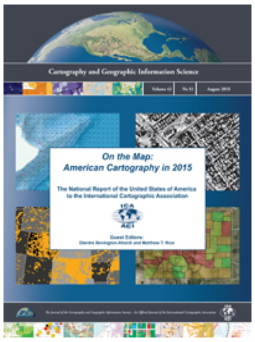

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SHORT ARTICLE

A cyberinfrastructure for community resilience assessment and visualization

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Disaster resilience is a major societal challenge. Cartography and GIS can contribute substantially to this research area. This paper describes a cyberinfrastructure for disaster resilience assessment and visualization for all counties in the United States. Aided by the Application Programming Interface-enabled web mapping and component-oriented web tools, the cyberinfrastructure is designed to better serve the US communities with comprehensive resilience information. The resilience assessment tool is based on the resilience inference measurement model. This web application delivers the resilience assessment tool to the users through applets. It provides an interactive tool for the users to visualize the historical natural hazards exposure and damages in the areas of their interest, compute the resilience indices, and produce on-the-fly maps and statistics. The app could serve as a useful tool for decision makers. This app won the top 10 runners-up in the Environmental Systems Research Institute (ESRI) Climate Resilience App Challenge 2014 and the top 5 in the scientific section of the ESRI Global Disaster App Challenge 2014.

Keywords: community resilience; resilience inference measurement (RIM) model; natural hazards; CyberGIS; web cartography

Introduction

Cyberinfrastructure, or more specifically CyberGIS, is increasingly needed to solve large-scale, multidisciplinary societal problems. Cartography and geographic information science and technology is essential to the building of cyberinfrastructure and can contribute substantially to this research area. A CyberGIS integrates data, methods, algorithms, visualization, and online collaboration into a common platform for knowledge discovery and decision-making (Wang 2010, 2013). With emerging techniques in Web 2.0 and volunteered GIS, CyberGIS has become a platform for the public to acquire and share geospatial information. These features make CyberGIS a powerful tool to handle public issues such as public health (Croner 2003), environmental management (Sakamoto and Hiromichi 2004, 2004) and urban planning (Wu, He, and Gong 2010). However, the great potential of web-based GIS in supporting sustainability and resilience analysis has not been fully exploited.

This paper reports the development of a cyberinfrastructure for community resilience assessment and visualization. The issues of hazards, vulnerability, resilience, and sustainability and their relation with climate change have been major topics spanning a number of disciplines and are being actively researched by various governmental and nongovernmental groups such as the Inter-governmental Panel on Climate Change (2014). A recent report by the US National Research Council (NRC 2012) considered disaster resilience a national priority for research and development. A cyberinfrastructure for resilience analysis that contains essential data, analytical functions, and geovisualization functions would be a critical first step toward a better understanding of the problem. The Resilience CyberGIS described in this paper includes an interface to visualize the hazard exposure, hazard damage, and census data for the conterminous United States, as well as a resilience assessment module called the resilience inference measurement (RIM) model, which was developed previously by this research team (Li 2011; Lam et al. 2014). The CyberGIS was programmed as a web app and submitted to two competitions in 2014 (Li et al. 2014). The app won the top 10 runners-up in the Environmental Systems Research Institute (ESRI) Climate Resilience App Challenge 2014 (ESRI 2014a) and the top 5 in the scientific section of the ESRI Global Disaster App Challenge 2014 (ESRI 2014b). Below, we briefly describe the data, the resilience assessment method, the computing architecture, and the visualization functions of the Resilience CyberGIS, and demonstrate functionality with a few examples. The paper concludes with suggestions on future research.

Methodology

The RIM model

Many researchers from a wide range of disciplines have examined various aspects of hazards, risk assessment, vulnerability, adaptability, and social-ecological resilience (Adger et al. 2005; Cutter, Boruff, and Shirley 2003; Cutter, Burton, and Emrich 2010; Lam et al. 2014; Vogel 2006). However,

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despite the voluminous literature in the field of disaster resilience, there is not yet a convincing approach to quantifying and measuring community resilience. There are two key issues in resilience measurement. First, most resilience or vulnerability indices were developed as a weighted average of social-ecological indicators but their weights were subjectively determined. Second, the methods used to derive the resilience indices cannot be applied to and generalized to other domains. In an attempt to overcome these two issues, we developed the RIM method and applied this method to measure the community resilience to coastal hazards for the US counties along the Gulf of Mexico. It resulted in a high degree of accuracy (Lam et al. 2014). Hence, the method was implemented in this CyberGIS for resilience assessment.

The RIM model considers three dimensions and two relations (Figure 1). The three dimensions are exposure to hazards, damage from exposure to hazards, and recovery indicators such as population growth. The relation between exposure and damage is vulnerability, whereas the relation between damage and recovery is adaptability. Communities with high vulnerability are those with low exposure but high damage, whereas communities with high adaptability are those that recover quickly even though they incur damage. We borrowed the ecological concept and classified resilience into four ranks (Batista and Platt 2003). From low to high, they are susceptible, recovering, resistant, and usurper. In general, a susceptible community has high vulnerability but low adaptability, a recovering community has average vulnerability and adaptability, a resistant community has low vulnerability but average adaptability, and a usurper community is characterized by low vulnerability and high adaptability.

To overcome the issue of validation, the RIM procedure involves two steps. First, a K-means clustering method is used to derive the resilience groups of communities based on the values of the three dimensions (exposure, damage, and recovery). Then, discriminant analysis is used to validate the groups based on a set of social-ecological indicators. These indicators can be used to indicate both the abilities to reduce damage and induce recovery and could include social, economic, governmental, health, and environmental variables. Figure 2 shows the flowchart of the procedures used in the RIM model.

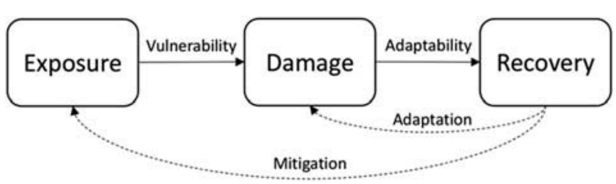

Figure 1. The RIM model (Lam et al. forthcoming).

Data

For the current version, data were obtained from two sources. Data for exposure and damage for all the counties in the US states (including Alaska, Hawaii, and District of Columbia) were obtained from the Spatial Hazard Events and Losses Database for the United States (SHELDUS™) maintained by the University of South Carolina (http://www.sheldus.org). SHELDUS is a county-level hazard loss data set for the United States for 18 different natural hazard events types such as thunderstorms, hurricanes, floods, wildfires, and others. The original data came from the National Oceanographic and Atmospheric Administration's (NOAA) National Climate Data Center. SHELDUS tabulated the data into a county-level data set. SHELDUS version 10.0 was used in this study. We computed the damage variable for each county, which is the sum of the damage from each event divided by the population of the county at the time of the event.

To more accurately represent exposure, we adjusted the number of hazard events by a weighting method because some events such as Hurricane Katrina are far more severe than a thunderstorm. The weight of an event type i (w_i) is derived as the ratio between the total damage of event type i and the total damage of all events:

$$w_i = \frac{TotalDamage_i}{TotalDamage} \tag{1}$$

The exposure for county x was calculated by Equation (2):

$$Exposure(x) = \sum_{i=1}^{M} \sum_{j=1}^{N_{xi}} w_i \left(BeginDate_{ij} - EndDate_{ij}\right) \tag{2}$$

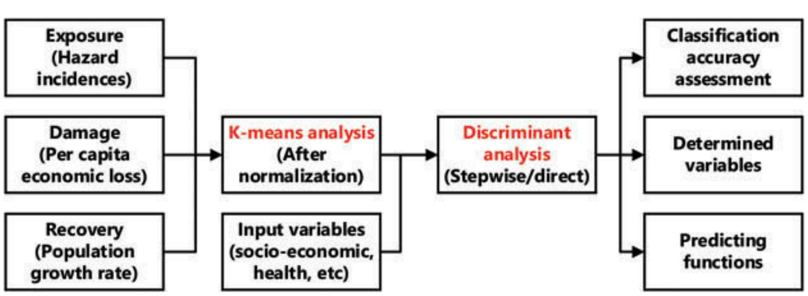

Figure 2. Flowchart of the procedures used in the RIM model.

where M is the total number of hazard types, N_{xi} is the number of hazards of type i occurred in county x, and $BeginDate_{ij}$ and $EndDate_{ij}$ are the begin and the end dates of hazard event j of type i, respectively.

Population and socioeconomic data were obtained online from the US Census Bureau (2000). The recovery variable was estimated by the population growth rate between 2000 and 2010. The 25 social-economic variables were for the years between 2000 and 2002, as listed in Table 1, to indicate the pre-event condition.

Web interface architecture

The community RIM cyberinfrastructure consists of three components: the web server, ArcGIS server, and ArcGIS Online (Figure 3). The web server collects the requests from clients and delivers the requested web services such as the computation of resilience ranks using K-means clustering and discriminant analysis as responses. ArcGIS server contains the core module for web map publishing and analysis functionalities. ArcGIS Online is used to obtain relevant base maps published by other ArcGIS server hosts.

Table 1. The 25 variables used to characterize the capacity for resilience.

Demographic	**Government**
Percent African-American, 2000	Local government finance, revenue per capita, 2002
Percent Hispanic, 2000	Local government finance general expenditures per capita, 2002
Percent under 5 years old, 2000	Local government finance expenditures for education, 2002
Percent over 65 years old, 2000	Percent of the population that voted in 2000 presidential election, 2000
Average number of people per household, 2000	
Social	**Health**
Percent of the population over 25 with no high school diploma, 2000	Disabled and not working labor forces per 10,000 individuals, 2000
Percent of the workforce that is female, 2000	3-year total low-birth-weight babies per 10,000 live births, 1998–2000
Percent female-headed households	Households with no fuel used per 10,000 house units, 2000
Percent of homes that are mobile homes, 2000	Households with no plumbing per 10,000 house units, 2000
Percent of the population that rents, 2000	Nonfederal active medical doctors per 10,000 individuals, 2000
Number of houses per square mile, 2000	
Economic	
Percent of the population living below poverty, 1999	Median rent, 2000
Percent of the workforce that is employed, 2000	Percent rural farm population, 2000
Median value of owner-occupied housing, 2000	

Results and discussion

The community RIM cyberinfrastructure is currently running online (Li et al. 2014). An Internet Information Services server is deployed to host the front-end web interface. Several ArcGIS Online base maps have been integrated using the ESRI ArcGIS for Developers API. The web interface is shown in Figure 4.

The web interface consists of two major parts: a panel window on the left and a map window on the right. The panel window has two separate panels: one for data querying and displaying and the other for the resilience assessment. Users are allowed to choose and visualize a variety of resilience-related variables (including natural hazards data and socioeconomic data) using the provided controls and the associated maps are interactively updated in the corresponding map window. An example screenshot using the total coastal hazard incidents as the selected variable is shown in Figure 5. The US counties are shaded from light yellow (lowest) to dark green (highest) to represent the values of the selected variable using the natural breaks method.

In addition, the user can highlight every county to open the pop-up box for more details. The pop-up boxes consist of three tabs (Figure 6): the first one offers the details of the top 3 hazard types in terms of the total number of incidents, total damages, and total per capita damage for each category of the selected county. The second tab is a pie chart for the total number of incidents of different kinds of natural hazard in the selected county, and the third one is a pie chart for the total damages.

In the map window, users can toggle between the topographic base map and the satellite base map for ease to find the location of their area of interest. Users can also choose the cartography and analysis unit between the county and the state level with check boxes.

In the resilience index calculation panel, users could choose the study area by using the check boxes. After the selection, the selected counties' boundary will be highlighted in the map window, and the counties' name as well as their Federal Information Processing Standard code will also be shown in the calculation panel. The 25 socioeconomic variables (Table 1) are listed for the users to assess resiliency. Users can either choose a subset or input all of these variables. After the calculation, the selected counties will be shaded according to their resilience ranks, and their resilience ranks will output as a table in the panel window (Figure 7). A complete video demo can be accessed online from the nomination page of both the

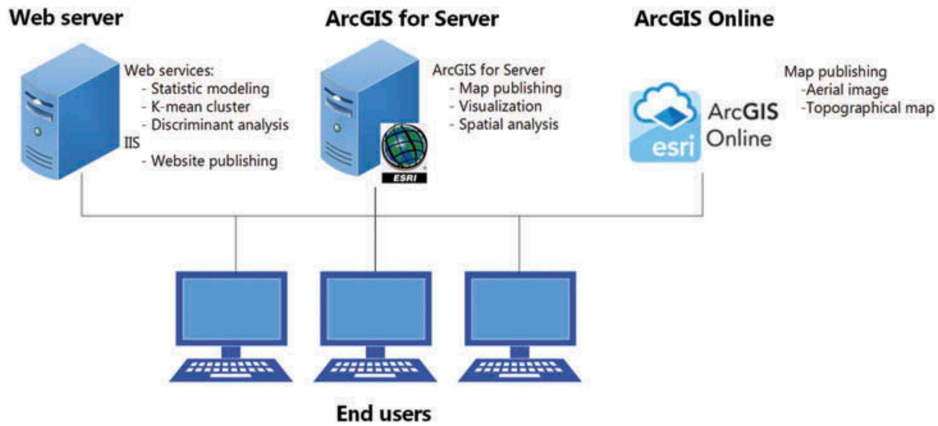

Figure 3. The community RIM cyberinfrastructure architecture.

Figure 4. Web interface of the resilience cyberinfrastructure.

Figure 5. Interactive mapping (using total number of coastal hazard incidents as an example).

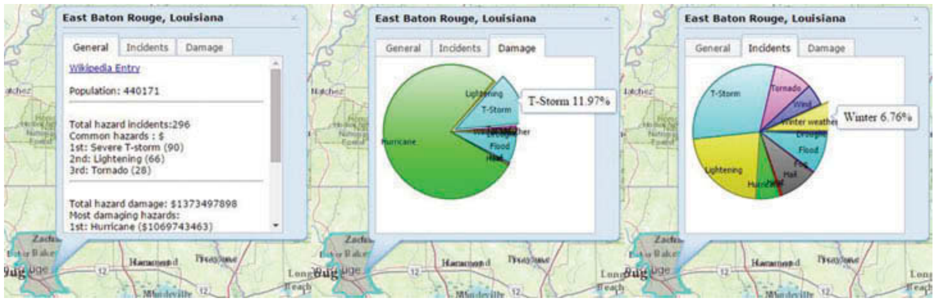

Figure 6. A pop-up window with inside tabs (using data from East Baton Rouge Parish, Louisiana, as an example).

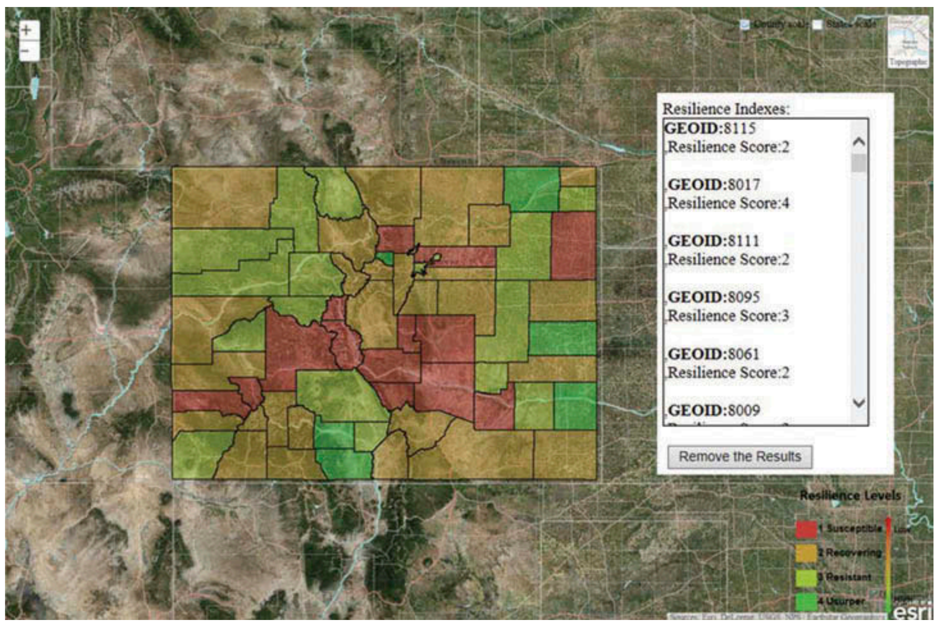

Figure 7. Results of the RIM assessment (using all counties in Colorado as an example).

App Challenges (ESRI Climate Resilience App Challenge 2014; ESRI Global Disaster App Challenge 2014), see video in supplementary data section.

The results of the resilience assessment are highly dependent on the study area and the socioeconomic variables selected. The resilience ranks computed are relative to the study area selected. Users can compare the results and the difference when certain variables are not selected. For future research, resilience calculation in the form of a simple equation derived from the discriminant analysis will be tested. Also, additional data for various aspects of resilience, especially the ecological and environmental variables such as elevation and land use land cover, will be considered.

Conclusion

This paper demonstrates the development of a cyberinfrastructure for resilience assessment and visualization. This cyberinfrastructure has many potential applications for both the public and for researchers in hazard mitigation, risk management, and resilience assessment. With the Resilience CyberGIS, more people will be able to view the hazards events, damages, and resilience-related socioeconomic factors in their local areas. The application could serve as a powerful tool for planners and stakeholders to formulate adaptability planning. For example, after identifying southern Louisiana as areas of high exposure to coastal flooding, adaptive measures such as elevating the houses could be used to reduce the property damage. Evacuation routes could be designed ahead to avoid loss of lives (Liang et al. 2015). This CyberGIS offers useful geographic information for the public to understand the world we live in, for government to assist decision-making in hazard planning, and for researchers to inspire new perspectives in resilience assessment and its application.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Supplemental data

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/15230406.2015.1060113

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