

Social Vulnerability Algorithms*

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* This document discusses and provides detail instructions for the creation of social vulnerability mapping products that were implemented into the Mid-American Earthquake Center's MAEViz program focusing on Shelby County, Tennessee. Originally this document was accompanied by a power point with example maps. This documents integrates the power point directly into the original document. This work was supported by the Mid-American Earthquake Center with funding from the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation or the Mid-American Earthquake Center.

Suggested Reference: Lu, J.C., W.G. Peacock, and Y. Zhang (2007) *Social Vulnerability Algorithms*. Hazard Reduction and Recovery Center, Texas A&M University. HRRC Reports: 07-02R. ([hrrc.arch.tamu.edu/publications/research reports/07-02R Social Vulnerability Algorithms.pdf](http://hrrc.arch.tamu.edu/publications/research%20reports/07-02R%20Social%20Vulnerability%20Algorithms.pdf))

Social Vulnerability Algorithms

Research on the impact of natural disasters, such as earthquakes, has consistently found that a complete understand of impacts requires not only understanding the physical vulnerabilities of the build and physical environment, but also understanding the social vulnerabilities of the population. For example, research has generally shown that the elderly, children, female-headed households, the poor and minorities have greater difficulty preparing for, coping with, and recovering from natural disasters. These populations are often termed socially vulnerable because social factors shape their vulnerability. It is important for emergency managers, planners, concerned community organizations and policy makers to identify areas within their communities where socially vulnerable populations are concentrated, particularly if these areas are also physically vulnerable (i.e., due to high concentrations of unreinforced structures, liquefaction zones, fault lines, etc), so that targeted mitigation planning policies and emergency response planning can be undertaken. By highlighting the vulnerable, policy makers can take actions to mitigate disaster impacts prior an event, reduce disorder during the emergency and response stages, and potentially enhance the restoration and recovery phase.

The goal of developing social vulnerability algorithms and maps is to develop a tool set of options to assist policy makers and planners to identify areas with high concentration of socially vulnerable populations within their community. The following outlines methods for using public data (U.S. Census and National Land Cover Data) and GIS to map the spatial distributions of social vulnerabilities. Specifically the following describes the creation of 11 primary or first order social vulnerability layers, 4 secondary or second order social vulnerability tools indicating areas likely to have high child care needs, elder care needs, transportation needs and temporary shelter and housing recovery needs, and a final layer that combines the base layers to form a social vulnerability hotspot analysis. These data can be filtered using the National Land Cover Data to provide maps that provide a clearer spatial representation for where these vulnerable populations are located. Furthermore the data can be weighted by population density to enhance those areas with higher concentrations of vulnerable populations within a county. The user should be able to decide how these tools are displayed using these filtering and weighting options.

I. Base data requirements: there are two base data requirements: US Census data and the National Land Cover Data (NLCD).

1. **Census data, at block group level:** There are a variety of levels of aggregation that might be utilized for this analysis including census blocks, block group, tracts, etc. We are recommending that block-group data be utilized since they provides more detailed population information than the block level and yet is a smaller geographic/areal units than census tracts which should facilitate planning within local communities and counties. The following are the data needed for the social vulnerability algorithms. These are provided in the excel spreadsheet for Shelby County (they originally were generated by Steve French's group).

Variable name	Variable definition
• TOTPOP	→ Total Population
• P_WHITE	→ Total Population -- Whites Alone
• PM_0_17	→ Total Male Population less than 17 years
• PM_65P	→ Total Male Population above 65 years
• PF_0_17	→ Total Female Population less than 17 years

- PF_65P → Total Female Population above 65 years
- TOT_WORK → Total Workers above 16 years
- W_PUB_T → No. of Workers who took Public Transportation to work
- AGG_PTTM → Aggregate Travel Time to work by Public Transportation in minutes
- P_16PYR → Total Population over 16 years
- M_INLF → Males over 16 years in Labor Force
- M_UNEMP → Male over 16 years -- Unemployed
- F_INLF → Females over 16 years in Labor Force
- F_UNEMP → Female over 16 years -- Unemployed
- PRCAPINC → Per capita Income in dollars
- P_UPOV → Total No. of Persons below Poverty Level
- P17_UPOV → No. of Persons under 17 years below Poverty Level
- P65_UPOV → No. of Persons above 65 years below Poverty Level
- TOT_HU → Total Housing Units
- H_OCC → No. of Occupied Housing Units
- H_VAC → No. of Vacant Housing Units
- H_RNT → No. of Renter-occupied Housing Units
- FHF → No. of Female Householder, no Husband Present

2. **National Land Cover Data (NLCD) 2001:** These data are necessary for the “filtering” of the social vulnerability maps so they can help visualize areas within census block groups more likely to have population concentrations.

- Web site: http://www.mrlc.gov/mrlc2k_nlcd.asp
- FTP site:
<http://www.mrlc.gov/scripts/mapserv.exe?map=d%3A%5Cinetpub%5Cwwwroot%5Clicp%5Cmrlc2k%5Czones%5Czones.map>
- A variety of land coverage designations are delineated in the NLCD. A complete listing of the land use codes is in Appendix A. In order to filter the mapping tools we are suggesting that two possibilities discussed below. In general for filtering purposes the areas of particular interest are those that could be termed “Developed Areas” that have the following codes: 21 (open space), 22 (low intensity), 23 (medium intensity), and 24 (high intensity).
- Cell size: 30-meter
- These data have been provided for Shelby County.

II. Social vulnerability maps and algorithms: The following table displays the social vulnerability maps that will be created following the algorithms discussed below. The primary or first order social vulnerability maps display various social characteristics that have been found by social scientists to be associated with social vulnerability. There will be 11 different characteristics mapped by this analysis. These can be particularly useful for planners seeking to target particular populations and programs seeking to promote hazard mitigation and preparation with a community. The second order measures, combine first order measures into 4 different measures reflecting areas likely to need including child and elder care, transportation, and temporary/long-term housing needs. The final or 3rd order social vulnerability measure combines the second order measures into a global social vulnerability hot-spot analysis. The latter can be used to get an overall picture of where populations with high levels of social vulnerability are concentrated within a community.

Social Vulnerability		
1 st order	2 nd Order	3 rd Order
1.1. Poverty (% persons below poverty)	2.1 Potential child care needs	3.1 Vulnerability Hot-Spot Projection
1.2 Female Headed Households (% female Headed households)		
1.3 Children (% persons below 17)		
1.4 Elders (% persons above 65)	2.2 Elder care needs	
1.5 Elder Poverty (% Elders below poverty level)		
1.6 Public Transportation dependency (% workers using Public Transportation)	2.3 Public transportation needs	
1.7. Travel Time (Aggregate travel time by Public Transportation /Total Pop.)		
1.8 Unemployment (% unemployed over 16)	2.4 Temporary Shelter and Housing Recovery needs	
1.9 Renters (% renters)		
1.10 Minorities (% non-White)		
1.11 Income (Per capita income)		

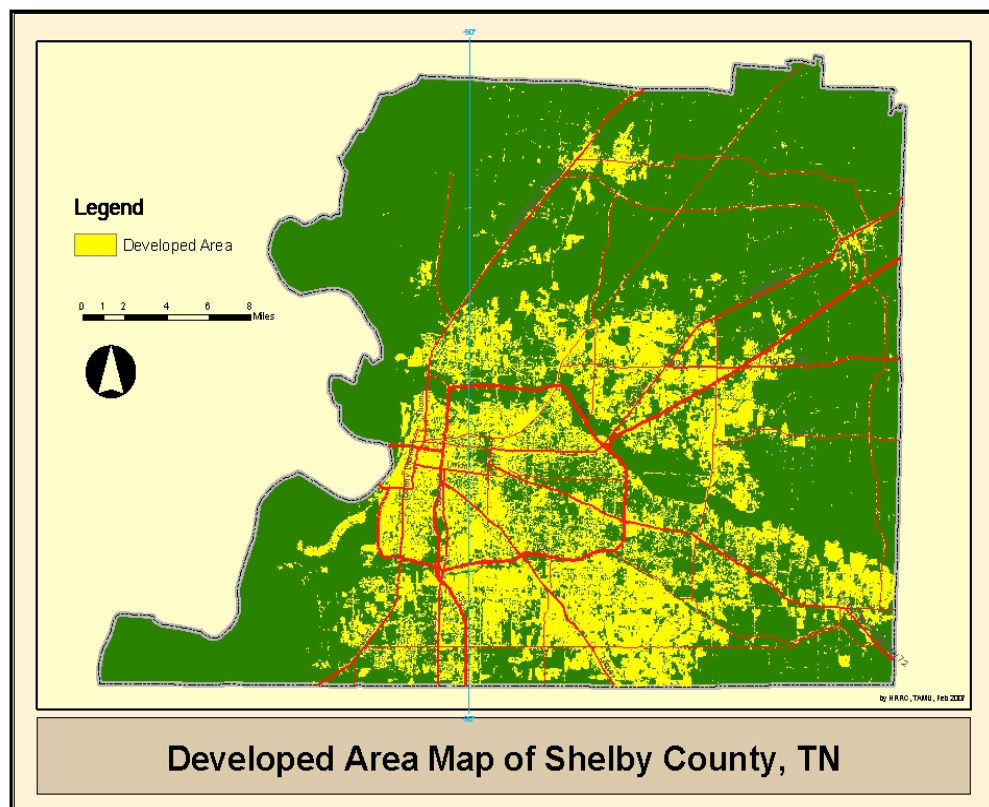


Figure 1: Special Developed Areas in Shelby County

III. Process for creating social vulnerability maps:

1. **Extract the developed area from National Land Cover Data 2001 for map filtering.** The filtering should be based on “developed” areas, which are more likely to include the actual residential locations of vulnerable populations. (See Appendix A for a listing of NLCD designations) The NLCD designates 4 “developed” classifications: 21 (open space), 22 (low

intensity), 23 (medium intensity), and 24 (high intensity). The potentially problematic developed area designation is “open space” areas since they may not actually include many residential areas. We are therefore suggesting that MaeViz may want to allow for the user to specify whether “open space” areas are included in the filtering for developed areas or not. Hence we are designating two possible filters, one based on “special developed areas” versus “general developed areas.” Special developed areas should be the default (probably preferred) option. The definitions are:

- **Special developed areas:** 22 (low intensity), 23 (medium intensity), and 24 (high intensity). Special developed areas are applied here. An example of this classification is presented in Figure 1.
- **General developed areas:** 21 (open space), 22 (low intensity), 23 (medium intensity), and 24 (high intensity)
- For filtering purposes all land cover codes are recoded with the values for special/general developed areas equaling “1”, other areas to “no data”.

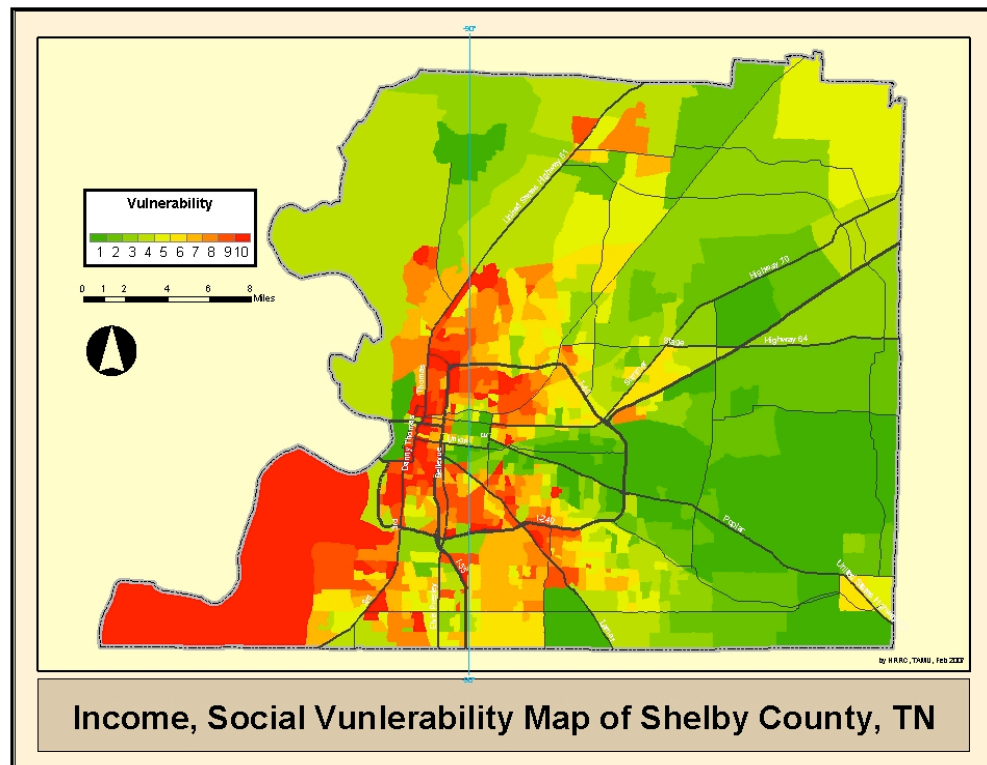


Figure 2. Standard 1st Order Social Vulnerability Map for Median Household Income Using Block Group Data

2. 1st order maps: First order social vulnerability maps for each of the 11 dimensions are generated by the following steps:

2.1 Calculate new variables for the 1st order variables

- Poverty (i_poverty) = $P_{upov} / Totpop$
- Female Headed Households (i_femhh) = Fhf / Tot_hh
- Children (i_child) = $(Pm_0_17 + Pf_0_17) / Totpop$
- Elders (i_elder) = $(PM_65p + Pf_65p) / Totpop$
- Elder Poverty (i_elderpov) = $P65_upov / (PM_65p + Pf_65p)$
- Pub. Transportation dep. (i_pubtrans) = W_pub_t / Tot_work

- Travel Time (i_ptanst) = $\text{Agg_pttm} / \text{Tot_work}$
- Unemployed (i_unempl) = $(\text{M_unemp} + \text{F_unemp}) / (\text{M_inlf} + \text{F_inlf})$
- Renters (i_renter) = $\text{H_rnt} / \text{H_occ}$
- Race/Ethnicity (i_minority) = $(\text{Totpop} - \text{P_white}) / \text{Totpop}$
- Income (i_income) = $108571 (\text{the maximum of Prcapinc}) - \text{Prcapinc}$

2.2 Rank and classify 1st order variables (i_poverty etc.) by decile. In other words, each of the first order variables for the block groups within a county are ranked and broken into deciles. Each block group is then given the decile ranking (1-10) on each of the first order variables. (In the future other procedures for ranking these variables can be developed such as ranking by quartile, quintile or some other transformation).

- New variables indicating the decile ranking of each block group on each first order variable should be designated as follows (see Appendix 2 for a detailed listing):
de_poverty de_femhh de_child de_elder de_elderpv
de_pubtran de_ptanst de_unempl de_renter de_minority de_income
- The higher the decile ranking, the more socially vulnerable the population in the block group: 1 is the least vulnerable and 10 is the most vulnerable.

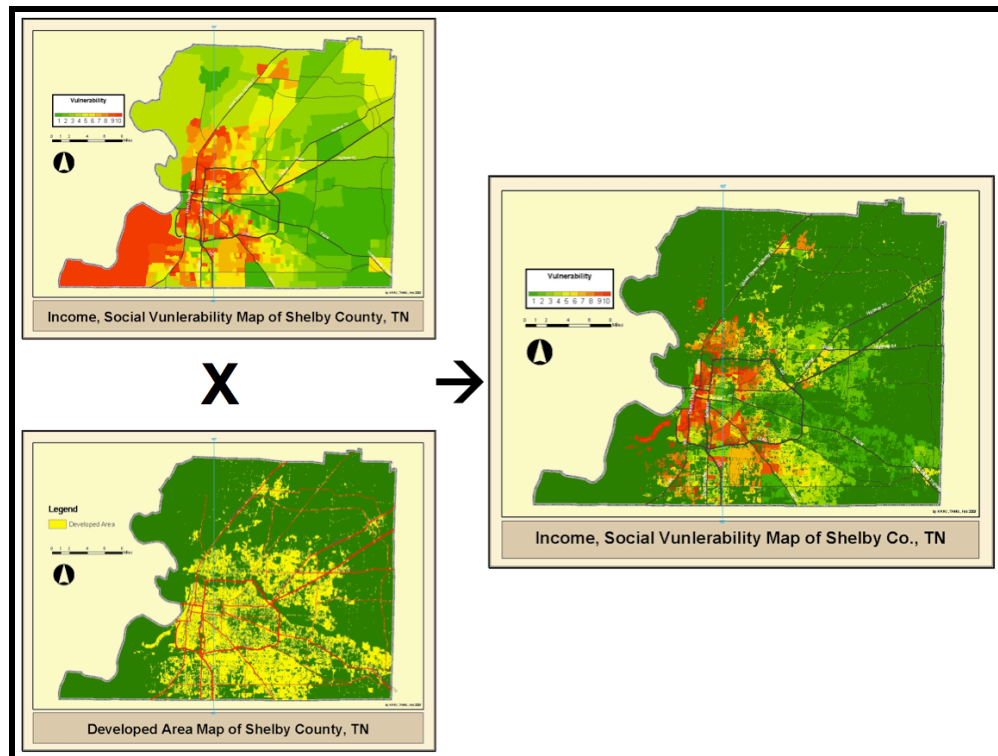


Figure 3. Filtering the SV Map Based on Special Development Data.

2.3 Create the 1st order maps

- Convert the vector maps of 1st order variables to raster maps (use the same spatial resolution as NLCD 2001). Figure 3 provides a graphic depiction for combining the social vulnerability data (in this case per-capita income) for how the two data are combined to create a first order map.
- Use map algorithm to create refined social vulnerability maps.
1st order map = Raster map of 1st order variable * developed area map (created from #1).
Figures 4 and 5 are examples of these maps and more are presented in Appendix 3.

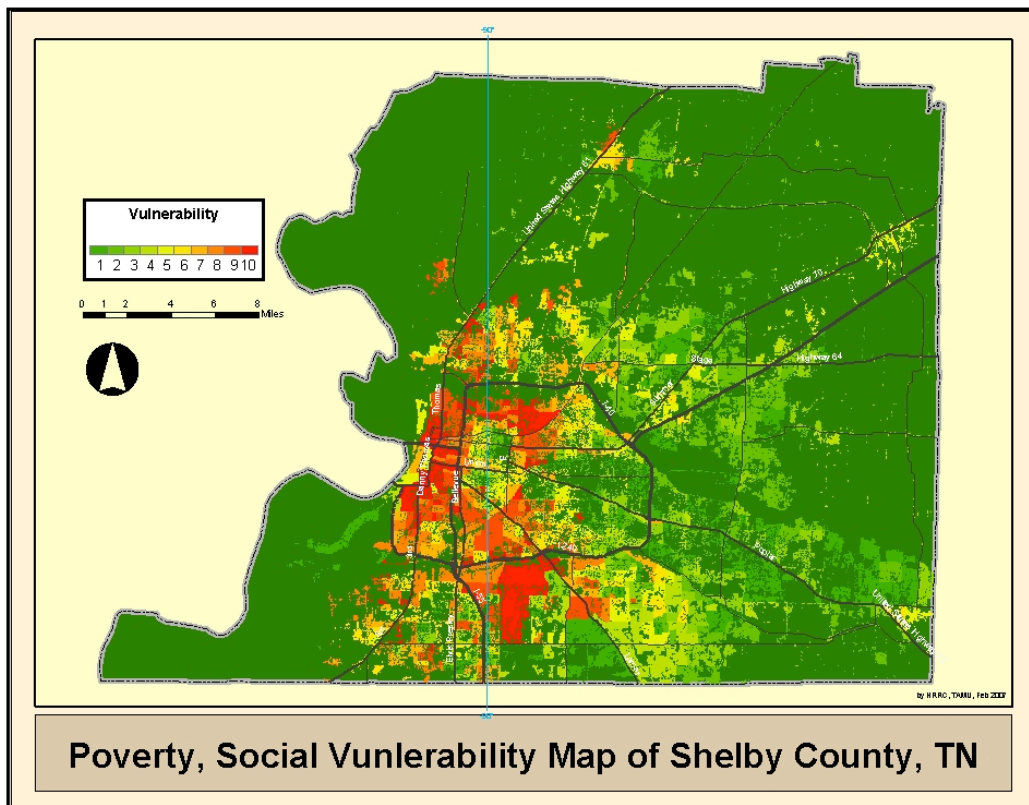


Figure 4. Poverty Social Vulnerability for Shelby County

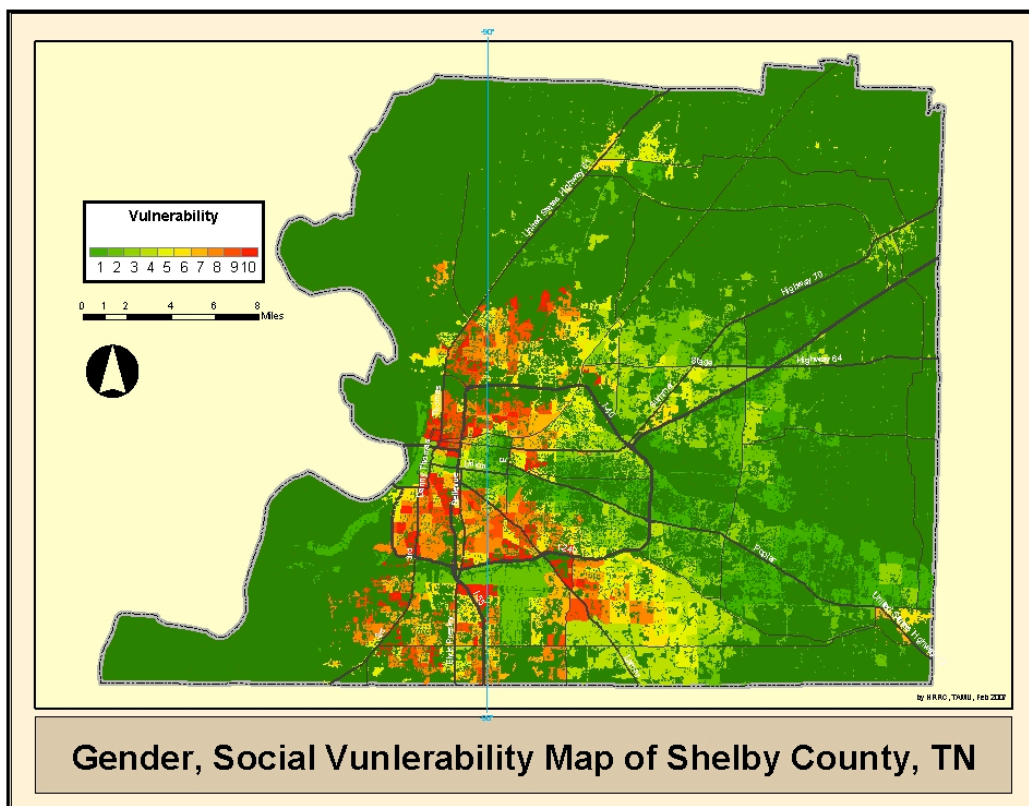


Figure 5. Female Headed Households Social Vulnerability Map for Shelby County

3. Weighted 1st order maps: The following steps are necessary to create weighted versions of the 1st order social vulnerability maps. These should be an optional display for the user.

3.1 Calculate population density and weighted values

- Count the number of developed area cell within each block group (new variable: cellnum, by using zonal statistic).
- Calculate population densities: $\text{pop_dens} = \text{Totpop} / (\text{cellnum} * 0.03 * 0.03)$
- New weighted variables (note: 12705.76 is the maximum of pop_dens for other counties in the United States this will have to be determined and entered into formulas below):
 - $w_poverty = i_poverty * 100 * \text{pop_dens} / 12705.76$
 - $w_femhh = i_femhh * 100 * \text{pop_dens} / 12705.76$
 - $w_child = i_child * 100 * \text{pop_dens} / 12705.76$
 - $w_elder = i_elder * 100 * \text{pop_dens} / 12705.76$
 - $w_elderpov = i_elderpov * 100 * \text{pop_dens} / 12705.76$
 - $w_pubtrans = i_pubtrans * 100 * \text{pop_dens} / 12705.76$
 - $w_ptranst = i_ptranst * 100 * \text{pop_dens} / 12705.76$
 - $w_unempl = i_unempl * 100 * \text{pop_dens} / 12705.76$
 - $w_renter = i_renter * 100 * \text{pop_dens} / 12705.76$
 - $w_minoirty = i_minoirty * 100 * \text{pop_dens} / 12705.76$
 - $w_income = i_income * 100 * \text{pop_dens} / 12705.76$

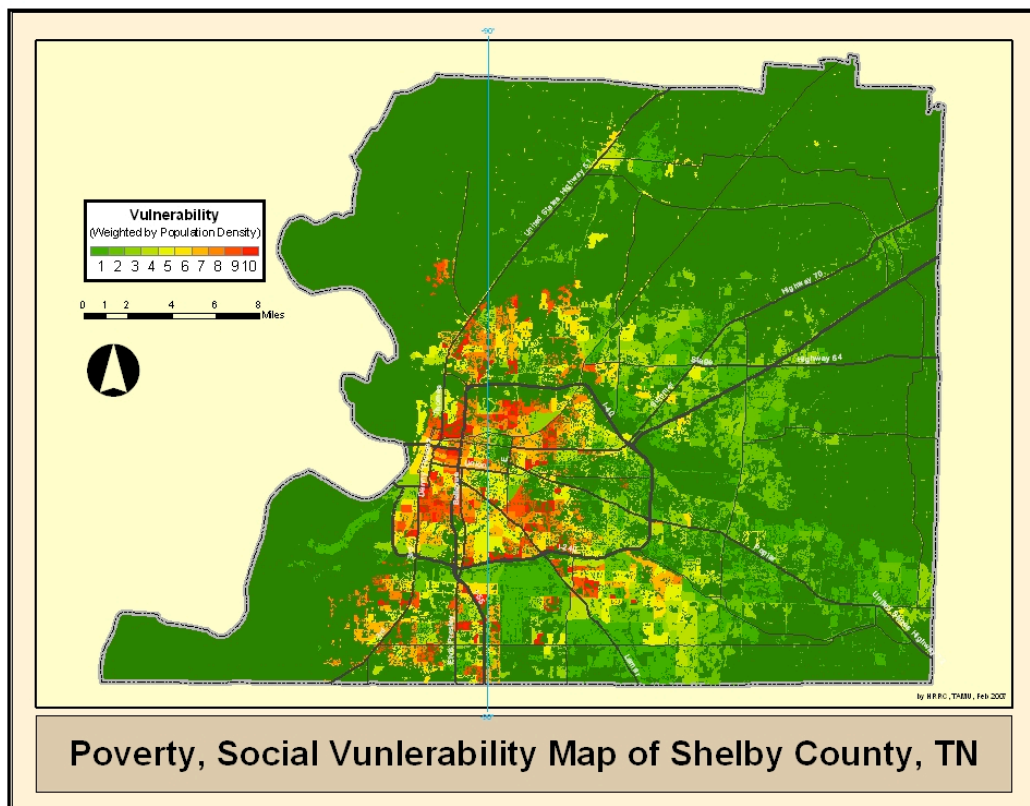


Figure 6. Weighted Poverty Social Vulnerability

3.2 Rank and classify weighted 1st order variables (w_poverty etc.) by decile. This classification can also be done by quartile or quintile.

- Higher the values of variables, higher the vulnerabilities. 1 is the least vulnerable, and 10 is the most vulnerable.
- New weighted ranking variables (Again see Appendix 2 for a complete listing):
 wd_poverty wd_femhh wd_child wd_elder wd_elderpo
 wd_pubtran wd_ptanst wd_unempl wd_renter wd_minority
 wd_income

3.3 Create the weighted 1st order maps

- Convert the vector maps of weighted 1st order variables to raster maps (use the same spatial resolution as NLCD 2001).
- Use map algorithm to create refined social vulnerability maps. Weighted 1st order map = Raster map of weighted 1st order variable * developed area map (created from #1). Figure 6 presents the weighted poverty social vulnerability map for Shelby County. A comparison of this map, with the unweighted version in Figure 4 suggests that higher concentrations of poverty are seen within the loop and urban areas of central Memphis, as well as some block groups southwest of the urban core. Other examples of weighted maps can be found in Appendix 4.

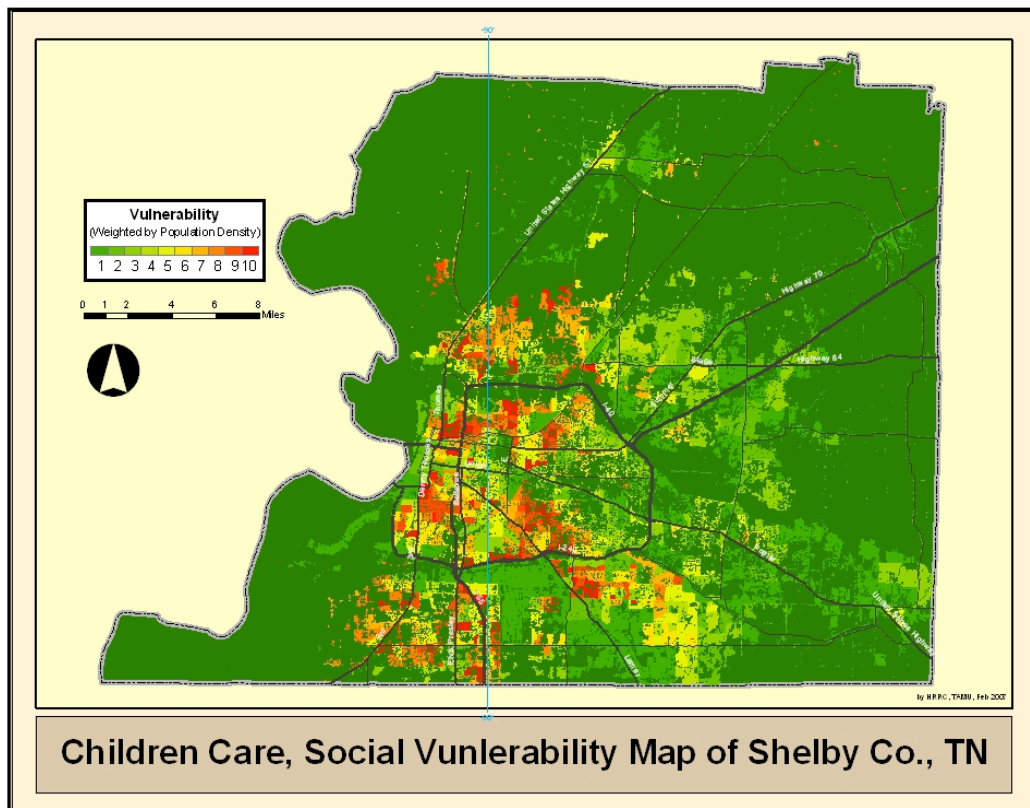


Figure 7. 2nd Order Social Vulnerability Map – Child Care Needs

4. 2nd order Social Vulnerability Maps: 2nd order social vulnerability maps are generated by combining 1st order measures into 4 social vulnerability indexes for child and elder care, public transportation needs and shelter and housing recovery needs.

4.1 Calculate the 2nd order variables

- Child Care (i_chldcare) = de_poverty + de_femhh + de_child
- Elder Care (i_eldcare) = de_elder + de_elderpv

Social vulnerability Algorithm

- Public Transportation (i_ptneed) = de_pubtran + de_pttranst
- Shelter and Housing Recovery (i_housing) = de_unempl + de_renter + de_minority + de_income

4.2 Rank and classify 2nd order variables (i_chlcare etc.) into a new set of variables which indicated the decile ranking of the block group by county for each of the four second order measures. (As mentioned above, future versions should allow the user to classification based on quartiles, quintiles or other ranking methods that may be designed).

- Higher the values of variables, higher the vulnerabilities. 1 is the least vulnerable, and 10 is the most vulnerable.
- New decile ranking variables should be given the following names: de_chlcare, de_eldcare, de_ptneed, and de_housing (see Appendix 2).

4.3 Create the 2nd order maps

- Convert the vector maps of 2nd order variables to raster maps (use the same spatial resolution as NLCD 2001).
- Use map algorithm to create refined social vulnerability maps. 2nd order map = Raster map of 2nd order variable * developed area map (created from #1). Figure 7 is an example of a 2nd order social vulnerability map for potential child care needs. Examples of other second order maps can be found in Appendix 5 .

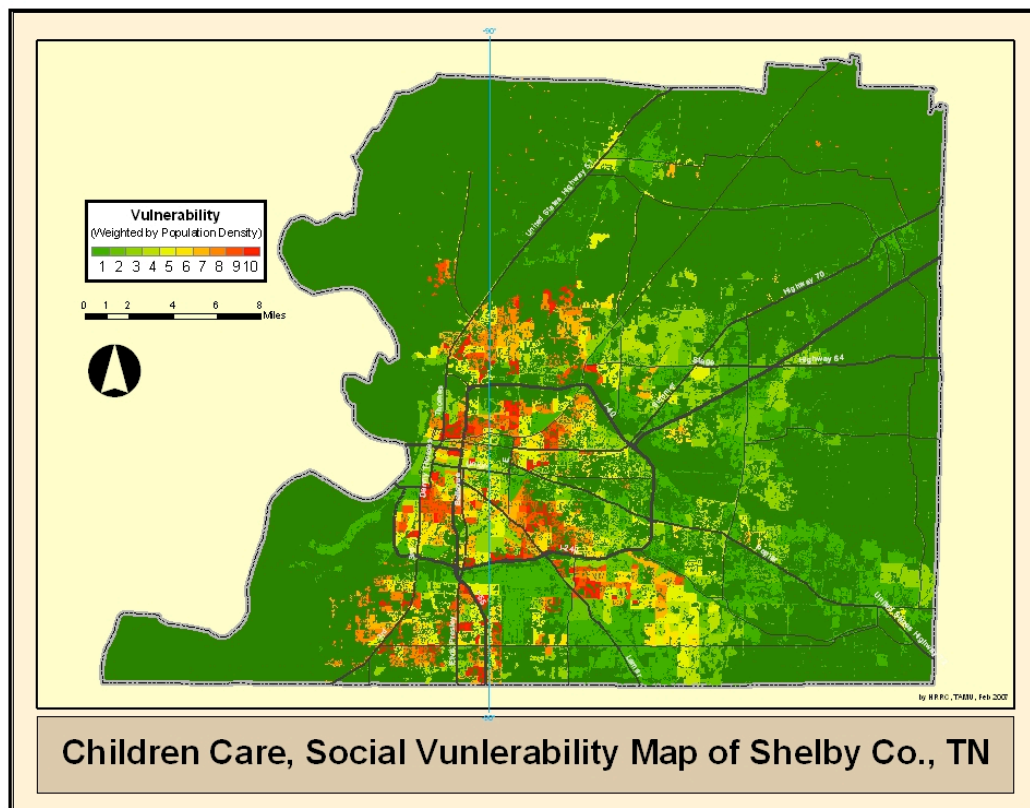


Figure 8. 2nd Order Weighted Social Vulnerability Map – Child Care Needs

5. Weighted 2nd order maps: Weighted versions of the 2nd order maps are generated using the weighted measures calculated in 3.1 above.

5.1 Calculate the weighted 2nd order variables

- Child Care (w_chldcare) = wd_poverty + wd_femhh + wd_child
- Elder Care (w_eldcare) = wd_elder + wd_elderpo
- Public Transportation (w_ptneed) = wd_pubtran + wd_ptranst
- Shelter and Housing Recovery (w_housing) = wd_unempl + wd_renter + wd_minority + wd_income

5.2 Rank and classify 2nd order variables (w_chldcare etc.) by decile. This classification can also be done by quartile or quintile.

- Higher the values of variables, higher the vulnerabilities. 1 is the least vulnerable, and 10 is the most vulnerable.
- New Variables: wd_chldcare, wd_eldcare, wd_ptneed, and wd_housing (see Appendix 2).

5.3 Create the weighted 2nd order maps

- Convert the vector maps of weighted 2nd order variables to raster maps (use the same spatial resolution as NLCD 2001).
- Use map algorithm to create refined social vulnerability maps. Weighted 2nd order map = Raster map of weighted 2nd order variable * developed area map (created from #1).
- An example of the weighted version of the 2nd order for potential child care needs can be found in Figure 8 and other examples can be found in Appendix 6.

6. 3rd order map

6.1 Calculate the 3rd order variable, i_hotspot.

- Vulnerability Hot Spot (i_hotspot) = de_chldcare + de_eldcare + de_ptneed + de_housing

6.2. Rank and classify i_hotspot by decile. This classification can also be done by quartile or quintile.

- Higher the values of i_hotspot, higher the vulnerabilities. 1 is the least vulnerable, and 10 is the most vulnerable.
- de_hotspot: decile ranking of i_hotspot for the block groups (see Appendix 2)..

6.3. Create the un-weighted 3rd order map

- Convert the vector map of “de_hotspot” to a raster map (use the same spatial resolution as NLCD 2001).
- Use map algorithm to create refined social vulnerability map. 3rd order map = Raster map of de_hotspot * developed area map (created from #1).
- Figure 9 below displays the unweighted 3rd order social vulnerability map for Shelby County.

7. Weighted 3rd order map

7.1 Calculate the weighted 3rd order variable.

- Vulnerability Hot Spot (w_hotspot) = wd_chldcare + wd_eldcare + wd_ptneed + wd_housing

7.2. Rank and classify w_hotspot by decile. This classification can also be done by quartile or quintile.

- Higher the values of w_hotspot, higher the vulnerabilities. 1 is the least vulnerable, and 10 is the most vulnerable.
- wd_hotspot: decile ranking of w_hotspot for the block groups (see Appendix 2)..

7.3. Create the un-weighted 3rd order map

- Convert the vector map of “wd_hotspot” to a raster map (use the same spatial resolution as NLCD 2001).
- Use map algorithm to create refined social vulnerability map. Weighted 3rd order map = Raster map of wd_hotspot * developed area map (created from #1).).
- Figure 10 displays the weighted version of the 3rd order social vulnerability map for Shelby County. A cursory comparison of Figures 9 and 10 indicates that there are again some variations in the densities and hence concentrations of population that become evident when compared the two.

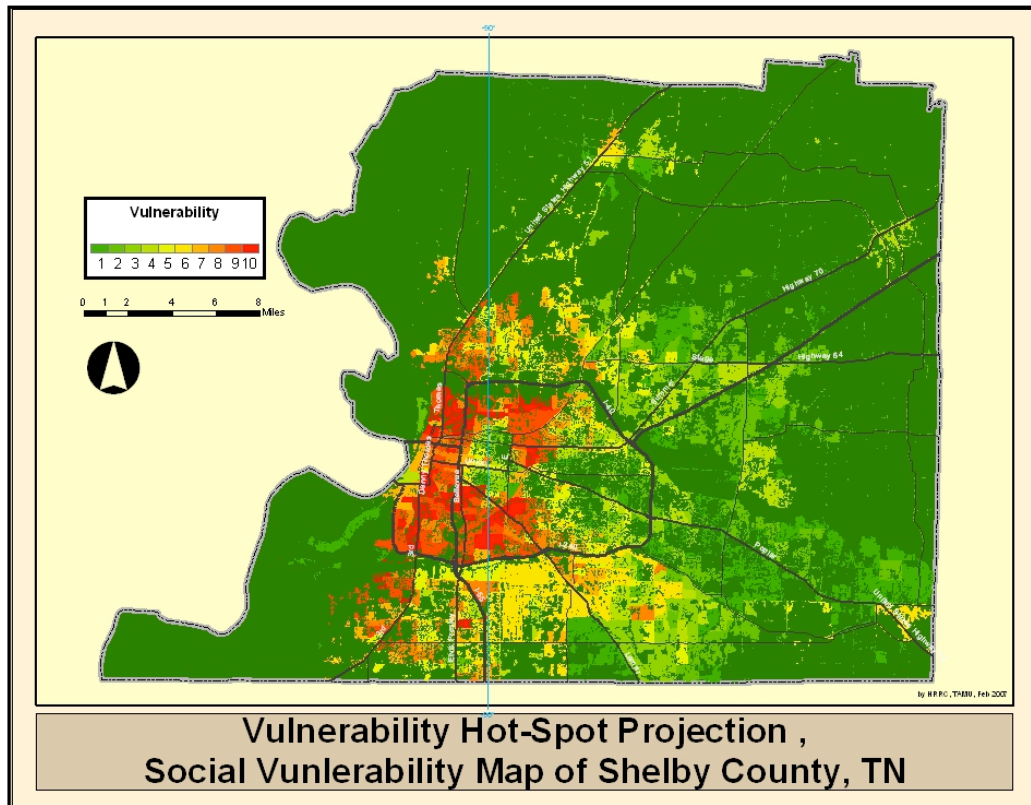


Figure 9. 3rd Order Unweighted Social Vulnerability Map

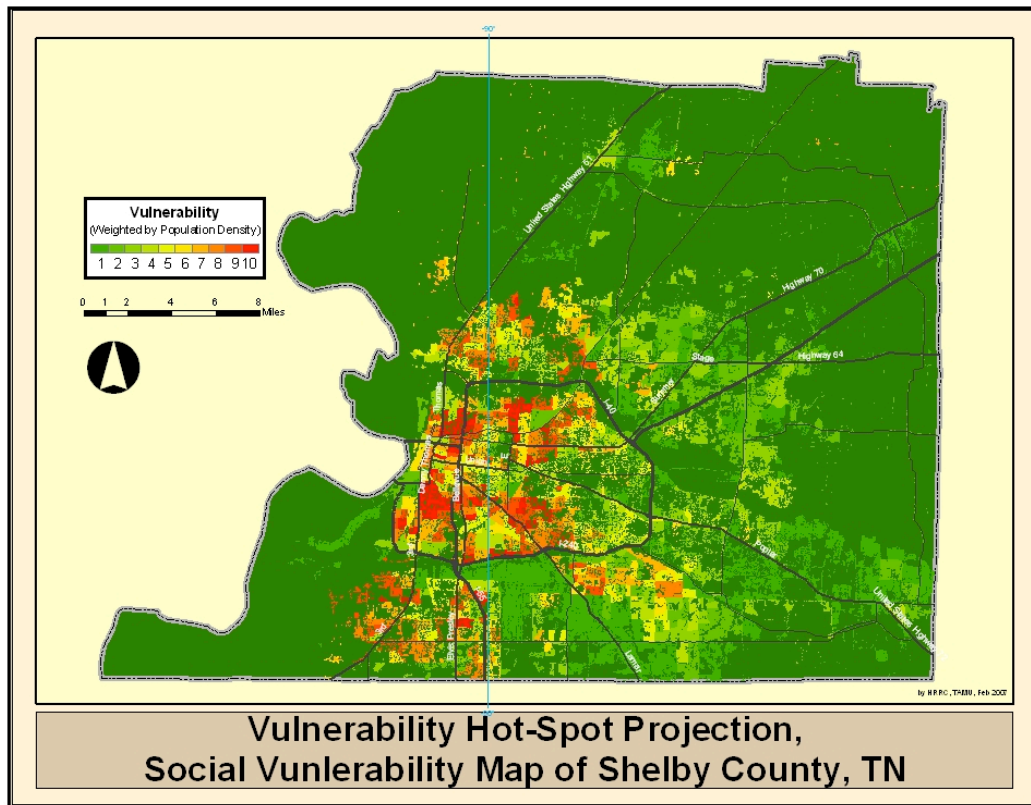


Figure 10. 3rd Order Unweighted Social Vulnerability Map

Appendix 1

Definition and coding of National Land Cover Data 2001

Code	Land Cover Type	Definition
21	Developed, Open Space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
24	Developed, High Intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.
11	Open Water	
12	Perennial Ice	
31	Barren Land	
32	Un-consolidated Shore	
41	Deciduous	
42	Evergreen	
43	Mixed Forest	
51	Dwarf Scrub	
52	Shrub/Scrub	
71	Grassland/Herbaceous	
72	Sedge/Herbaceous	
73	Lichens	
74	Moss	
81	Pasture/Hay	
82	Cultivated Crops	
90	Woody Wetlands	
91	Palustrine Forested Wetland	
92	Palustrine Scrub/Shrub Wetland	
93	Estuarine Forested Wetland	
94	Estuarine	

	Scrub/Shrub Wetland	
95	Emergent Herbaceous Wetlands	
96	Palustrine Emergent Wetland	
97	Estuarine Emergent Wetland	
98	Palustrine Aquatic Bed	
99	Estuarine Aquatic Bed	

Source: EPA webpages, <http://www.epa.gov/mrlc/definitions.html>, 2007.2

Appendix 2

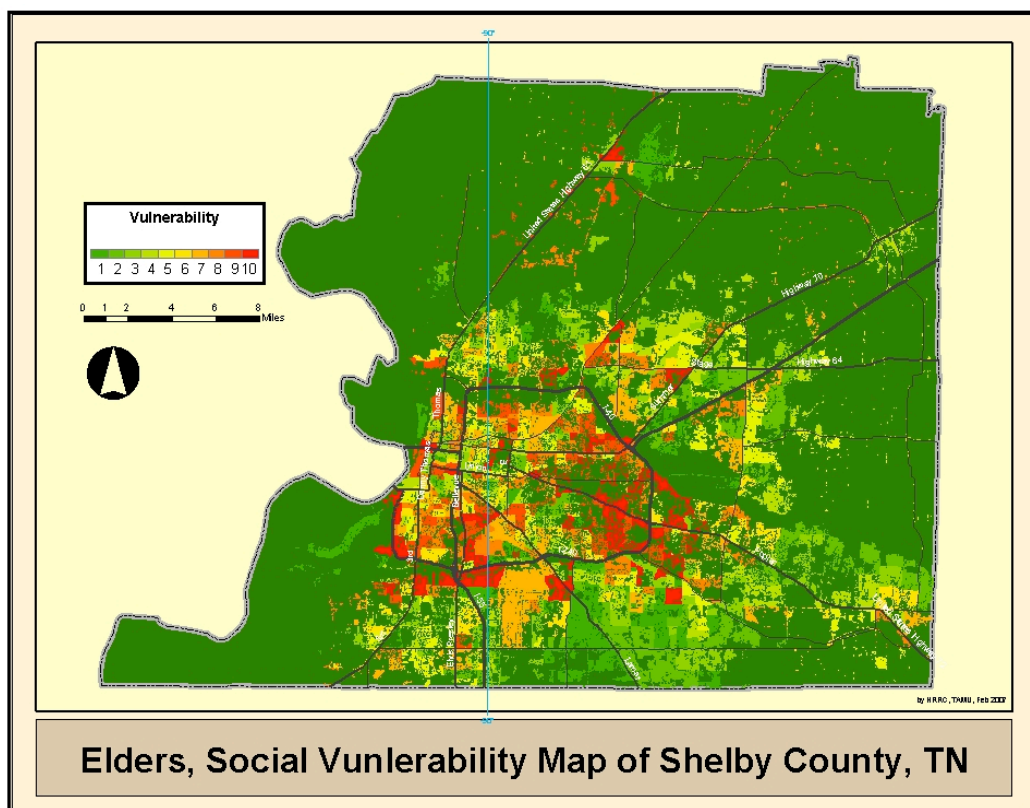
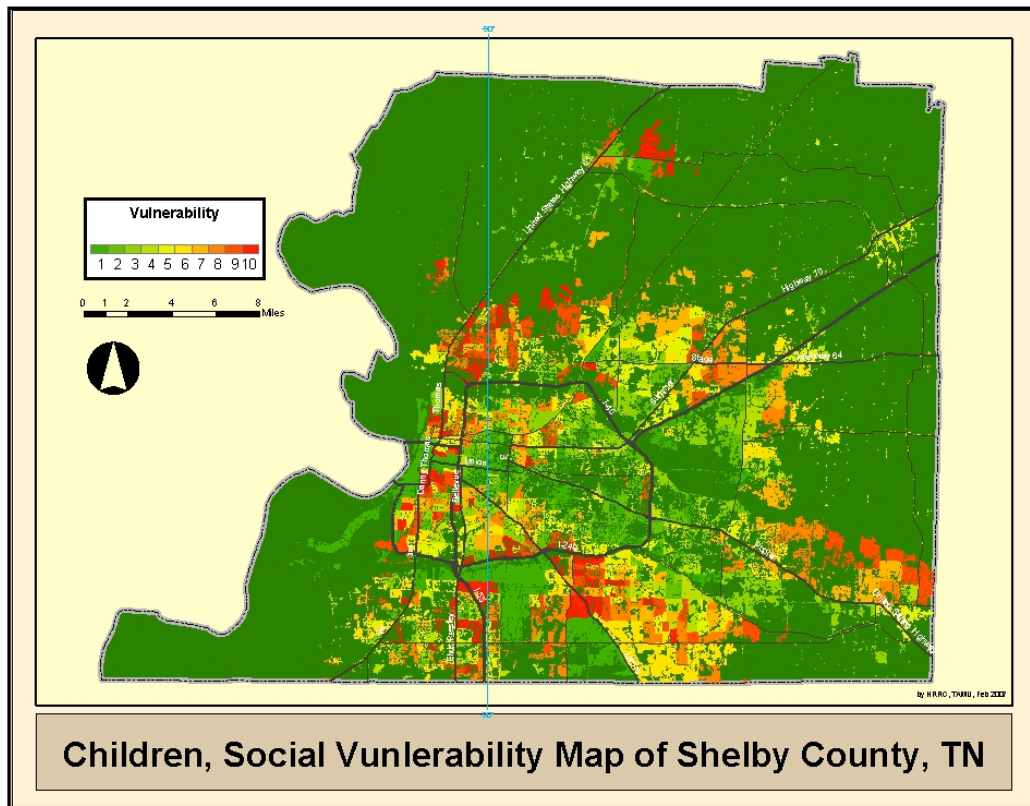
Variables

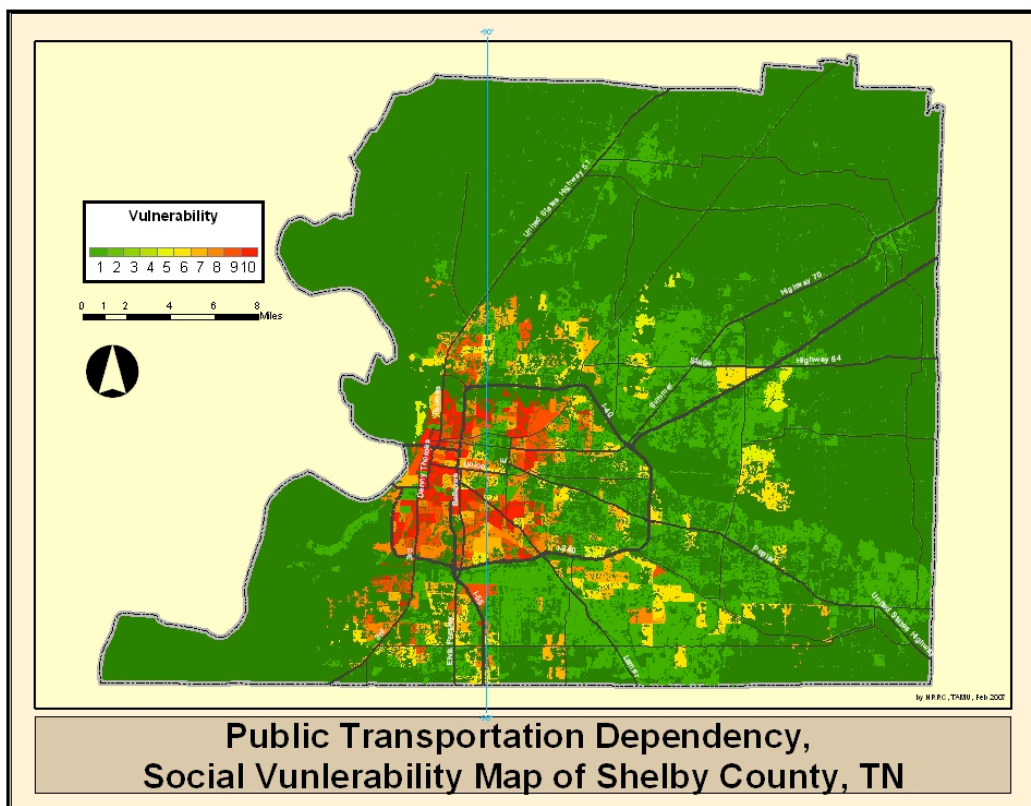
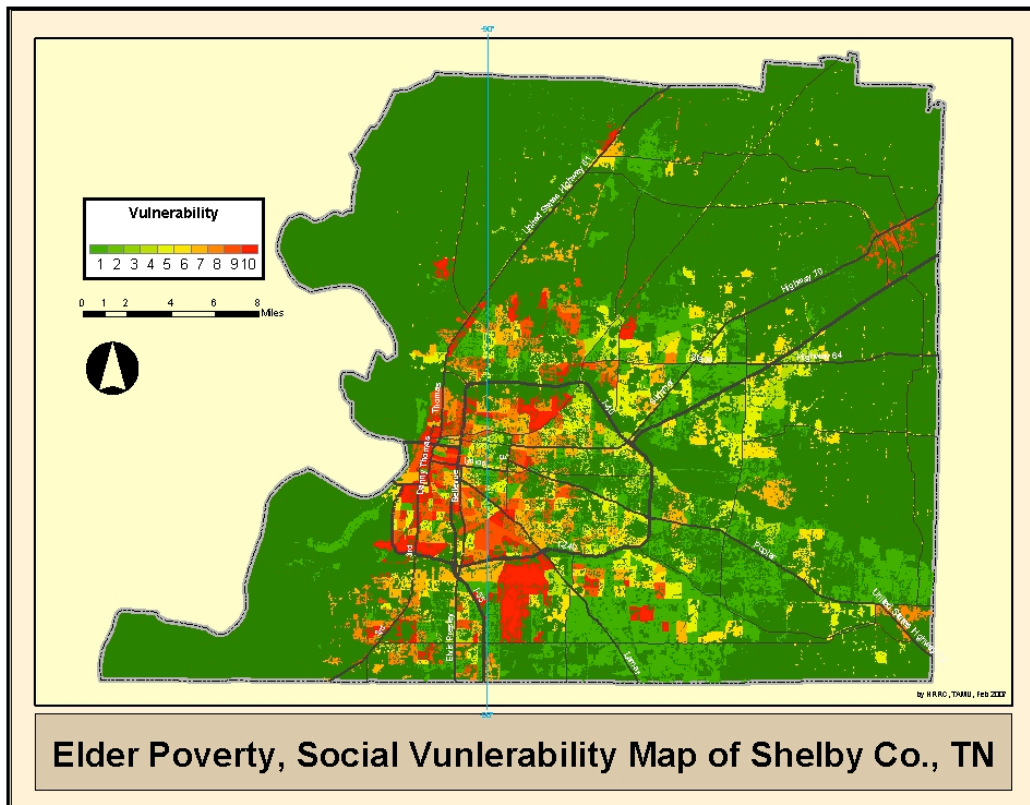
Variable Name	Description	Note
TOTPOP	Total Population	2000 Census (from Dr. French)
P_WHITE	Total Population -- Whites Alone	2000 Census (from Dr. French)
PM_0_17	Total Male Population less than 17 years	2000 Census (from Dr. French)
PM_65P	Total Male Population above 65 years	2000 Census (from Dr. French)
PF_0_17	Total Female Population less than 17 years	2000 Census (from Dr. French)
PF_65P	Total Female Population above 65 years	2000 Census (from Dr. French)
TOT_WORK	Total Workers above 16 years	2000 Census (from Dr. French)
W_PUB_T	No. of Workers who took Public Transportation to work	2000 Census (from Dr. French)
AGG_PTTM	Aggregate Travel Time to work by Public Transportation in minutes	2000 Census (from Dr. French)
P_16PYR	Total Population over 16 years	2000 Census (from Dr. French)
M_INLF	Males over 16 years in Labor Force	2000 Census (from Dr. French)
M_UNEMP	Male over 16 years -- Unemployed	2000 Census (from Dr. French)
F_INLF	Females over 16 years in Labor Force	2000 Census (from Dr. French)
F_UNEMP	Female over 16 years -- Unemployed	2000 Census (from Dr. French)
PRCAPINC	Per capita Income in dollars	2000 Census (from Dr. French)
P_UPOV	Total No. of Persons below Poverty Level	2000 Census (from Dr. French)
P17_UPOV	No. of Persons under 17 years below Poverty Level	2000 Census (from Dr. French)
P65_UPOV	No. of Persons above 65 years below Poverty Level	2000 Census (from Dr. French)
TOT_HU	Total Housing Units	2000 Census (from Dr. French)
H_OCC	No. of Occupied Housing Units	2000 Census (from Dr. French)
H_RNT	No. of Renter-occupied Housing Units	2000 Census (from Dr. French)
FHF	No. of Female Householder, no Husband Present	2000 Census (in P18 column, STF1)
i_poverty	Poverty index	$=P_upov / Totpop$
i_femhh	Female Headed Household index	$=Fhf / Tot_hh$
i_child	Children index	$=(Pm_0_17 + Pf_0_17) / Totpop$
i_elder	Elders index	$=(PM_65p + Pf_65p) / Totpop$
i_elderpov	Elder poverty index	$=P65_upov / (PM_65p + Pf_65p)$
i_pubtrans	Public transportation dependence index	$=W_pub_t / Tot_work$
i_ptranst	Travel time index	$=Agg_pttm / Tot_work$
i_unempl	Unemployment index	$=(M_unemp + F_unemp) / (M_inlf + F_inlf)$
i_renter	Renter index	$=H_rnt / H_occ$
i_minority	Race/ethnicity index	$=(Totpop - P_white) / Totpop$
i_income	Income index	= the maximum of Prcapinc (108571) - Prcapinc

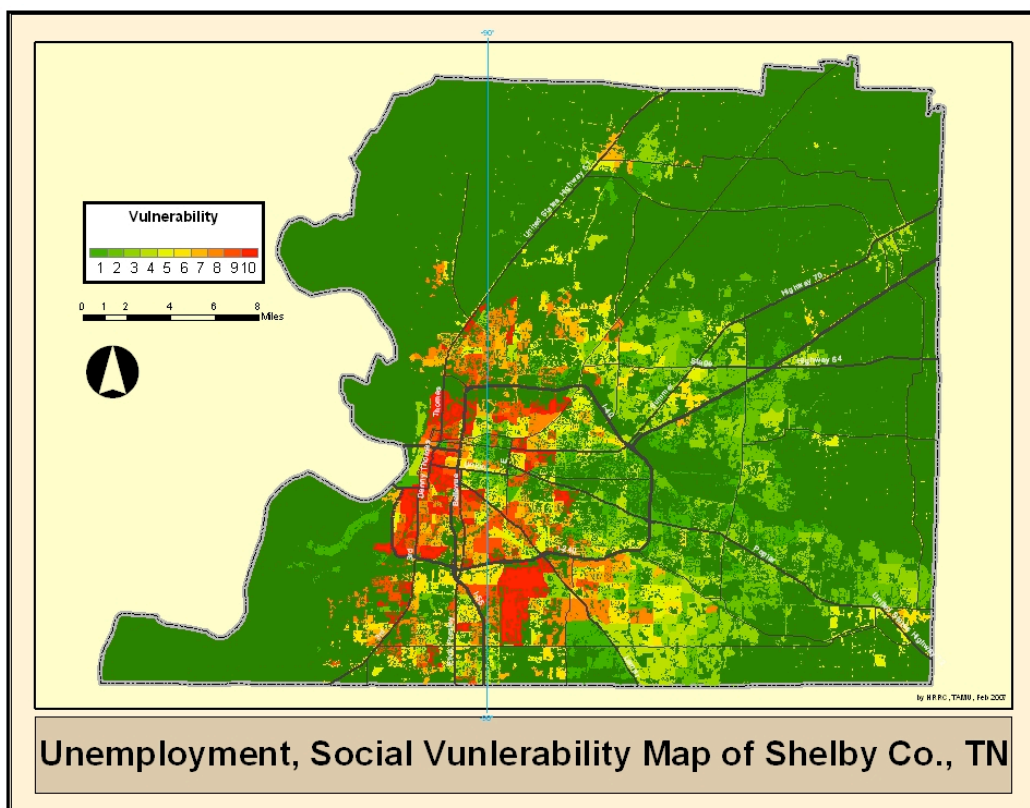
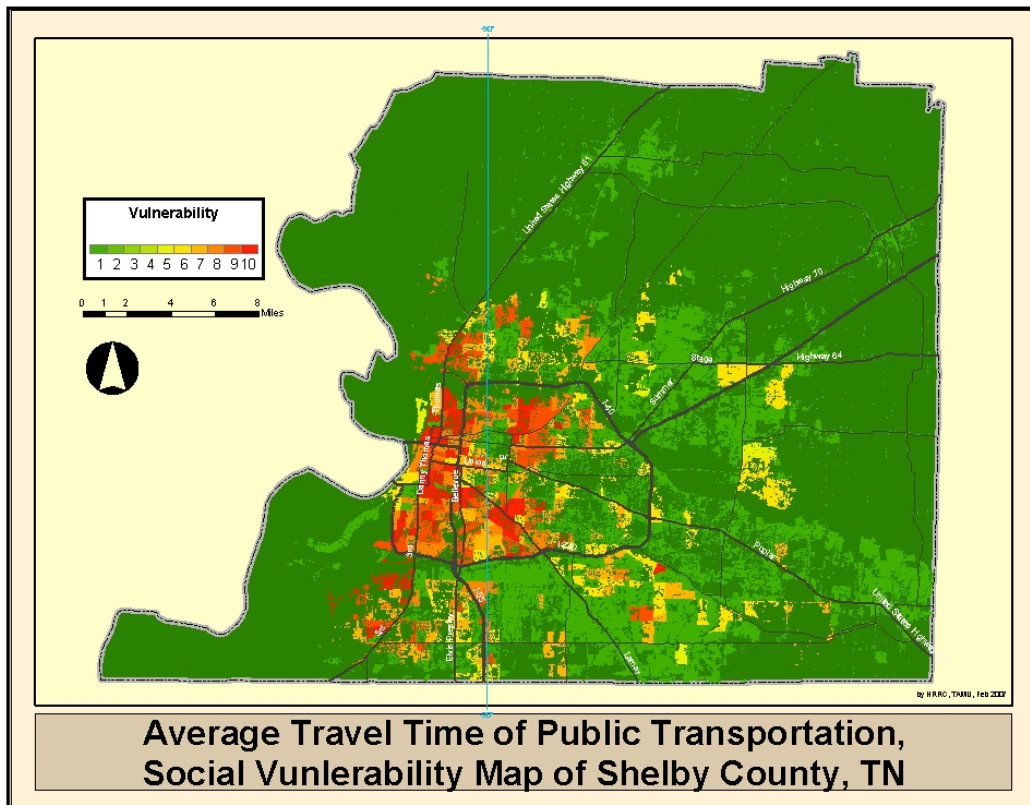
Variable Name	Description	Note
de_poverty	Decile ranking of i_poverty	Rank i_poverty
de_femhh	Decile ranking of i_femhh	Rank i_femhh
de_child	Decile ranking of i_child	Rank i_child
de_elder	Decile ranking of i_elder	Rank i_elder
de_elderpv	Decile ranking of i_elderpov	Rank i_elderpov
de_pubtran	Decile ranking of i_pubtrans	Rank i_pubtrans
de_ptanst	Decile ranking of i_ptanst	Rank i_ptanst
de_unempl	Decile ranking of i_unempl	Rank i_unempl
de_renter	Decile ranking of i_renter	Rank i_renter
de_minority	Decile ranking of i_minority	Rank i_minority
de_income.	Decile ranking of i_income	Rank i_income
Pop_dens	Population density (persons / km ²)	[Totpop] / ([cellnum] * 0.03 * 0.03)
cellnum	Number of developed area cell within the block group	Using zonal spastics to calculate
w_poverty	Weighted poverty	= i_poverty * 100 * pop_dens / 12705.76
w_femhh	Weighted female headed households	= i_femhh * 100 * pop_dens / 12705.76
w_child	Weighted children	= i_child * 100 * pop_dens / 12705.76
w_elder	Weighted elders	= i_elder * 100 * pop_dens / 12705.76
w_elderpov	Weighted elder poverty	= i_elderpov * 100 * pop_dens / 12705.76
w_pubtrans	Weighted Public transportation dependency	= i_pubtrans * 100 * pop_dens / 12705.76
w_ptanst	Weighted travel time	= i_ptanst * 100 * pop_dens / 12705.76
w_unempl	Weighted unemployed	= i_unempl * 100 * pop_dens / 12705.76
w_renter	Weighted Renter index	= i_renter * 100 * pop_dens / 12705.76
w_minoirty	Weighted race/ethnicity	= i_minoirty * 100 * pop_dens / 12705.76
w_income	Weighted income	= i_income * 100 * pop_dens / 12705.76
wd_poverty	Decile ranking of w_poverty	Rank w_poverty
wd_femhh	Decile ranking of w_femhh	Rank w_femhh
wd_child	Decile ranking of w_child	Rank w_child
wd_elder	Decile ranking of w_elder	Rank w_elder
wd_elderpo	Decile ranking of w_elderpov	Rank w_elderpov
wd_pubtran	Decile ranking of w_pubtrans	Rank w_pubtrans
wd_ptanst	Decile ranking of w_ptanst	Rank w_ptanst
wd_unempl	Decile ranking of w_unempl	Rank w_unempl
wd_renter	Decile ranking of w_renter	Rank w_renter
wd_minority	Decile ranking of w_minority	Rank w_minority

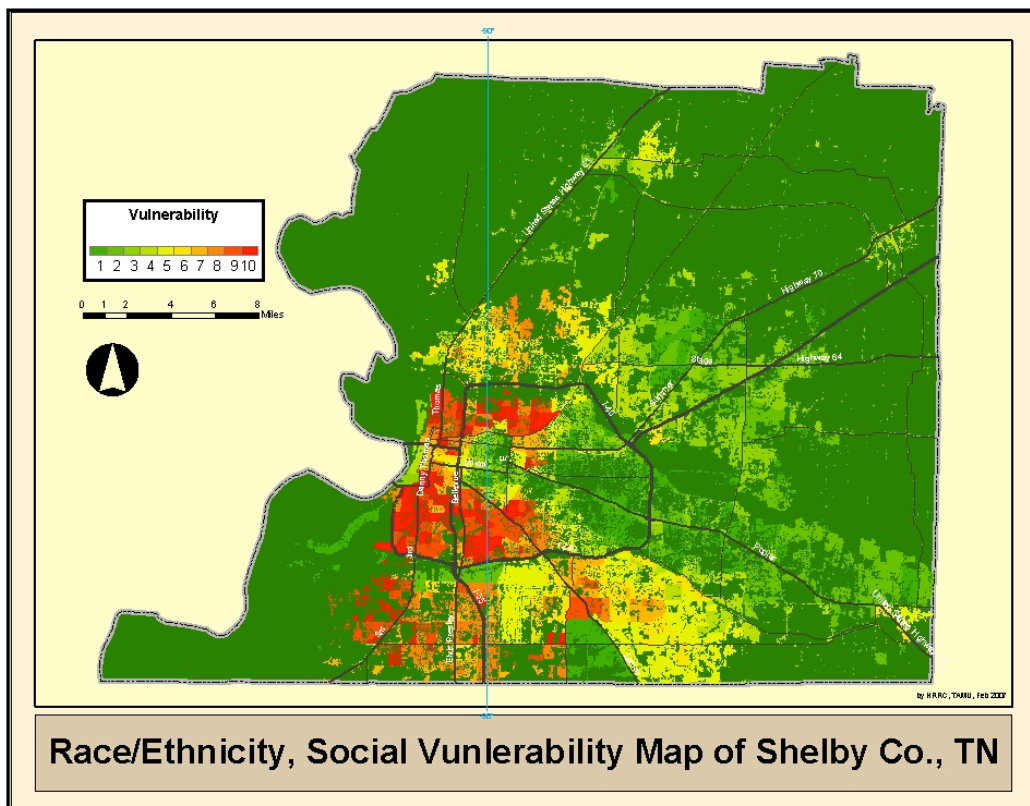
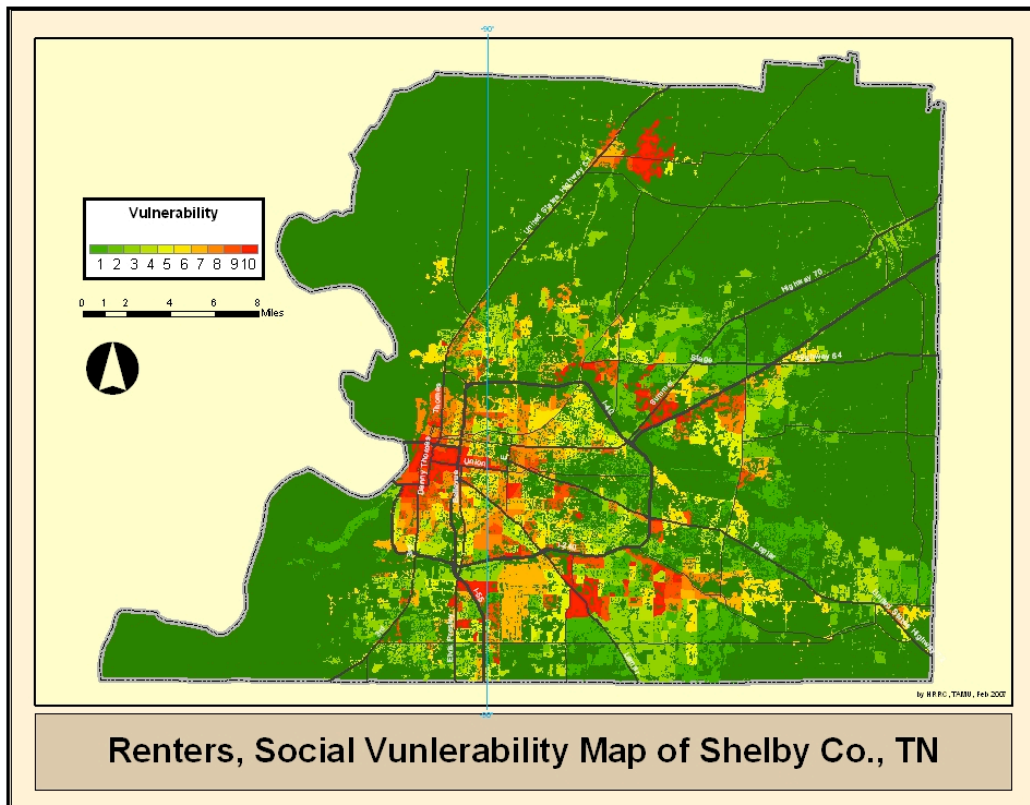
Variable Name	Description	Note
wd_income.	Decile ranking of w_income	Rank w_income
i_chldcare	Child Care index	= de_poverty + de_femhh + de_child
i_eldcare	Elder Care index	= de_elder + de_elderpv
i_ptneed	Public Transportation index	= de_pubtran + de_ptanst
i_housing	Shelter and Housing Recovery index	= de_unempl + de_renter + de_minority + de_income
de_chlcare	Decile ranking of i_chldcare	Rank i_chldcare
de_eldcare	Decile ranking of i_eldcare	Rank i_eldcare
de_ptneed	Decile ranking of i_ptneed	Rank i_ptneed
de_housing	Decile ranking of i_housing	Rank i_housing
w_chldcare	Weighted child care index	= wd_poverty + wd_femhh + wd_child
w_eldcare	Weighted elder care index	= wd_elder + wd_elderpo
w_ptneed	Weighted public transportation index	= wd_pubtran + wd_ptanst
w_housing	Weighted shelter and housing recovery index	= wd_unempl + wd_renter + wd_minority + wd_income
wd_chdcare	Decile ranking of w_chldcare	Rank w_chldcare
wd_eldcare	Decile ranking of w_eldcare	Rank w_eldcare
wd_ptneed	Decile ranking of w_ptneed	Rank w_ptneed
wd_housing	Decile ranking of w_housing	Rank w_housing
i_hotspot	Vulnerability hotspot index	= de_chlcare + de_eldcare + de_ptneed + de_housing
de_hotspot	Decile ranking of i_hotspot	Rank i_hotspot
w_hotspot	Weighted vulnerability hotspot index	= wd_chdcare + wd_eldcare + wd_ptneed + wd_housing
wd_hotspot	Decile ranking of w_hotspot	Rank w_hotspot

Appendix 3. Additional filtered 1st order Social Vulnerability Maps.

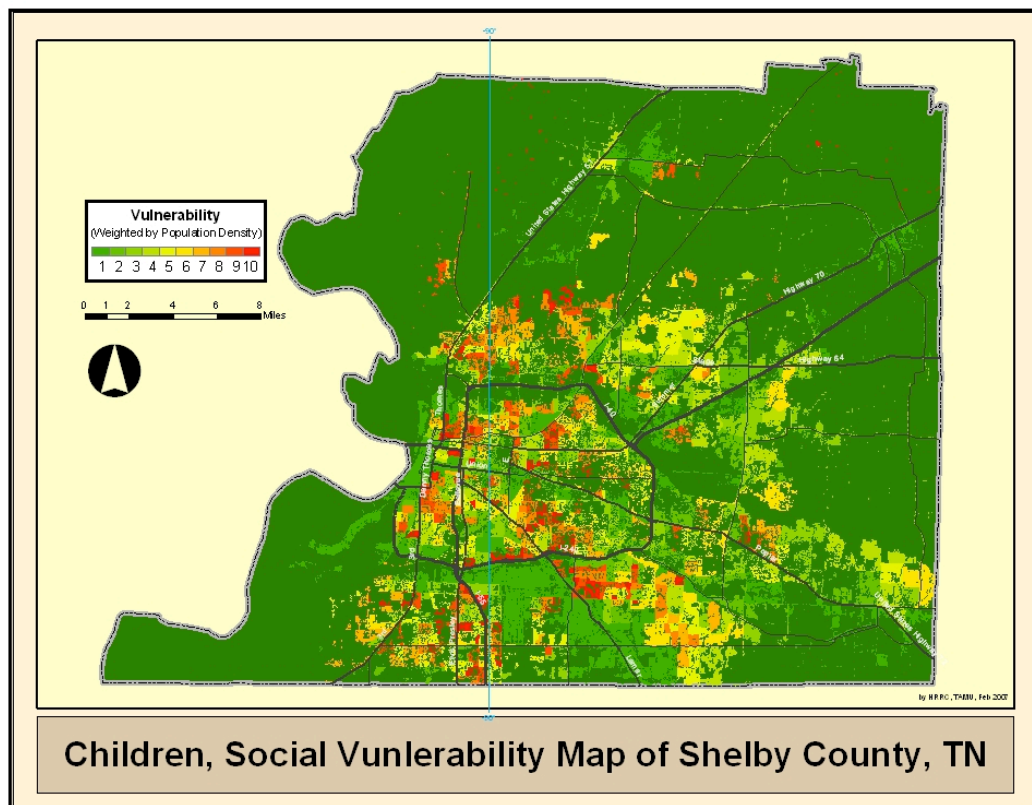
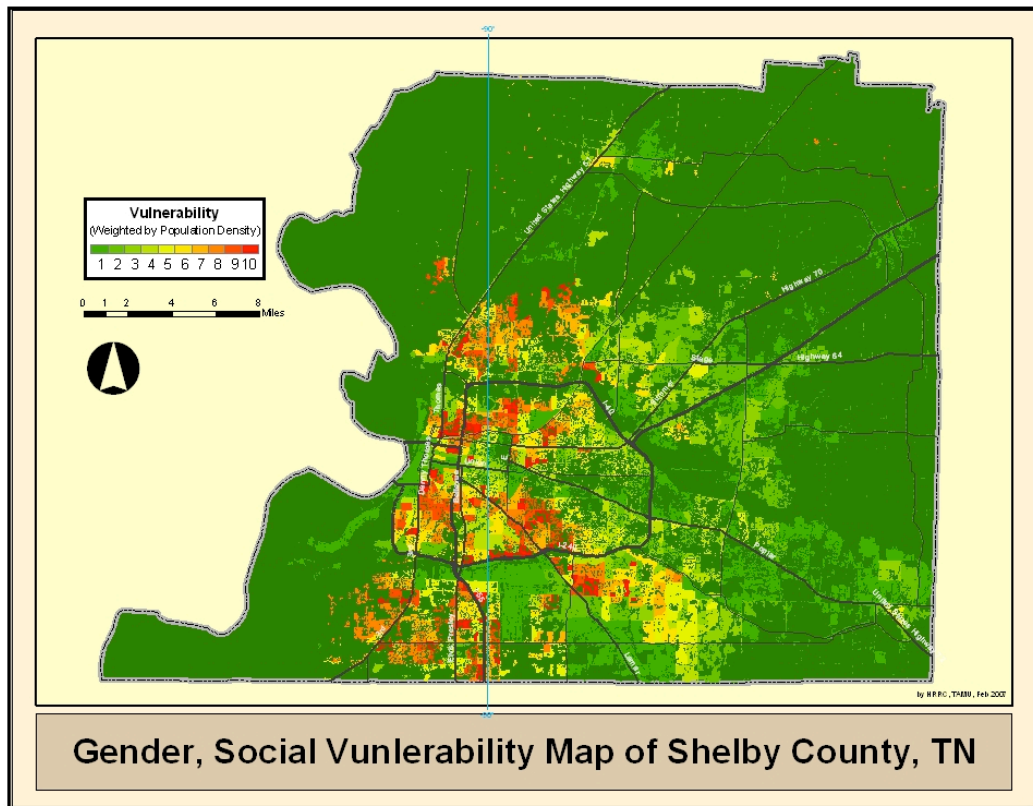


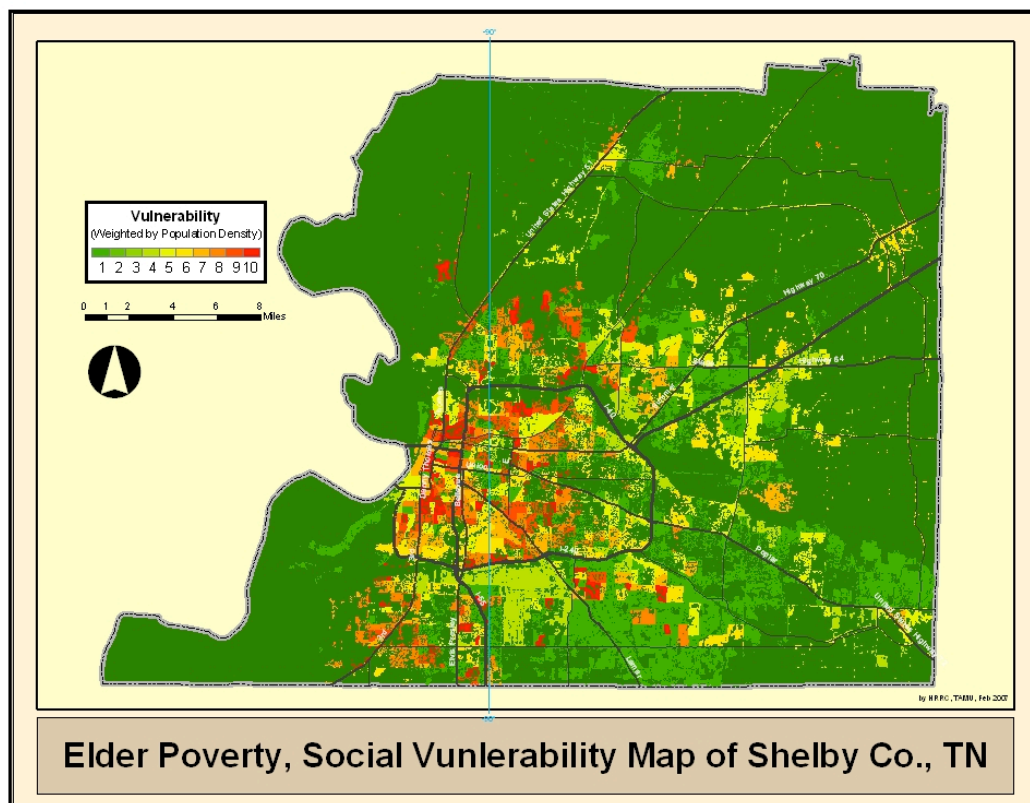
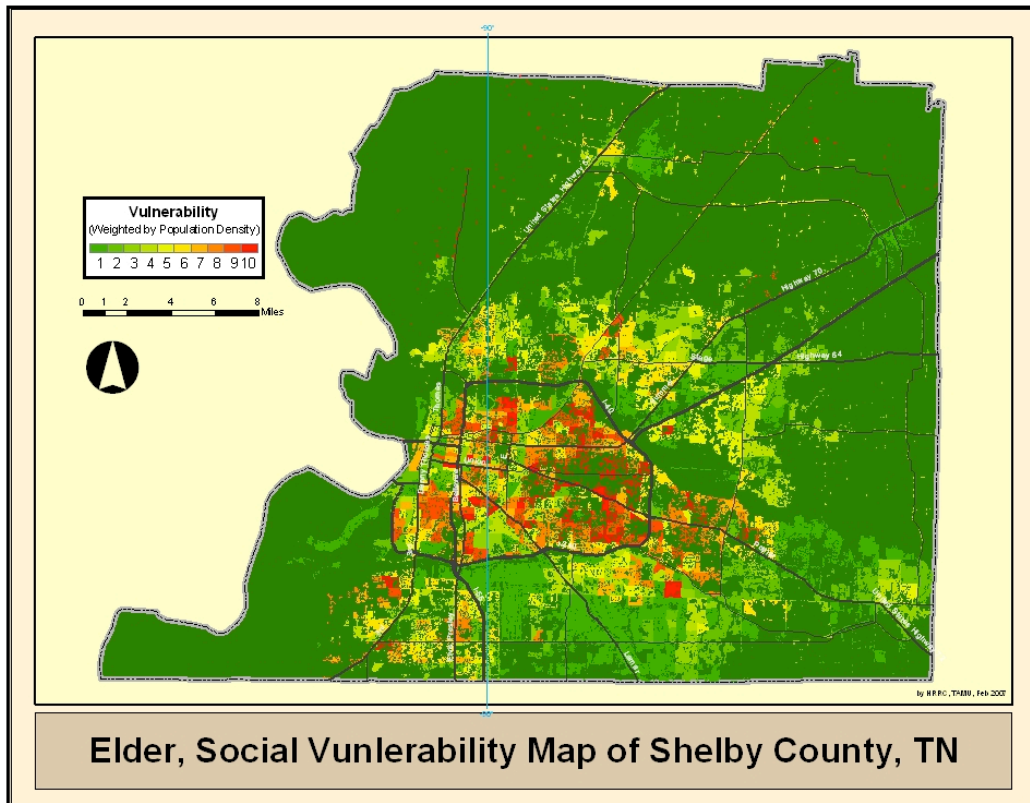


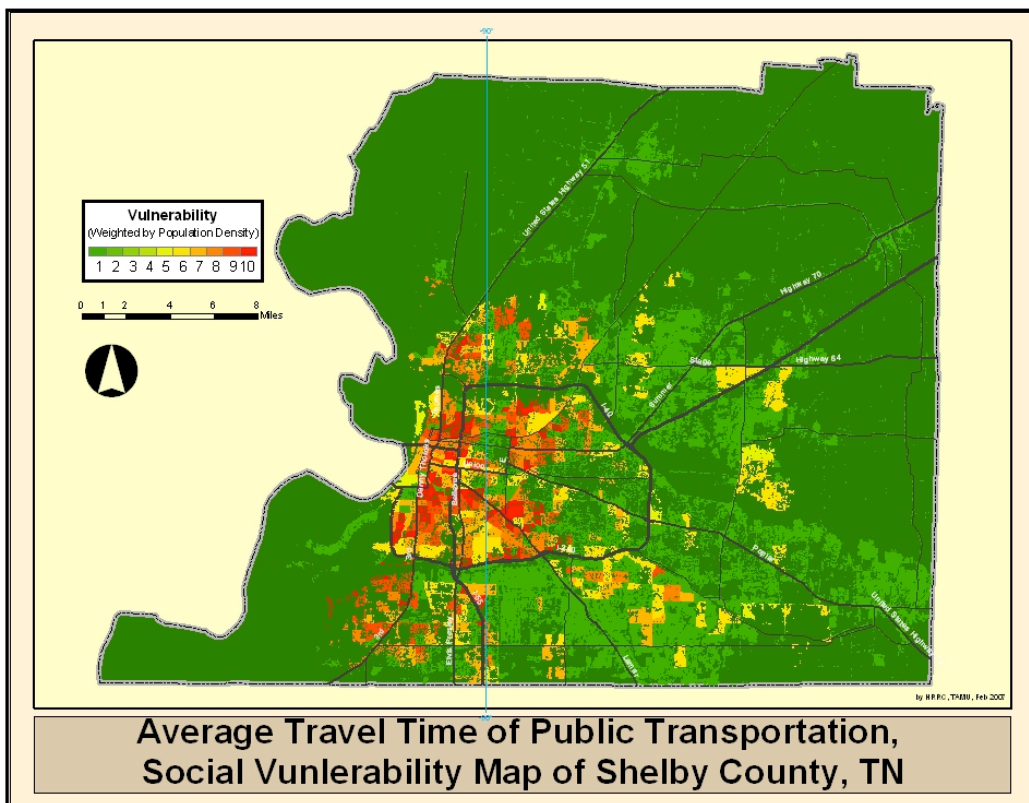
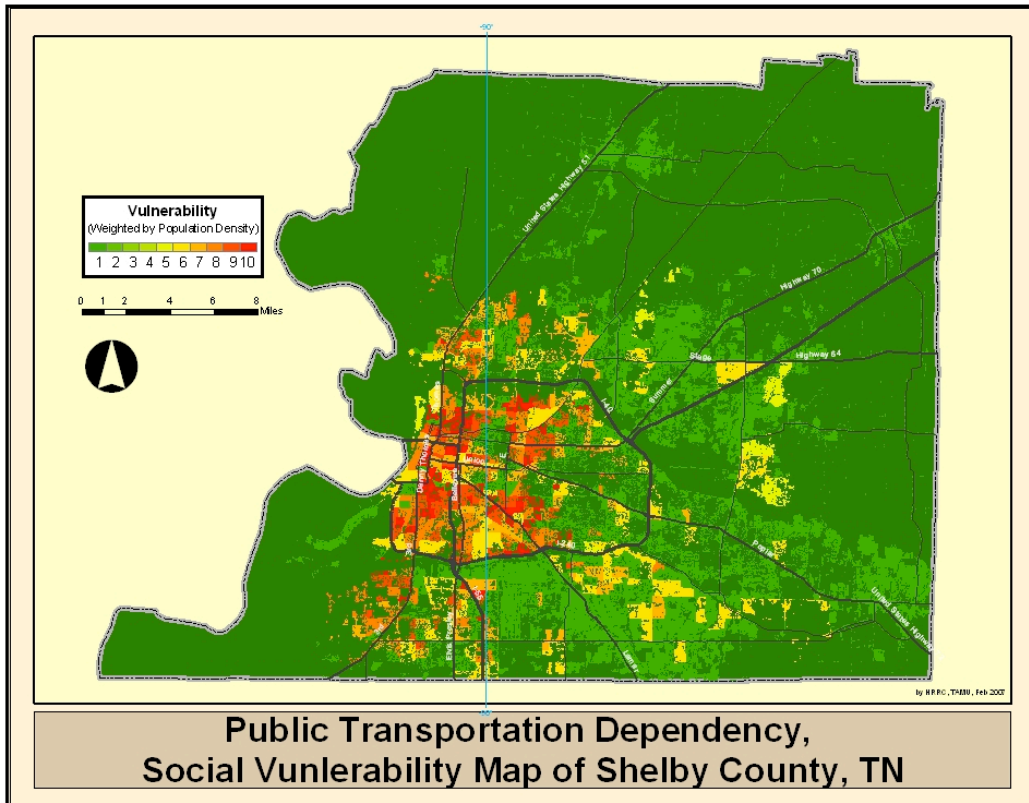


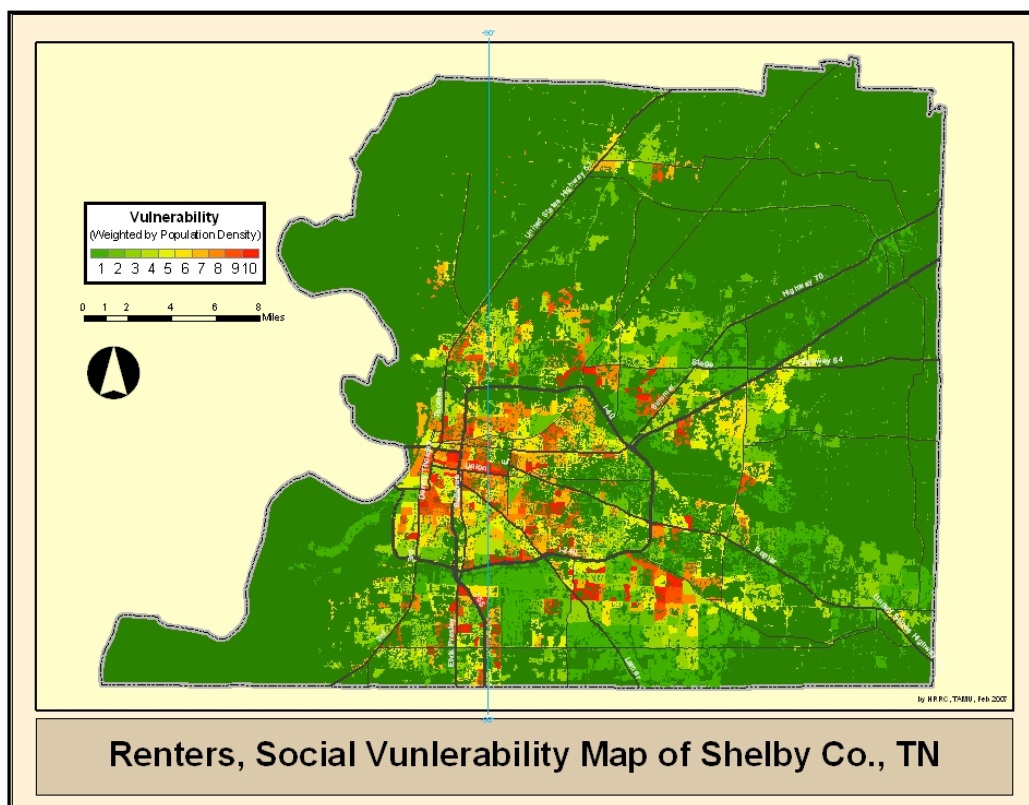
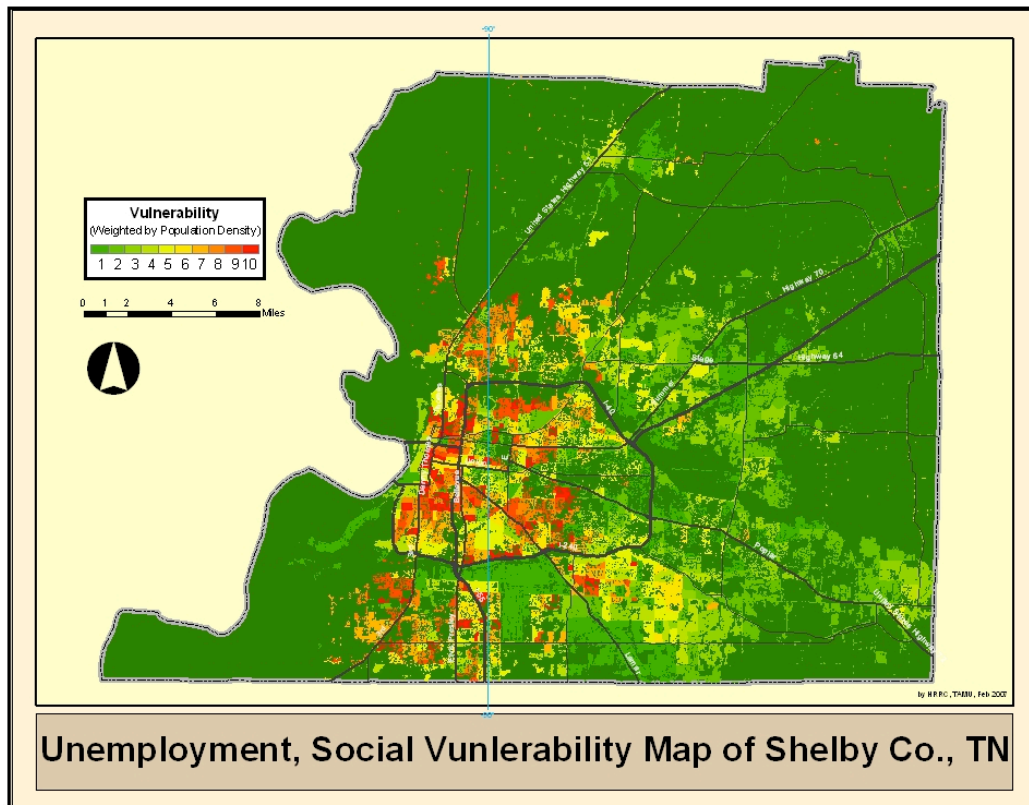


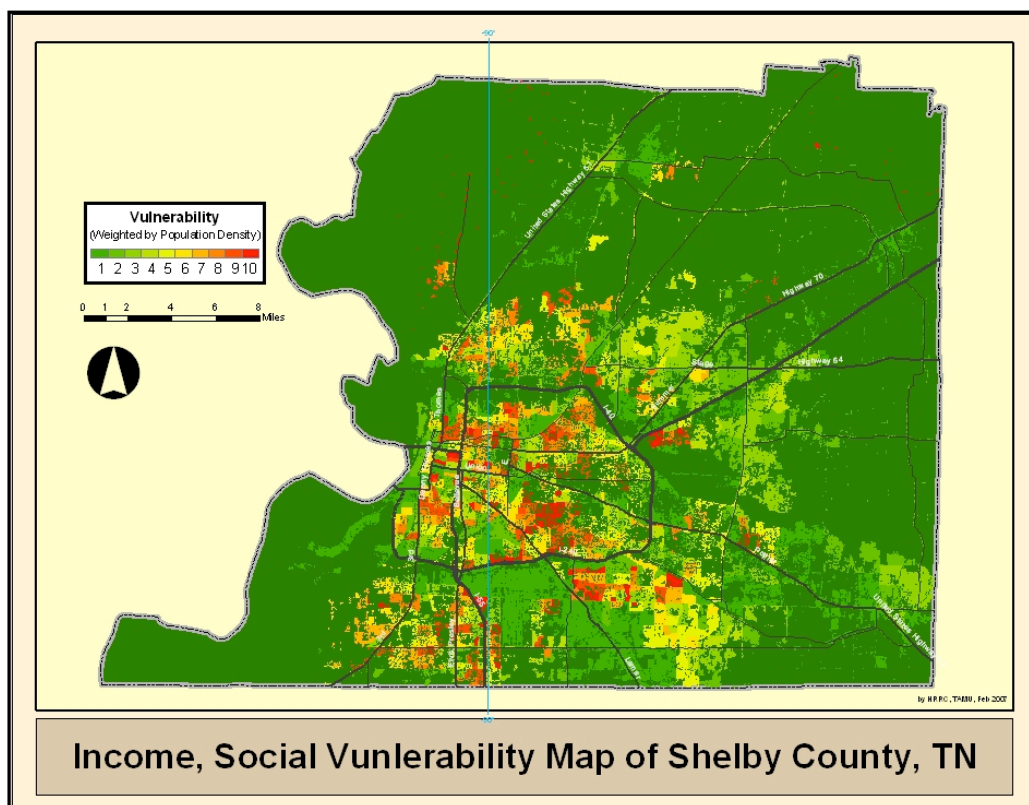
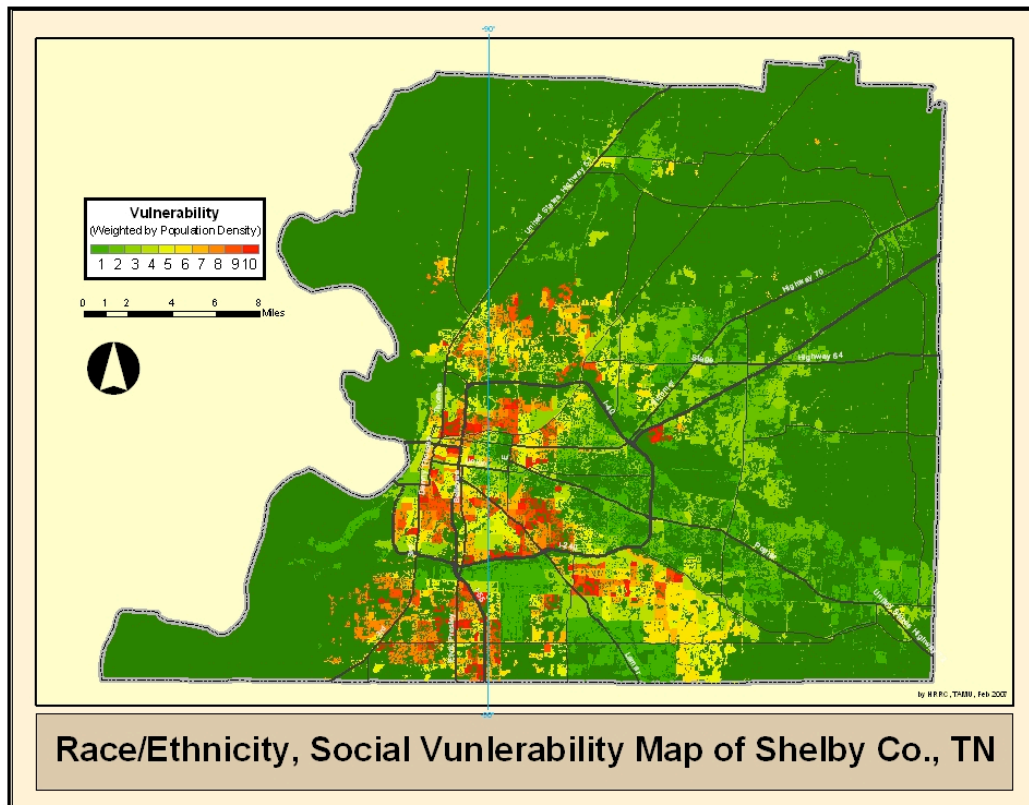
Appendix 4. Examples of Weighted 1st Order maps



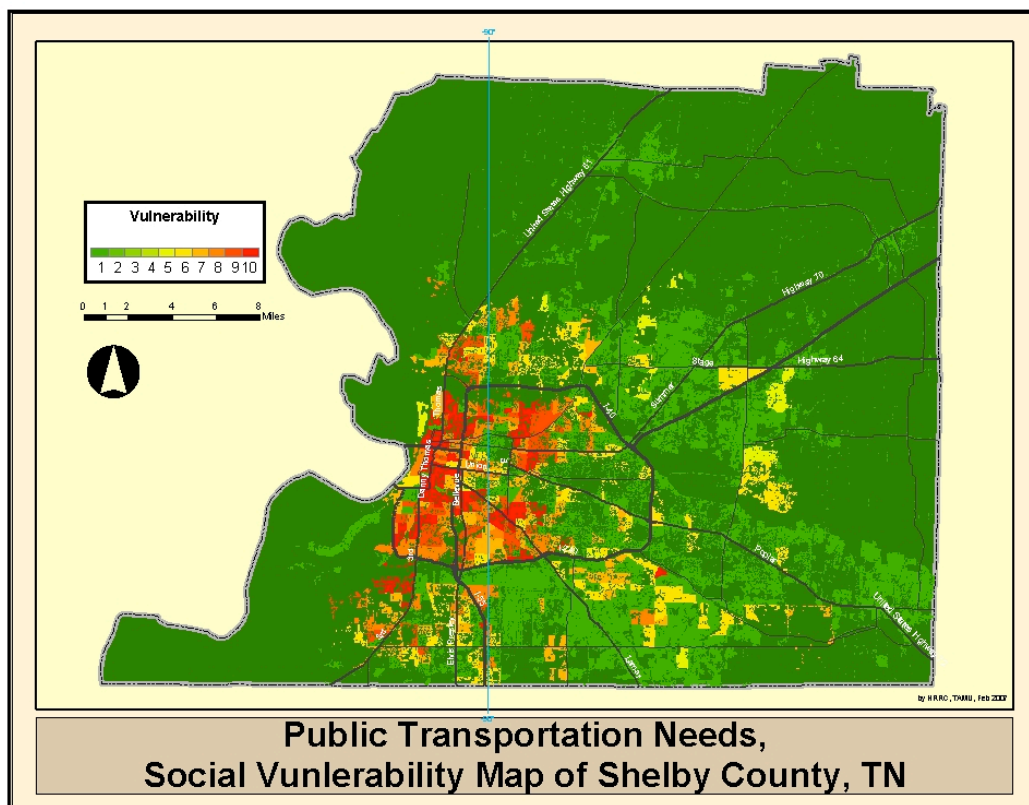
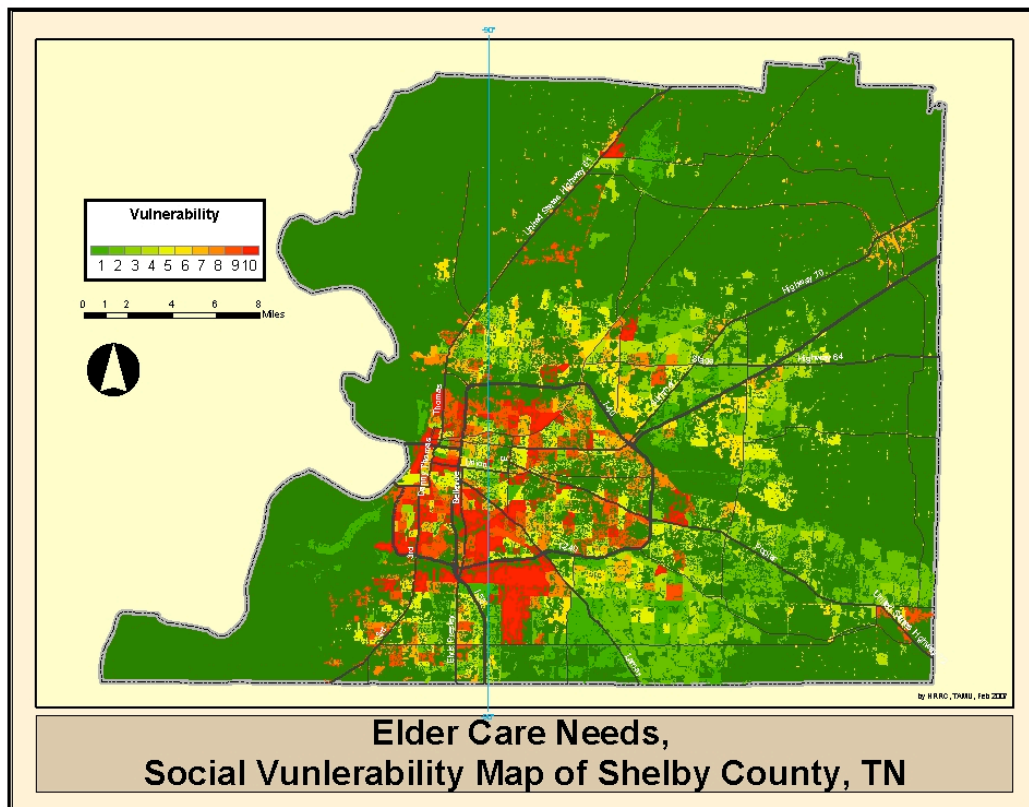


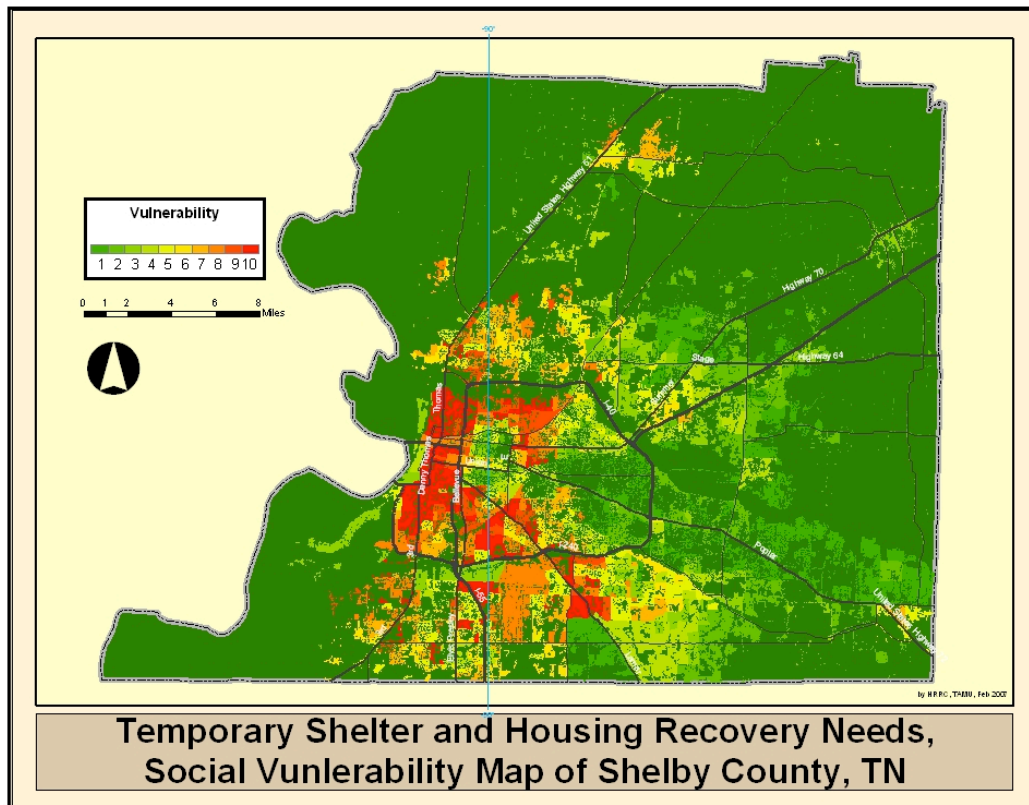






Appendix 5. Unweighted 2nd Order Social Vulnerability Maps





Social vulnerability Algorithm

