Assessing the Vulnerability of the Mississippi Gulf Coast to Coastal Storms Using an On-Line GIS-Based Coastal Risk Atlas

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I. INTRODUCTION

Natural disaster losses in the U.S. have been estimated to be between $10 billion and $50 billion annually, with an average cost from a single major disaster estimated at approximately $500 million. One of the primary factors contributing to the rise in disaster losses is the steady increase in the population of high-risk areas, such as coastal areas. The population in coastal counties represents more than half of the U.S. population, but occupies only about one-quarter of the total land area. Coastal areas are particularly susceptible to the catastrophic impacts of hazards. Between 1992 and 1997, nearly three-quarters of the federally declared disasters in the U.S. occurred in coastal states or territories [1]. Efforts to mitigate the effects of coastal hazards can be complicated by insufficient information concerning coastal vulnerability. Vulnerability factors include the geologic nature of the coast, the patterns and characteristics of the built environment, and socio-economic conditions. Providing a better understanding of these factors to allow communities to undertake the most appropriate mitigation strategies provides the rational for developing the Coastal Risk Atlas (CRA).

The CRA is under development by the National Oceanic and Atmospheric Administration (NOAA) National Coastal Data Development Center (NCDDC) in collaboration with the NOAA Coastal Services Center (CSC). Its purpose is to deliver an on-line risk/vulnerability atlas for the coastal U.S. using NCDDC information technologies [2] and methodologies proven by the CSC. The project has been initially implemented in two pilot areas, the Mississippi Gulf Coast and Northeast Florida. Based on success and lessons learned, it will be expanded to a larger coastal region, and eventually nationwide. This phased approach enables identification and resolution of technical issues, better identification of necessary data, and determining data inadequacies that could drive future data collection and coastal research initiatives. This paper documents the development of the CRA and its application in the pilot areas.

II. CRA DEVELOPMENT

The NCDDC is a new NOAA Center commissioned in April 2002. Its mission is to access and integrate diverse coastal data distributed in multiple repositories and provide these data to users via the Internet using established and emerging technologies. It accomplishes this by maintaining a searchable metadata catalog of coastal data, developing gateways to data repositories and using middleware technology that provides data in user specified formats. The CRA is one of a number of initial projects undertaken by the NCDDC in order to identify and catalog high priority data sets and to develop its information technology infrastructure.

The CSC developed the original concept of the CRA based largely on their Community Vulnerability Assessment Tool (CVAT) [3]. The CVAT demonstrates how the use of Geographic Information Systems (GIS) can assist communities in their efforts to identify and reduce hazards vulnerability through strategies relating to awareness, education and mitigation. This product, distributed via CD-ROM and the Internet, also contains a methodology that helps state and local governments determine and prioritize their vulnerabilities to coastal hazards. Physical factors such as the location of critical facilities and infrastructure relative to high-risk areas, the distribution of vulnerable populations such as the elderly, poor and under-insured, significant environmental resources and the vulnerability of primary economic sectors are all included as issues for consideration.

While the CVAT was well received by the coastal community, many of its users found it difficult to access all the data required to effectively apply the tool. With a mission to provide users with easy access to distributed coastal data, it was a natural choice for the newly established NCDDC to assume the CRA, in partnership with the CSC, as one of its initial projects. Not only does the CRA address a major national need, natural hazard mitigation, but it also provides the NCDDC opportunities to refine technologies to identify, access and distribute coastal data for a wider variety of applications.

III. VULNERABILITY ASSESSMENT

Before a community can develop informed mitigation strategies, they must identify where they are most vulnerable. With limited resources and poor access to hazards information, communities may perform ineffective assessments, basing their mitigation efforts on perceived rather than actual vulnerability [4]. Communities need to identify the overall vulnerability of their populations, economies and resources to hazards. Vulnerability assessment is a comprehensive process involving hazard identification and analysis and determining the resultant vulnerabilities of critical infrastructure, society, economic resources and environment. Using the CVAT as a template and by providing a one-stop shop for required data, the CRA seeks to aid communities in performing credible vulnerability assessments.

IV. HAZARD IDENTIFICATION

The vulnerability assessment process begins with the identification of local hazards. Since the CRA deals primarily with coastal storms, these include the direct and indirect effects of hurricanes, tropical storms and extratropical storms. The hazards considered are storm surge inundation, damaging wind, flooding, tornados, hazardous spills and toxic release. Local officials may include additional hazards or choose to exclude some of the above hazards, as they may not be pertinent to their particular locality. To help local officials determine the significant hazards in their respective communities, the CRA provides access to a database of significant weather related events maintained by the National Climatic Data Center (NCDC). Such data provide a historical perspective on the occurrences of major events for a particular locality. The hazards assessed in the CRA are described in the following sections.

A. Storm Surge

Historically, the greatest loss of life associated with hurricanes has been the result of storm surge inundation, an abnormal rise in water caused by wind forcing. Digital storm surge maps for the Mississippi Coast were obtained from the U. S. Army Corps of Engineers (USACE) Mobile District Office. The maps were created as part of the Mobile District's Hurricane Evacuation Study for the Mississippi Gulf Coast. They depict areas of potential surge inundation for each of the five Saffir-Simpson hurricane intensities, from a minimum (Category 1) through a maximum intensity (Category 5) hurricane. They were produced from the results of multiple simulations by the National Hurricane Center using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model [5]. The model simulations included Category 1 through Category 5 intensities, from nine directions, and at speeds of 5, 10, and 15 mph. The CRA assigns the highest risk score to areas potentially inundated by a Category 1 hurricane. Areas only potentially inundated by a Category 5 hurricane are assigned a risk score of 1. Areas outside the inundation zone receive a risk score of 0. The combined surge inundation risk map is shown in Fig. 1.

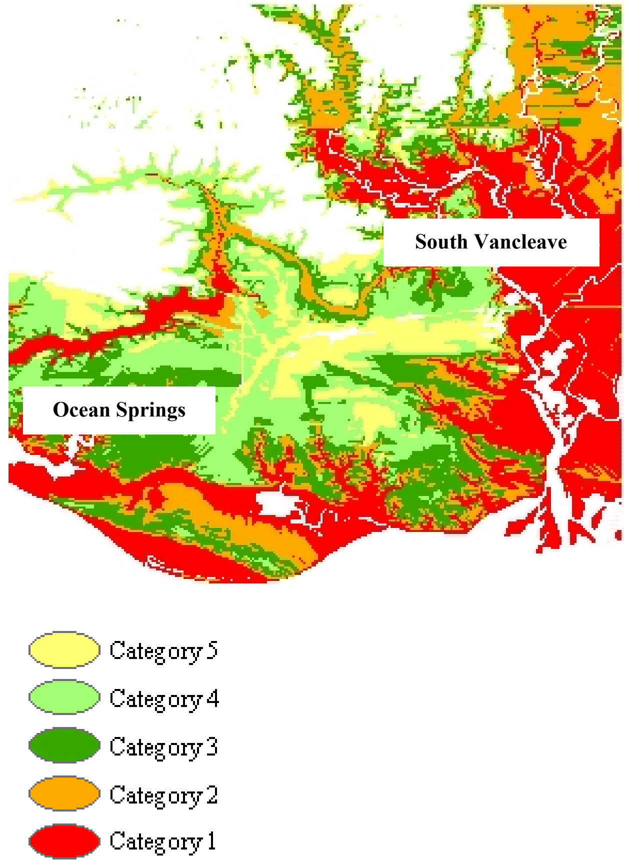

Fig. 1 Storm Surge

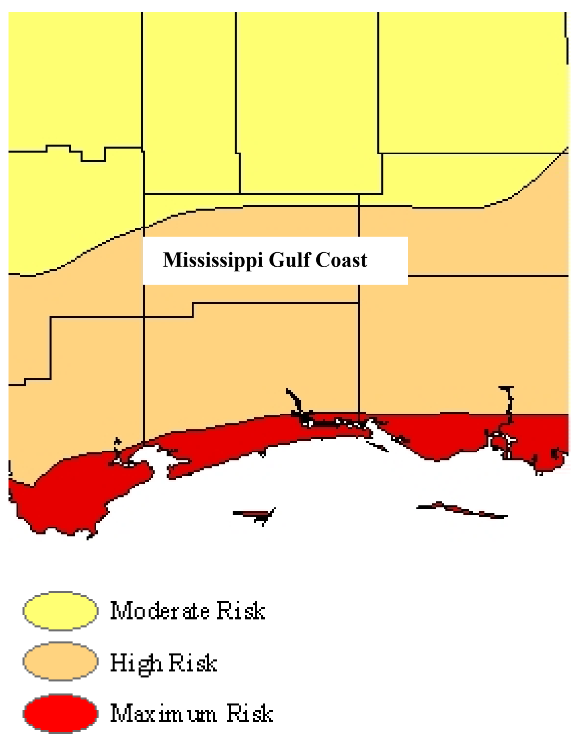

Fig. 2 Wind Envelopes

B. High Winds

Winds associated with major hurricanes can cause considerable destruction. Therefore, wind risk assessment is a very important aspect of the CRA. The wind envelope data used in the CRA were obtained from the Federal Emergency Management Agency's (FEMA) Hazards US (HAZUS) CD-ROM series. These digital wind envelope maps are based on the inland wind model developed by DeMaria and Kaplan [6] and used by the National Hurricane Center to estimate maximum sustained winds for inland moving hurricanes. The HAZUS digital maps depict wind envelopes for Category 1 through 4 hurricanes moving at slow, moderate and fast speeds. The fastest overland speeds produce the deepest inland penetration of damaging sustained wind speeds. Along the Gulf Coast, the CRA uses the wind envelopes produced by a Category 4 hurricane moving inland at moderate speed (12 knots) to estimate high wind risk. The area immediately along the coast is assigned the highest risk score of 3. The wind risk envelopes are shown in Fig. 2.

C. Inland Flooding

Inland flooding often occurs as a result of heavy precipitation associated with hurricanes and tropical storms. The CRA uses FEMA Q3 thematic layers to determine flood risk scores. These are the vectorized versions of the FEMA Flood Insurance Rate Maps (FIRM) [7]. Q3 layers used for the Mississippi pilot area were obtained from the Mississippi Automated Resource Information Service (MARIS). The highest flood risk score (5) is assigned to areas designated as within the 100-year flood zone and subject to wave action, the velocity zone. A score of 4 is assigned all other areas within the 100-year flood zone. Areas outside the 100-year zone, but within the 500-year flood zone are assigned a score of 3. All other areas are assigned a risk score of 2. A flood risk map is depicted in Fig.3.

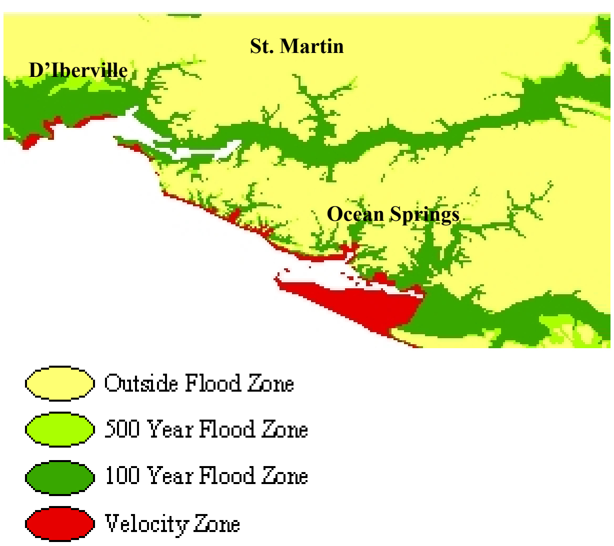

Fig. 3 FEMA Q3 Flood Map

D. Tornado

Tornados occur along the Mississippi Coast with moderate frequency and can be associated with land falling hurricanes. Because they are typically small-scale, low exposure events, the risk score assigned to tornados on the Mississippi Coast is 1. Since the risk of a tornado does not vary within a local area, it is treated as a constant in each county.

E. Secondary Hazards

Toxic release, spills, or runoff from industrial or agricultural activities are hazards in addition to those posed by the primary effects of coastal storms. Areas around activities with the potential to release toxic material into the environment require special consideration since the effects can be devastating, not only to the human population, but also to sensitive coastal habitats.

V. SOCIAL VULNERABILITY

Identifying populations that are most at risk to the effects of natural hazards is an important part of a thorough vulnerability assessment. U.S. Census data at the Block Group Level were obtained from ESRI ArcData Online in order to map the concentrations of vulnerable populations. This is the sector of the population that, for socio-economic reasons, is most at risk to coastal hazards. The CRA follows the CVAT template of using a number of vulnerability indicators to identify populations at risk. The motivation for including the indicators presently used by the CRA is discussed in [4]. Each is briefly described below.

A. Poverty

Community members living at or below the poverty level often inhabit poorly maintained housing that may not withstand an intense hurricane. Also, many of them live in lower cost mobile or modular homes that are highly vulnerable to wind damage.

B. Rental Units

Residents who rent their homes often lack control over the structural integrity of their homes. Landlords may be unwilling to spend the money to make updates and modifications to their buildings that will improve the chances of withstanding a hurricane.

C. Lack of English Proficiency

People who don't speak English are often at a disadvantage in the event of a coastal storm. Lacking English skills can be a deterrent in seeking and receiving storm warnings and evacuation information. Also, recent immigrants may not have a solid family base in the area to act as their safety net should their residences become unlivable.

D. Single Parent Households

The vulnerability connected with single parent households is associated with the ratio of able-bodied adults to children. For example, if one adult must help four children evacuate the process could be greatly slowed.

E. Lack of Transportation

The community needs to consider those who do not have access to transportation. These residents may not have the opportunity to evacuate without assistance.

F. Elderly

The CRA has also taken into account the community population 65 years of age and older. The elderly often lack the physical ability and monetary resources to respond to disasters in a timely manner. Also, older people are more likely to experience health problems associated with the storm event.

G. Lack of Education

Just as disadvantages exist among those with a lack of English proficiency, lack of education or illiteracy can also hamper the ability of individuals to seek information.

VI. APPLICATIONS IN JACKSON COUNTY, MS

The NCDDC is located at Stennis Space Center and is within miles of the Mississippi Gulf Coast, making the region an ideal pilot area for the CRA. The Mississippi pilot area is made up of the three coastal Mississippi counties. See Fig. 4. Data for Jackson County, Mississippi are used to illustrate the vulnerability assessment process applied by the CRA.

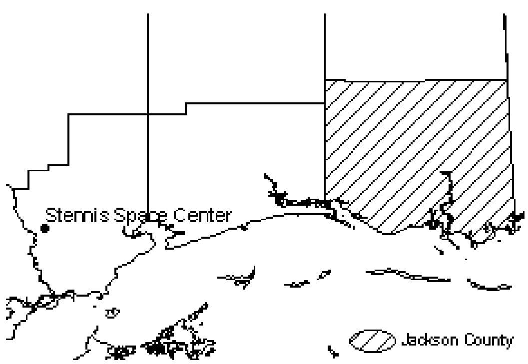

Fig. 4 Map of Mississippi Coastal Counties highlighting Jackson County

A. Data Sources

Many of the sources of digital data used in the pilot area assessment are presently available from a variety of sources by direct download through the Internet or on CD-ROM by request from data providers. One does need to know where to look, however, since considerable effort can be spent in the data discovery process, as was learned through the course of the project. Some of the data sources have already been mentioned. As in the case of many states, Mississippi has a GIS clearinghouse, MARIS, which makes GIS data relevant to the state available directly over the Internet. MARIS was the source of most of the base map layers and a variety of other important data used in the pilot area. Obtaining some data sets, such as the digital storm surge inundation maps, required direct personal contact with the provider. A listing of the most significant data and sources is provided in Table 1. As stated earlier, one of the motivating factors behind the development of the CRA is to ease the data discovery and acquisition process.

Table 1 Data Sources

Hazard Layers	
Storm Surge	USACE
FEMA Q3	MARIS/FEMA
Wind Envelopes	FEMA HAZUS / NHC
Base Map	
Evacuation Routes	MEMA*
Roads	MARIS
Streams & Water Bodies	MARIS
Demographic	
Census Data	ESRI
Miscellaneous	
Critical Facilities	FEMA HAZUS
Wetlands	U.S. Fish & Wildlife
Land Use Land Cover	FEMA HAZUS
Toxic Release Facilities	MARIS
*Mississippi Emergency Management Agency	

A. Hazard Analysis

Each hazard layer is scored according to Table 2. The numerical value assigned to each unique attribute quantifies the risk associated with each attribute. The CRA applies the union functionality in ArcGIS to combine the hazard layers into a composite data set to ease analysis. A union uses the logical operator "AND" to combine all the information in "Input" with all of the information in "Overlay". The resultant "Output" contains all the data from both layers (Fig. 5). Once all hazard layers are unioned into a single layer (Fig. 6), the risk scores of the individual hazard layers are summed in order to yield a total risk score. For example, if an area were within the category 1 storm surge, in the velocity zone, within the category 4-wind area, within a county of low tornado risk, and within one-half mile of a toxic release point, the total score for the area would be 16. See Table 3. Once the combined hazard risk layer has been created, the user possesses the base elements necessary for analysis.

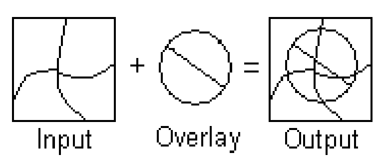

Fig. 5 ArcGIS Geoprocessing Union Function

Table 2 Hazard Risk Scores

Storm Surge	
Category 1	5
Category 2	4
Category 3	3
Category 4	2
Category 5	1
FEMA Q3	
Velocity Zone	5
100-year	4
500-year	3
Outside flood zone	2
Remainder of county	1
Wind Envelopes	
Maximum Risk	3
High Risk	2
Moderate Risk	1
Tornado	
Total county area	1
Toxic Release	
Buffer areas	2
Remainder of county	1

Table 3 Composite Score Calculation

Total Risk	
Hazard	Risk Score
Category 1 Storm Surge	5
Q3 Velocity Zone (V,VE)	5
Category 4-Wind Area	3
Low Tornado Risk	1
Near Toxic Release Point	2
Total	**16**

B. Critical Facilities

Critical facilities may include schools, hospitals and homes for the elderly, fire and police stations, communication facilities, and shelters. Since these facilities serve vital roles, particularly during and immediately after a storm event, their closure could negatively impact the surrounding community. Determining where facilities are at greater risk can serve mitigation efforts and assist in future development decisions. FEMA makes data on critical facilities available through their HAZUS CD-ROM series, but this type of data is best developed and maintained at the local level. Fig. 7 shows how facilities at risk are identified by overlaying their positions on the composite hazard layer.

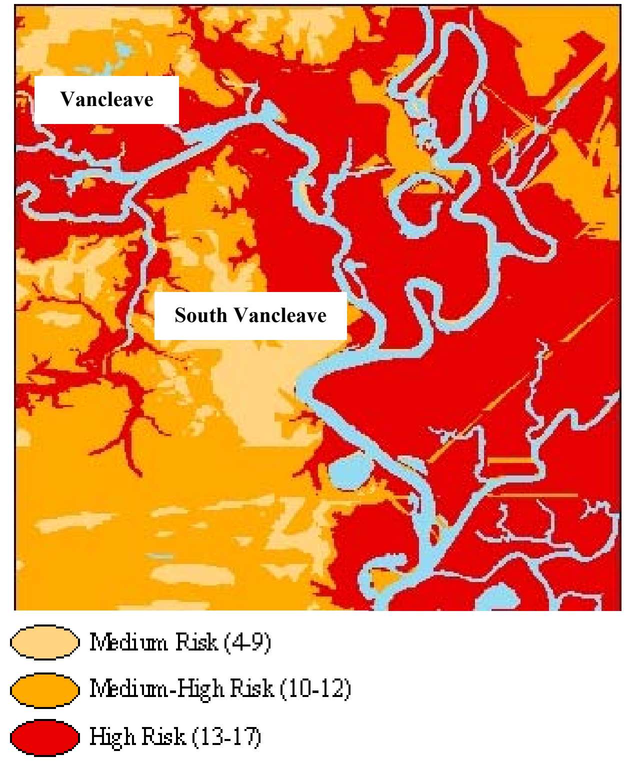

Fig. 6 Composite Risk Layer and Associated Risk Scores

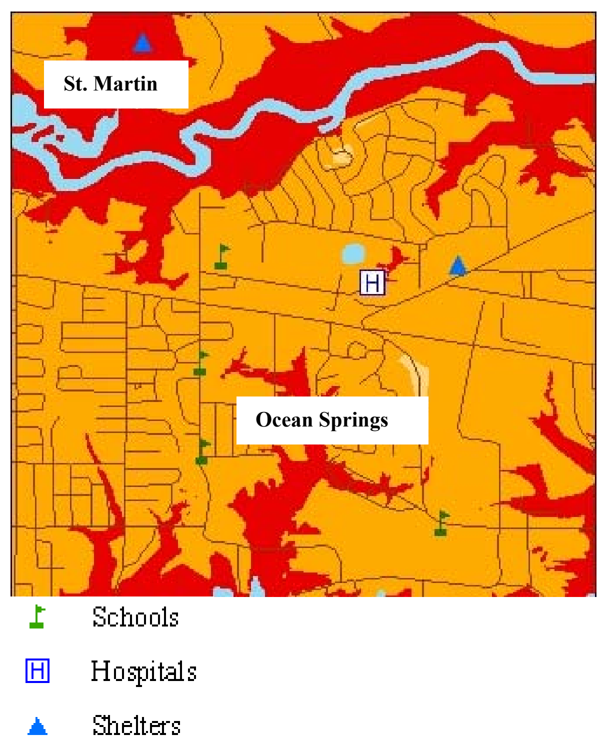

Fig. 7 Locations of Critical Facilities Relative to High Risk Areas

C. Environmental Analysis

Coastal storms can have devastating effects on the natural environment both on and offshore. The storms often cause habitat loss and displacement thus disrupting the natural ecological processes present in the area. For example, a fresh water species could be displaced to brackish water or vice versa. New predators in these changed environments can take advantage of vulnerable displaced species possibly devastating species numbers. Using the vulnerability assessment methodology, a user can gauge potential impacts to the environment by identifying the location of high valued habitats in relation to areas at high risk. Fig. 8 shows the location of wetlands in relation to high-risk hazard zones and sites of potential toxic release.

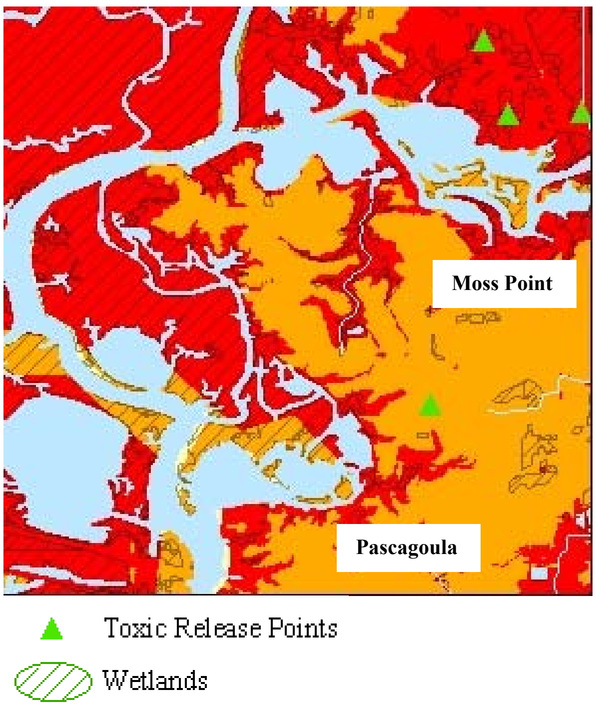

Fig. 8 Locations of Wetlands and Toxic Release Sites Relative to High Risk Zones

D. Economic Analysis

Economic vulnerability to natural hazards can be direct as in losses associated with the damage to the economic infrastructure and indirect in the form of lost jobs or erosion of the tax base. As a result, it is important to identify where the key centers of economic activity are in relation to high hazard risk areas and develop appropriate mitigation strategies. The CRA employs land use land cover data to identify concentrations of agricultural, commercial, and industrial activities.

E. Societal Analysis

Data at the block group level are used for the societal analysis since it is the smallest unit of study distributed by the U.S. Census Bureau for which extensive demographic statistics are compiled. The census data used in the CRA must be manipulated to prepare it for use in a vulnerability assessment. Percentages by block group were calculated for each of the seven different societal factors analyzed in the CRA. The calculations for Jackson County, MS as well as the other counties included in the pilot areas were performed globally within the attribute table in ArcView 8.1. (An ArcView extension is under development that will automate the census data manipulation process as well as some of the other calculations required in the vulnerability assessment process.) The percentages for each societal factor are divided into quartiles. Each quartile is given a risk score based on the percentages represented (Table 4). A map of the percentage of the population in poverty by block group is shown in Fig. 9. Risk scores associated with each societal factor are summed for each block group. The resultant total risk figure is then mapped to identify where high concentrations of vulnerable populations are located in relation to high-risk zones.

Table 4 Societal Risk Scores

Percent in poverty	Risk Score
0-5%	1
6-16%	2
17-33%	3
34-68%	4

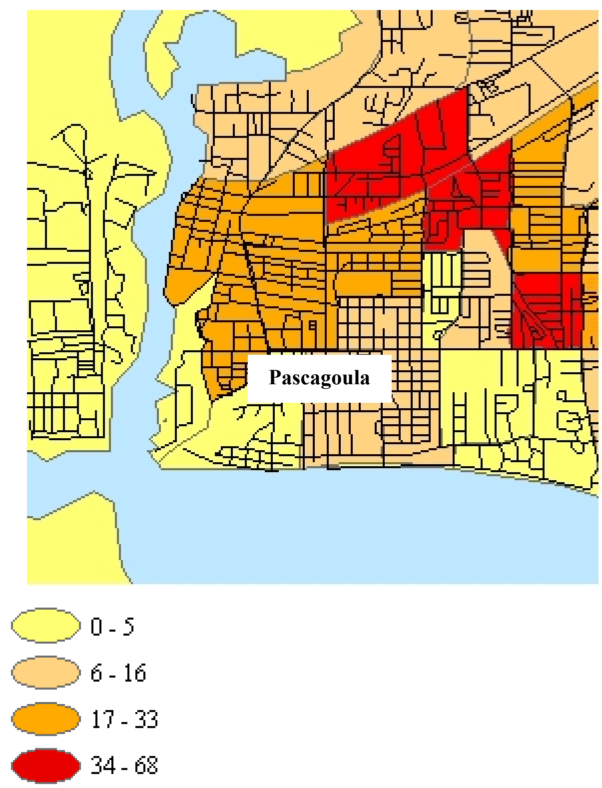

Fig. 9 Percent in Poverty

VII. CONCLUSION

The Mississippi pilot implementation of the CRA is available through the NCDDC website at www.ncddc.noaa.gov. It is being served using ESRI's Internet Map Server (ArcIMS), which permits viewing the source data and layers generated for the vulnerability assessment using only a web browser. The map layers may also be downloaded directly through the website for use in a GIS. The data made available for download are presently being served from a database resident at the NCDDC. This is expected to continue for an interim period, while the CRA coverage continues to expand into additional coastal areas. The ultimate goal, however, is to make data and information that is distributed at remote sites available through the CRA, thus eliminating the need to store vast amounts of data at the NCDDC. This will be accomplished through completion of the advanced metadata search capabilities and gateways to data providers at the NCDDC. While the initial implementation of the CRA has focused on providing data to complete coastal community vulnerability assessments, the content will be expanded to address topics such as erosion and coastal change monitoring. The goal is to provide a single source for data and information related to coastal hazards and vulnerability.

References

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