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Key Aspects in Community-Based Coastal Emergency Response GIS

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ABSTRACT
The catastrophes of Hurricane Katrina and the 2004 Asia Tsunami have highlighted the vulnerabilities of coastal communities, regardless of whether they are located in a developed or a developing country. A GIS-based community coastal emergency response is of critical importance in saving lives and reducing economic loss. This paper discusses the key aspects of developing a community-based coastal emergency response GIS. They include geospatial, socio-economic, temporal, and technical aspects.

INTRODUCTION
The catastrophic disasters from the recent Hurricane Katrina and the 2004 Asia tsunami have once again highlighted the vulnerability of coastal communities. The impact of natural disasters may continue to escalate as global warming reportedly will increase the intensity and frequency of storms even as the low-lying coastal areas are being settled at alarming rates (Changnon & Changnon, 1999; McGuire et al., 2002). The population of coastal cities has increased twice as fast as that of inland regions, with half of the global population being concentrated along coastal zones (Finkl, 2000). More strikingly, 11 of the world's 15 largest cities are on the coasts (Cohen & Small, 1998). Absolute population numbers and population density both decrease greatly with elevation and distance from the shorelines (Nicholls & Small, 2002). The population density of coastal areas within 100km of the shoreline and an elevation of 100m or less is three times higher than that of the global average, and the density is much higher in the low-lying coastal areas within 5km of a shoreline (Small & Nicholls, 2003). Consequently, effective coastal emergency response has become increasingly important because of high population density and heightened coastal vulnerabilities.

The government's decision-making process at different levels in preparing and mitigating for natural hazards is not well understood (Beller-Simms, 2004). To date, very limited research attention has been focused on community-based coastal emergency planning, while greater emphasis has been given to the studies of large area coastal management at international, national, and regional scales (Ballinger et al., 2000; Thumerer et al., 2000; Huang & Fu, 2002; Leatherman, 2003), as well as long-term coastline changes (Hennecke et al., 2000; Crowell et al., 2000; Esnard et al., 2001). In a community-based coastal emergency planning process, it is critical to understand the imperative for detailed and complete databases and the integrated and applicable mitigation strategies. This paper argues that geospatial, social-economic, temporal, and technical aspects need to be taken into consideration in developing an integrated community-based coastal emergency response GIS.

GEOSPATIAL ASPECT
Many natural hazards are dynamic natural phenomena, not necessarily hazardous to humans and human environments. They only become hazardous when their dynamic spheres intersect with the spaces of human residences and socio-economic activities. In any coastal emergency response planning, the first task is to identify the geospatial dimension of natural or human-induced hazards in relation to the human environment. Hazard inventory and assessment involves collecting the information on the hazard type, the site of the hazard origin, and the impact extent of hazardous events (Berke et al., 1984; Giarrusso et al., 1999; Papathoma et al., 2003; Wood and Good, 2004).

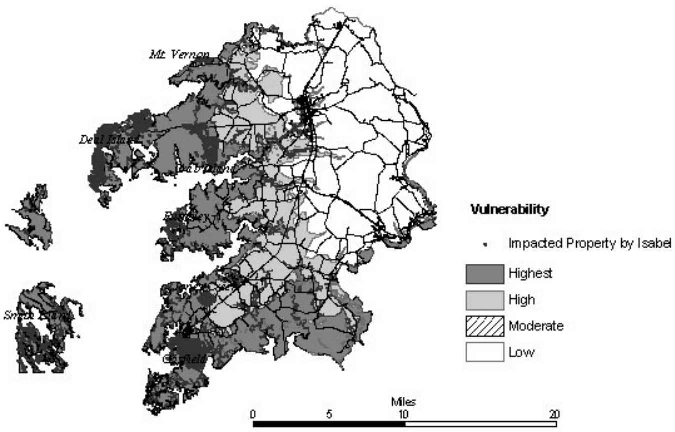
Many types of hazards threaten a coastal environment, including hurricanes, other severe storms, tsunamis, earthquakes, volcanic activity, floods, storm surge and erosion, subsidence, and salt-water intrusion, etc. In addition to these primary natural hazards, the secondary hazards, triggered by primary hazards, are also important; for example, a chemical leakage from plant structure damage caused by storms or environmental contaminants from a sewage spill caused by flooding. The site of origin is where a hazard occurs, but is not always where the impact is the worst. The impact risk is related to the hazard origin, its extent and intensity, as well as the settlement pattern of the affected community.

Geospatial studies include three steps: examining the geospatial dimensions of hazards, delineating the configuration of a community, and analyzing the spatial relationships between the hazards and the community. Defining the physical dimension for community-based coastal emergency planning requires detailed and intimate knowledge of the dynamic nature of hazards and the community. Individual flood damage estimates from National Weather Service (NWS) data for local jurisdictions are extremely inaccurate. These estimates are not reliable enough to be the basis for critical decision-making, and better damage data are needed to evaluate the effectiveness of mitigation measures and to make better preventative planning (Pielke et al., 2002). For instance, Hurricane Floyd (1999) caused more than 14.75 million dollars damage on the Eastern Shore of Maryland alone (Tallman & Fisher, 2001), but the NWS estimate of the flood damage for the whole state of Maryland for the entire year of 1999 was only 9.7 million dollars. Data at the national level, or even at the state level, may provide very limited specific guidance for local-level emergency resource allocation and management. In community-based disaster mitigation planning, all data should be geocoded and georeferenced at individual street and structure level.

Somerset County, Maryland, is an excellent example for coastal flooding risk assessment. It is a small, poor rural county, but has the longest coastline in the state of Maryland, with 619 miles of shoreline along the Chesapeake Bay. Topographically, the county is located in a low-lying coastal plain, with four major rivers. In addition, the county also includes three islands, all of them inhabited. Because of the county's low-lying topography and extensive coastline, the area is prone to coastal flooding hazards from storm and tidal surge and hurricane impact. For example, the coastal flood vulnerability map for Somerset County, Maryland is made by incorporating hurricane SLOSH model data, 100-year floodplain Special Flood Hazard Area (SFHA) data, and then local low-lying elevation data in GIS (Figure 1).

SOCIO-ECONOMIC ASPECT
Research on natural hazards calls for integrating socio-economic data into the emergency mitigation and response processes (Cutter, 1996;

Figure 1. Coastal flood vulnerability of Somerset County, Maryland



Fisher et al., 1998; Bowen & Riley, 2003; Beller-Simms, 2004). Socio-economic analysis should accomplish two important objectives: to identify the people who are exposed to the risks and at the same time incapable of protecting themselves from the risks and to delineate community critical resources and assets for allocation and protection.

First, using GIS to analyze the socio-economic characteristics of the most vulnerable groups to hazards allows a community to initiate and promote better emergency awareness, preparation, and fast response efforts. Natural disasters have the greatest effect on the poor people. Residents of small communities may experience more frequent risk exposures, have less access to opportunities to mitigate disasters, and often remain silent victims (Cross, 2001; Weichselgartner & Obertsteiner, 2002).

Second, socio-economic GIS analysis also includes an earnest assessment and optimal utilization of community resources and community asset protection. GIS addresses many where-&-what questions, such as where are the critical road networks and bridges for rapid response, recovery, and evacuations? What are the resources for protection and/or relocation? In addition, emergency services should be identified and geocoded into the database, such as law enforcement, fire department, ambulance services, health services, hospitals, emergency sheltering, food and water supply. GIS databases help a community to formulate a multi-tiered protocol of inter- and intra-organizational cooperation and activation strategies in response to an emergency. The emergency response to Hurricane Katrina was partly stymied by a leadership vacuum, according to the reports of major US news media.

The socio-economic study of Somerset County was done by examining census data, county property data, and flood vulnerability data through GIS. According to the U.S. 2000 census data, Somerset County has the lowest personal income per capita in Maryland, the lowest median household income of $29,903 in comparison with the state's average of $52,868, and 20.1% of people below poverty. Through the GIS analysis, of the 9,114 house structures, 48% are located within the 100-year floodplain, 35% in the impact zone of category I hurricanes, 69% within the impact zone of category IV hurricane, and 51% of these potentially affected properties are particularly poor structures (with values of 50,000 or less based on 2002 assessment). In addition, the concentrated areas of children, elderly, and people with poor health were mapped. These areas included daycare centers, schools, group homes, and nursing homes. Mapping the socio-economic information can optimize resource allocation and greatly facilitate the mass evacuation process in case of a disastrous emergency.

TEMPORAL ASPECT

The time dimension is rapidly warped once a disaster strikes a community. The hazard often rips through a community in a few short minutes, or hours, or days. But the recovery and rebuilding often stretch out into months, or decades, or beyond (Keller, 2004). Temporal study should capture all possible information over time about disasters as they rampage through a community or communities and track the changes and the rates of change to benefit future emergency planning and mitigation management efforts. Lessons learned through temporal study improve the resilience of a community and its natural environment.

The critical importance of the temporal aspect in coastal management has been documented by many studies (Crowell et al., 1991; Esnard et al., 2001; Leatherman, 2003). In community-based coastal management, the action timeline should be defined for different tasks, such as emergency notification and evacuation, response and recovery, and post-disaster management. In anticipation of an emergency, the priority sequence and timeframes should be clearly defined for utilizing the critical infrastructures and resources and communicating the info to the residents.

Hurricane Katrina gave the US government a crucial lesson: those people who are from disadvantaged socio-economic groups have the least access to resources and are more vulnerable and should be given timely and more expeditious response efforts during an emergency. In the mean time, the estimation of hazard duration is vital in formulating an emergency response plan.

TECHNICAL ASPECT

In today's information age, technology is not only visibly important, but also nearly indispensable in any effective and efficient emergency response. The 911 terror attacks heightened the critical nature of technology use in an emergency situation. Detailed studies using GIS and other new technologies have become important and necessary in a high precision emergency response decision-making process (Rubec et al., 1998).

GIS, GPS, and remote sensing technologies allow rapid data collection, processing and analysis, and integration. This capability is particularly suited for studying hazard prone coastal areas (Mumby et al., 1995; Chen et al., 2003; Wood & Good, 2004). These technologies have been successfully applied in coastal flood risk assessment and management (Hennecke et al., 2000; Thumerer et al., 2000; Huang & Fu, 2002), coastal GIS modeling and toolset development (Ji & Li, 2003), and change-detection studies (Eshard et al., 2001; Rubec et al., 1998; Scholten et al., 1998; Colby et al., 2000; Wang et al., 2002; Dobosiewicz, 2001; Papathoma et al., 2003). A combined application of spatiotemporal analysis of satellite imagery and GIS has become a new generation of techniques deployed in the emergency management preparedness process (Finkl, 2000; Greve et al., 2000).

It is an easy, yet terrible, mistake to make to think that all communities of various sizes nationwide operate in the same technical reality. There are major disparities in terms of the capability of communities to access and utilize new technologies in coastal emergency response and management. Given the reality that many decision makers are not GIS experts, community-based emergency response GIS should accomplish the following major tasks:

1. Provide a toolset for storing the data (geospatial, demographic, economic, and temporal datasets) that will present a more complete and accurate picture of strengths and weaknesses, demands and resources of a community.
2. Serve as the "CPU" to process the community-based emergency response databases and to address the "what-if" scenarios in an accurate and timely manner. Where would be the impact areas and evacuation routes? Relocation shelters? Which agency should respond? And when to respond?
3. Serve as a dynamic archive system where the databases are updated, where the changes of the community vulnerability and risks over time are monitored, and where the effectiveness of community mitigation efforts over time are compared.
4. Function as a powerful information visualization and distribution gateway in assisting community government agencies in the

decision-making and decision-dissimilating process. This gateway will integrate multi-dimensional data, depict the analysis results, and allow government and general public to access data, maps, and reports without getting involved with actual GIS operations.

On September 18, 2003, Hurricane Isabel made landfall at the northern Outer Banks of North Carolina and continued its onslaught, sweeping across the states around the Chesapeake Bay. After the storm, Somerset County faced the enormous task of quickly responding to emergency calls, restoring community services, as well as surveying the storm damages. Using GIS to incorporate Maryland PropertyView data with some ground observation reports allowed the rapid damage assessment of house structures (Figure1). Eight neighborhoods were flooded, and the total gross flood damage was estimated at greater than $20 million. Without the information and technical tools, local decision makers with limited resources often defer natural hazard mitigation to focus on other community services (Wolfe et al., 1997).

DISCUSSION AND CONCLUSION

Coastline is a dynamic battlefield full of threats imposed by the hazards of the natural processes and human-imposed activities from both the terrestrial and oceanic fronts. As more and more people are settling within coastal zones, development infringes into the dangerous zones of natural hazards. Coastal emergency response is an ever-evolving process in anticipation of the vicissitudes of coastal zones over time.

The patterns of population settlement and the development trends of society have presented a pressing need for more community-based coastal emergency response. The impact from hazards will no longer just involve a sparsely populated location, but rather include a community or several communities. With the accumulation of more data and the availability of new technology toolsets, it is time now to shift research attention from passive-response approaches to use GIS for community-based proactive-mitigation emergency response strategies.

The development of coastal emergency response GIS requires consideration of the geospatial, socio-economic, temporal, and technologic aspects. Geospatial study delineates a community's physical configuration in relation to the potential impact extents of hazards. It involves a complete inventory of the type, intensity, and spatial impacts of all hazards at street level. Socio-economic GIS analysis can further delineate the individual's risks within a vulnerable community. After all, not everyone in an impacted community is equally exposed to hazards, nor has the equal capacity to respond to them effectively. The socio-economic aspect also addresses the vital interests and assets of a community. It sets up a priority code for the community residents and the critical resources and infrastructures in response to an emergency. Temporal study tracks the dynamic changes of a coastal community and monitors the changes of the frequency, intensity, and spatial impact of hazards over time and formulates a timeline for future emergency response. Only if a community learns the lessons from its hazard history can the toll of human and economic loss be lessened or prevented. Finally, technical aspect incorporates the utilities of technologies (hardware, software and people) into the coastal community-based emergency response. GIS allows the integration of large volumes of comprehensive data in developing integrated, effective, and efficient coastal emergency response strategies.

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