the High Vulnerability/ Low Resilience quadrant was tallied, with values ranging from zero times to four times. Table 20 and Map 13 summarize this tally. Only ten percent of counties fell into the High Vulnerability/Low Resilience Quadrant in three or four of the categories.

Table 21. Tally of Placements in High Vulnerability/Low Resilience Quadrants

Number of placements	Number of U.S. Counties	Percent of U.S. Counties
Zero	1,017	32.4
One	1,077	34.3
Two	716	22.8
Three	302	9.6
Four	31	1.0
Total counties	3,143	100.0

Map 13. Tally of High Vulnerability/Low Resilience Quadrants



COMMENTARY

This paper represents the completion of a two-year development effort by the Institute of Public Policy and the Center for Applied Research & Environmental Systems (CARES) at the University of Missouri. However, this is just an early stage in a much longer process designed to provide communities the capacity and tools to improve their resilience it the face of a range of natural and human-made threats. A series of indexes in of themselves may be interesting but these will only have power if they can inform communities and their leaders to make necessary and wise policy and investment decisions for the long-term.

Within the Missouri EPSCoR project, the next steps will be to explore how these indexes can be applied as part of local and regional planning processes, and whether the results reflect reality on the ground. It can be expected that in due course there will be iterative steps to improve the variables and measures, and perhaps to experiment with different weighting systems.

In the long-term, one possibility might be to use the quadrants as the basis for a universal scoring system that might inform insurance premiums and investment finance rates in ways that reward communities that take substantive and impactful steps to improve their resilience.

Brian Dabson
Columbia, Missouri
May 2016

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APPENDIX: METHODS OF NORMALIZING VARIABLES

INTRODUCTION

This Appendix provides a detailed discussion of the impacts of capping the minimum and maximum values, and compares this technique with the alternative method of using standardized (z) scores. Standardizing each variable is an important first step in the construction of indexes, as variables differ on scales and ranges of values. Standardizing the variables allows the creation of sums and averages that are meaningful comparisons across variables and geographies.

There are two primary ways variables can be standardized. One is to utilize a min-max technique, in which all variables are rescaled to values between zero and one, where zero is assigned to the lowest value in the dataset and one assigned to the greatest value. All rescaled values are positive, and are based on the formula:

$$normalized(x_i) = \frac{x_i - X_{\min}}{X_{\max} - X_{\min}}$$

An alternative method is to use z-scores. A z-score is calculated as the number of standard deviations a value lies from the mean value across all observations. Thus, an observation with a z-score of zero has a value equal to the mean. A z-score of one (1) indicates a variable is one standard deviation greater than the mean, and a z-score of negative one (-1) indicates a variable is one standard deviation less than the mean. Thus, z-scores can be negative or positive, and are based on the formula:

$$z - score(x_i) = \frac{x_i - \overline{x}}{s_x}$$

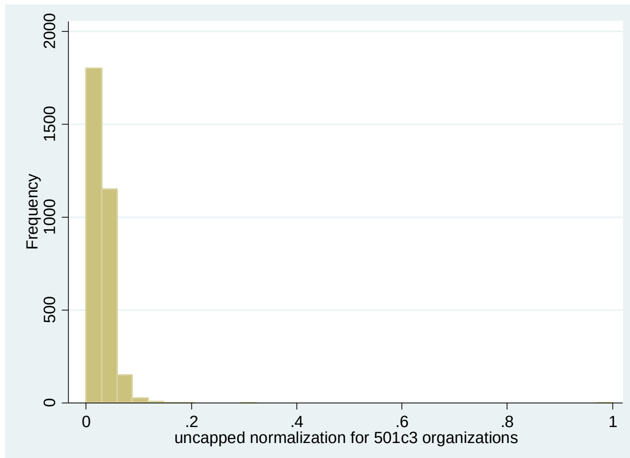
For this paper, the min-max rescaling technique was adopted as it allowed for all values to be positive and thus easier to interpret. In addition, it was decided to cap the minimum and maximum value at three standard deviations from the mean. In a normally distributed dataset, 99 percent of observations should lie within three standard deviations of the mean. Thus, three standard deviations was the selected cutoff to use for capping. This reduced the influence that extreme values had on the distribution of normalized values.

CAPPING

For most of the selected variables, many extremes were observed with values more than three standard deviations away from the mean value. Among the 46 variables included in the analysis, 44 contained observations that were more than three standard deviations above or below the mean value[34]. Without capping, a single extreme value could significantly skew the distributions of these variables, resulting in rescaled values clustered near 0. These uncapped scores might suggest that a majority of counties had low resilience (or vulnerability, depending on the indicator), and only a handful of counties – or occasionally a single county – had high resilience (or vulnerability). Capping had the effect of stretching out these clustered values while maintaining a 0 to 1 range. This modification did very little to affect the ranking of individual counties *within* a single indicator; however, rankings for the aggregated resilience

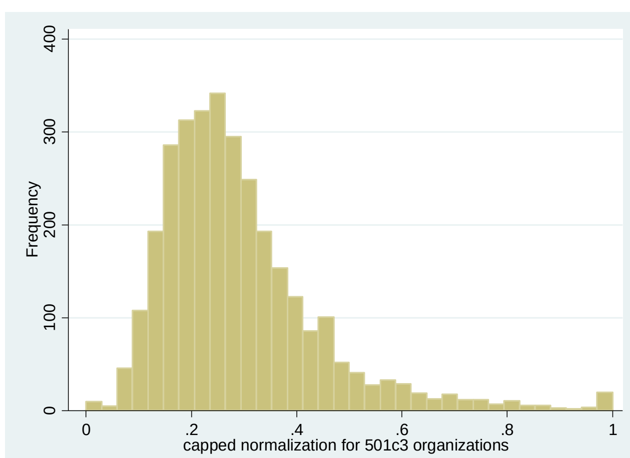
[34] Social – 16 of 16 variables; Economic – 9 of 9 variables; Infrastructure – 14 of 15 variables; Environment – 5 of 6 variables

or vulnerability indexes changed significantly. This suggested that stretching allowed previously clustered values to be redistributed across the 0 to 1 spectrum, thus influencing the outcome. For example, one variable within the social resilience index measured the number of 501(c)(3) organizations per capita in the county. The county-level data ranged from 0 to over 13,000, with a mean of 404 and a standard deviation of 320. There were 20 counties in which the rate of 501(c)(3) organizations fell more than three standard deviations from the mean. Therefore, the minimum-maximum rescaling technique for this variable produced a skewed distribution:



Without capping, the mean of the scaled variable was 0.03 with a median of 0.02. The rescaled variable ranged from zero to one, but the great majority of observations were very small (less than 0.02). By capping the distribution at three standard deviations, any observation that was more than three standard deviations above the mean was coded to equal 1, and those that were more than three standard deviations below the mean were coded to equal 0. The range utilized in calculating the scaled variable was set to equal the range between three standard deviations below and above the mean, in cases where there were observations in that range.

The figure below displays the distribution of the same rescaled variable, this time capping the maximum value at three standard deviations from the mean. The resultant scaled variable had a much more normal distribution. The mean of the capped variable was 0.29, and the median of 0.26.

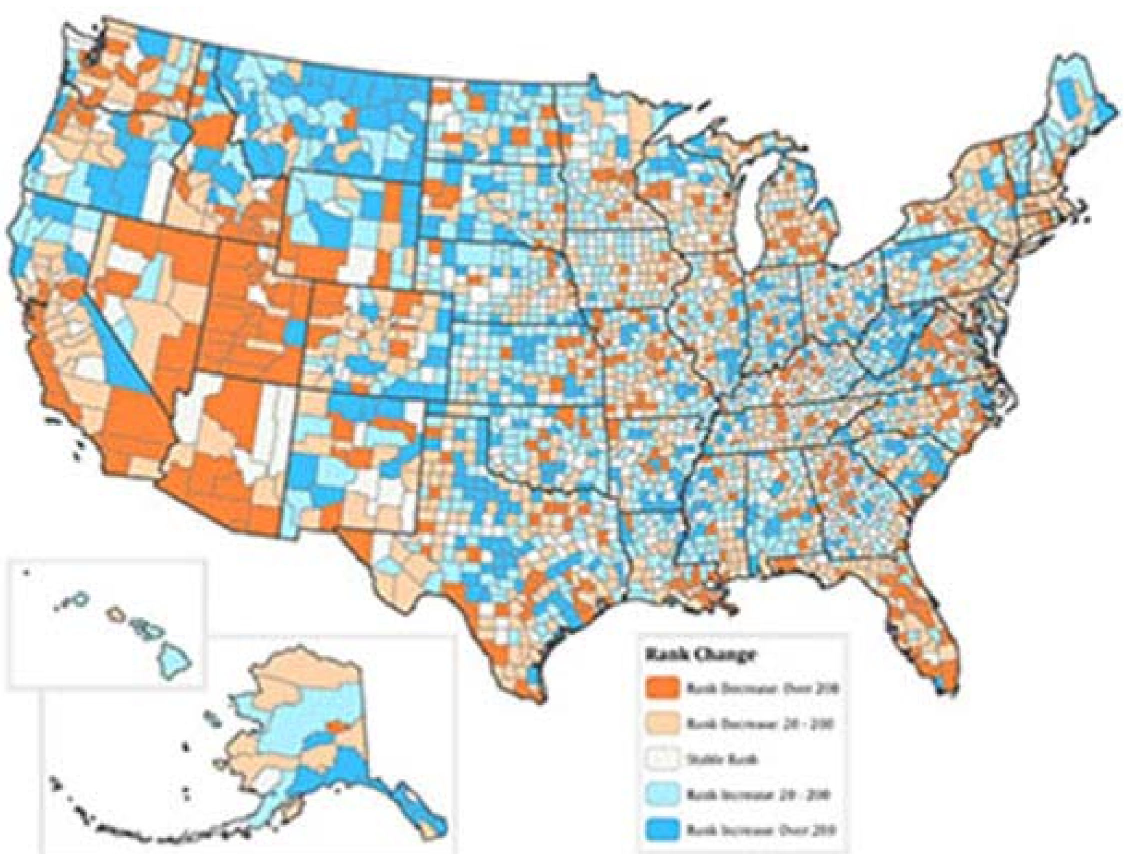


Capping still allowed extreme values to influence the distribution – there was still some apparent skew in the adjusted distribution. However, the distribution is more compatible with other indicators. Table A-1 displays a comparison of capped vs. uncapped values for a single variable, and for the social resilience index.

Table A-1 Comparison of capped and uncapped values		
Variable	**Min-Max, No Caps**	**Min-Max, Capped**
501c3 per Capita, Mean	0.03	0.29
501c3 per Capita, Median	0.03	0.26
Social Resilience Index, Mean	0.43	0.45
Social Resilience Index, Median	0.43	0.45

Map A-1 shows a comparison of capped vs. uncapped social resilience indexes. Values presented are the change in national rank when capping is removed.

Map A-1. Rank Change Between Capped and Uncapped Social Resilience Indexes



Z-SCORES

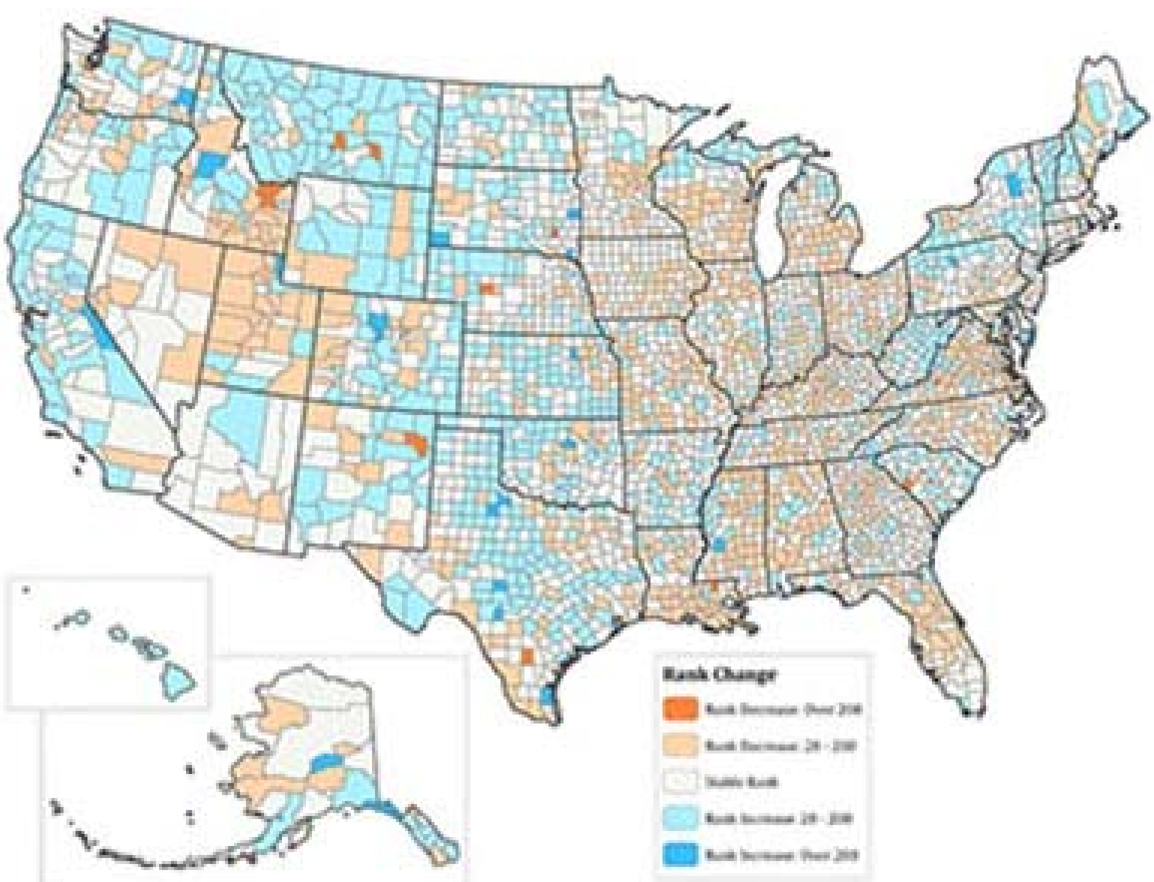
The alternative method to min-max rescaling is to use standardized z-scores, as described above. A comparison of the 501c3 organization data scaled by using z-scores is summarized in the table below.

Table A-2 Comparison of min-max rescaling and z-score standardization

Variable	Z-Score	Min-Max, Capped
501c3 per Capita, Mean	-0.02	0.29
501c3 per Capita, Median	-0.15	0.26
Social Resilience Index, Mean	0.00	0.45
Social Resilience Index, Median	-0.02	0.45

Map A-2 shows a comparison of social resilience indexes created using min-max rescaling vs. z-score rescaling methods. Values presented are the change in national rank when z-score is added (min-max rank minus z-score rank).

Map A-2 Rank Change Between Min-Max and Z-Score Rescaling Methods for Social Resilience Indexes



Finally, Table A-3 displays the frequency of counties falling in the 5 rank-change bins across the two mapped comparison methods.

Table A-3 Comparison of Social Resilience Index (Ranks)
Capped Min-Max Index vs. Uncapped Min-Max and Z-Score

Bin	Min-Max Uncapped	Z-Score
Rank Decrease: Over 200	453	12
Rank Decrease: 20 - 200	979	1139
Stable Rank (+/-20)	329	1068
Rank Decrease: 20 - 200	941	891
Increase: Over 200	441	33

The maps and table reveal that there is generally a large difference between final ranks between the chosen rescaling method (min-max with caps) and the uncapped min-max method. Comparatively, the difference between the final ranks of the capped min-max index and the z-score index are generally small. This suggests that the capping approach creates a distribution across the indexes that is more similar to the z-score approach, with the added benefit of maintaining a positive, 0-to-1 variable.

There is some geographic pattern to the shift in index values, however, this pattern does not hold across all of the resilience and vulnerability index dimensions as it is a product of the individual variables. In other words, the geographic concentration of extreme high or low values in one or more variables causes shifts in the index values when applying different rescaling methods.

A closer look at the rank changes across the social resilience indexes, for example, reveals that rank decreases in Utah can be explained primarily by the stretching of values for the Associations per Capita variable. Utah has some of the lowest rates of associations per capita, but before stretching, values for counties in many states clustered near zero. The rescaled values for this indicator kept Utah counties positioned consistently near 0, while increasing the values for counties in other states. In Florida, the same effect can be observed in the educational attainment variable. Rank increases in West Virginia, Montana and in Plains state counties can be explained by the stretching of the rescaled place attachment variables – percentage owner occupied and percentage living in the same county.

In conclusion, while each method results in ranking variations across the indexes, the capped min-max rescaling method provided a consistent approach to measuring relative resilience and vulnerability across the four dimensions, while minimizing the influence of extreme observations. The technique also gave values that were always positive, allowing for easier interpretation.