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Leveraging on Geographic Information Systems (GIS) for Effective Emergency Response Management

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1 Abstract:

Global climate change and worldwide instabilities have affected urban areas. In spite of all the technological advances, the impacts of natural and manmade disasters in urban areas represent an increasing challenge – therefore effective mitigation and emergency response strategies are pivotal.

An effective and efficient Emergency Response Management System (ERMS) for natural or manmade disasters in urban areas has been proposed. The ERMS includes vulnerability assessment, damage prediction, ERMS simulation, situation analysis, damage assessment and resource allocation which require real-time data, analysis, visual modeling and monitoring systems.

Advanced interactive capabilities of data capture, data management, analysis, modeling visualization, and real-time data exchange has made Geographic Information Systems (GIS) an effective information system for emergency response management. Increases to higher quality, real-time data coupled with easier connectivity between GIS and new communication technologies such as mobile and satellite phones, real time tracking systems and increased worldwide internet connectivity promotes the rapid improvement of emergency response.

The paper presents a GIS web-based interactive ERMS system that can be applied to many kinds of disasters across numerous environments. This system would be helpful for an ERM team to take proactive measures for effective emergency response planning and management by providing timely and valuable information. Professionals need to make informed decisions during a disaster response situation; this system will help them through real-time tracking and effective communication for effective emergency response management. Hence, this study is valuable for all professionals involved with disaster management.

2 Introduction

The recent sudden increase of natural and manmade disasters has taught many valuable lessons (Iglesias, 2007). Unfortunately, the need for preparedness is greater than ever before, given the increasing frequency and worsening intensity of weather-related storms and the escalation of technological threats. No geographical area is immune or protected from the threat of emergencies and disasters. The importance of a proactive approach in responding to a disaster scenario in term of learning from past projects cannot be overstated (Arain, 2008). Pre-planning with local public safety and emergency response agencies can decrease confusion when a jobsite incident occurs (Ahmed, 2008). A quick response due to proper pre-planning and preparedness can expedite saving lives and rehabilitation process (Arain, 2008).

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Post-disaster reconstruction and rehabilitation is a complex issue with several dimensions (Arain, 2008). Many professionals in both fields tend to focus on planning and immediate response and have only recently begun to consider the requirements and opportunities inherent in long-term mitigation and reconstruction (Vale and Campanella, 2005). The complex and multi-faceted processes of post-disaster recovery and reconstruction extend well beyond the immediate period of restoring basic services and life support infrastructure. While immediate restoration of services can be a matter of weeks, full recovery can stretch out 10-15 years (Pelling, 2003). Government, non-government, and international organizations have their own stakes in disaster recovery programs, and links must be established among them, as well as with the community as shown in Figure 1 (Shaw et al., 2003). In other words, a post-disaster rehabilitation and recovery programs should be seen as an opportunity to work with communities and serve local needs. Relief and development often leads to burdens on the recipient government, and also often fails to serve the actual purpose and to reach the people in need.

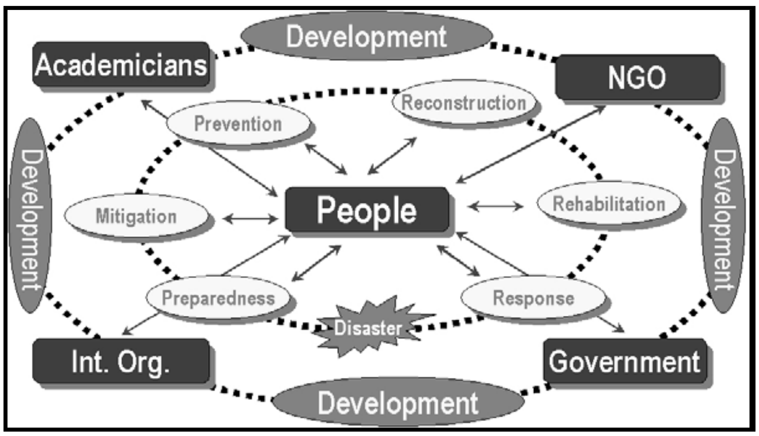

Fig. 1. Disaster cycle, development process and stakeholder involvement (Arain, 2008)
[Source: adapted from Shaw *et al.*, 2003]

Environmental management professionals are now concentrating on the sustainability of environmental quality and environmental improvement; emergency managers and planners are re-focusing their efforts on the survivability of systems, organizations, and communities (Vale and Campanella, 2005). Sustainability and survivability are, in truth, two aspects of the same concept, namely: how to encourage and achieve continual improvement in ecosystems, the built environment, and human society (Pellow and Brulle, 2005). Both environmental management and emergency management have much to contribute to, and to gain from, the planning and implementation of post-disaster reconstruction.

Development is a dynamic process, and disasters provide the opportunities to vitalize and/or revitalize this process, especially to generate local economies, and to upgrade livelihood and living condition. Shaw and Sinha (2003) suggested the ideal level of involvement of different stakeholders after the disaster, as shown in Figure 2. The standard time frame of rescue, relief, and rehabilitation are defined as short term, long term, and longer term respectively.

Increasing worldwide impact of climate change, environmental degradation from human exploitation, urbanization and economic and social instabilities, unknown patterns and consequences of recent type of natural and manmade disasters, social and cultural complexity of urban residences and the aging urban infrastructures has increased the level of vulnerability to any type and different level of disaster (Pelling, 2003). Due to the increasing urbanization and population growth, the impact of any type of disaster (natural or manmade) in an urban area can be devastating with longer recovery period.

According to the World Disaster report by the International Federation of Red Cross and Red Crescent (IFRC, 2001), natural disasters account for the most devastating types of disasters. Earthquake, flood and storms are the most expensive in economic terms; however, drought and famine are more devastating in human terms. Earthquakes accounted for 30 per cent of estimated damage, they killed 9 percent of all those killed by natural disasters. Meanwhile, famine killed 42 percent, but accounted for 4 percent of damage, over the past decade.

Highly concentrated urban environments and sophisticated manmade environments are increasingly impacted by new types of disasters. Increases to the number of natural disasters such as hurricanes, cyclones, typhoons, droughts and floods due to climate change, increases in growth and the complexity of manmade disasters such as International and national conflicts, fundamentalism and terrorism has made the urban areas the most vulnerable areas to any type of disasters (Hidellage and Pullenayegem, 2008).

The NATECH (Natural Hazard Triggering Technological Disasters) disasters, such as the recent Tsunami in Fukushima, and the TECHNA (Technological Hazard Triggering Natural Disasters) disasters, such as The Drying of Iran's Lake Urmia, and their environmental consequences can cause national, regional or even international disasters or catastrophes.

A review of news archives illustrates that the number of “natural” and “manmade” disasters have increased substantially over the past 30 years. In the past eight years, some 422 disaster declarations have been issued in the United States alone – etching disasters as an important part of contemporary American experience (Brunsma and Picou, 2008). Disasters as destabilizing events have cost thousands of lives and millions of dollars in damages to infrastructure and the economy at regional and national levels (Ahmed, 2005).

It is critical that governments across the globe develop their response capacity to different types of disasters by reviewing the risk analysis, using new technologies, communication methods and community participation in disaster management as part of their commitment to disaster risk and mitigation (Arain, 2008).

The international community continues to be the ‘provider of last resort’ for humanitarian assistance, but has an increasing role in supporting local efforts. In such a volatile and rapidly changing situation, the Civil Protection Plan (CPP) and the Emergency Response Management System (ERMS) require upgrades and constant information updating to predict, manage, analyze and plan for relief operations before, during and after disasters to minimize the loss of human life.

Information is a prerequisite in all research and development activities, and can be regarded appropriately as the life-blood within which business interactions unfold (Low, 1993). Knowledge acquisition is the major bottleneck in the industry (Skibniewski, et al., 1997). GIS (Geographical Information System) is a means of representing data in digital form that has been used increasingly in various domains. GIS has the ability to capture, model, manipulate, retrieve, analyze and present geographically referenced data (Low et al., 2007).

Efficient management of a disaster requires pre-identification, prediction and analysis of consequences prior to a disaster event. Advanced interactive capabilities of data capture, management, analysis, visualization, and real-time data exchange and modeling has made GIS the most effective information system for emergency response management. GIS compatibility with new communication technologies such as mobile and satellite phones, real time tracking systems and increased worldwide internet connectivity promotes the rapid improvement of emergency response (Hess *et al.,* 2002).

GIS uses stored data to create customized computer-based maps showing locations and attributing information about objects of interest to a decision maker. It can be used to create decision support system for use with specific decision needs (Cheng *et al.,* 1996). GIS software is widely used in various stages of planning management, and is also an invaluable asset in information system. GIS as a system for creating and managing spatial data and associated attributes (Longley *et al.*, 2001). In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, and displaying geographically-referenced information. In a more generic sense, GIS is a "smart map" tool that allows users to create interactive queries (user created searches), analyze the spatial information, and edit data (Low et al., 2007). Within the context of GIS, both urban infrastructure, and population are geographical features, subject to all characteristics of spatial and non-spatial data, which allows data collection of different features.

Analyzing the data related to each feature can help to mitigate a disaster and its impacts on urban environment. GIS technology supports the emergency response managers and organizations by facilitating real time data collection, data integration, querying, spatial, statistical and analytical modeling. GIS, web mapping services, and new communication technologies such smart phones, satellite phone, GPS equipped cameras and Wi-Fi technology enable the emergency mangers to create a net of interactive real time data.

A GIS based ERMS can respond to emergencies by centralizing disaster related data, develop a visual interactive vulnerability database, model the possible types of disasters and forecast consequences which enable the ERM teams to optimize the utilization of the response time after a disaster. The operations center can be in the disaster zone or remotely in an area offering a stable environment.

3 Emergency Response Management System (ERMS)

3.1 Urban Vulnerability Assessment

Understanding the urban vulnerabilities is as complex as managing a disaster and is an essential step in developing an EMRS. The bigger the vulnerability the bigger will be the impact of the natural and manmade disasters.

Urban vulnerability within the context of the ERMS indicates that an urban texture will face a critical situation if confronted with any type of disaster. In order to identify and classify vulnerable urban areas it is essential to study the urban areas based on the type and level of vulnerability with an integrative vision to understand the urban infrastructure and its social, cultural and interconnected complex layers (Pelling, 2003).

In the GIS based ERMS the urban vulnerabilities are classified as Technical and Non-technical vulnerabilities. It is important to understand the distinct nature of different technical & non-technical complex vulnerabilities and to cultivate a database that has geographical relationship to tie in with real word to the areas of interest with their specific history when it comes to emergency needs.

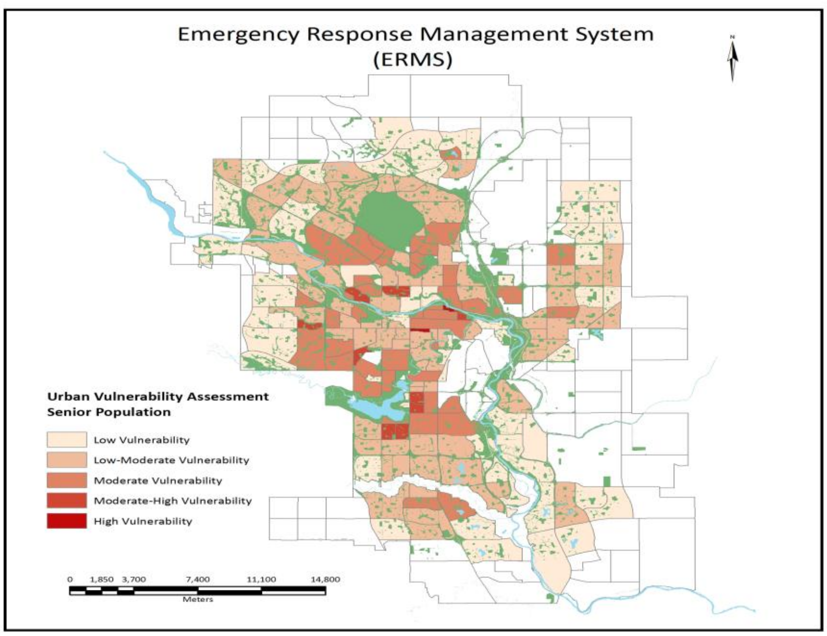

Fig. 2. Urban Vulnerability Assessment Senior Population

The technical vulnerabilities are based on the impact of different type of disaster that eventually affects urban infrastructure and residential, commercial, and industrial buildings (Pelling, 2003). Classification of disaster impacts, based type of structure, dimension of infrastructures, overall age of the establishment, construction materials, standards used will allow EMRS managers to determine the level of risks and consequences based on different scenario, an example is shown in Figure 2.

The non-technical vulnerabilities refer to social, cultural, religious, economical, ethnic and demographic, components of the urban communities (Pelling, 2003). The urban communities have different level of vulnerability toward various type of disasters based on their ethnicity, income, health, family formation, number of vulnerable population (women, children and elders).

GIS enables ERMS mangers to collect, classify and analyze data regarding both technical and non-technical vulnerabilities to determine the most sensitive urban communities and predict possible scenarios, and model the required emergency response.

3.2 GIS and Urban vulnerability

The GIS use in EMRS includes two main phases:

Phase 1- Pre disaster data collection and analysis phase

a. collecting, integrating, visualizing and analyzing the spatial and non-spatial vulnerability data (categories and level of vulnerabilities) to identify different type of vulnerable zones and section in urban areas
b. modeling different type of disaster scenario and analyzing their consequences on different areas based on the level of vulnerability

Phase 2- Disaster response and operational phase

a. Interactive and real time data collection by the use of mobile GIS, smart phones, and Wi-Fi technology
b. Integrated communication with emergency response organizations and team operating in the disaster affected area

The result of the urban vulnerabilities assessment integrated into an EMRS geo-database as different layers enable ERMS team to visualize the level of vulnerability. The vulnerability layers are the essential layers to predict the consequences of different types of disasters and analyze their impacts based on their intensity level.

The identification of different type of construction standards in the urban environment will enable the ERMS team to categorize urban infrastructure based on the resistance/ vulnerability level to each type of disaster.

For example, the consequences of a tropical storm can be directly related to the standards of construction used in residential building. A different reaction to different factors would occur in the event of an earthquake. Residential areas with low construction standards are more vulnerable to different type of storms or earthquakes.

In the case of terrorist attacks targeted on civilians the highly populated areas are more vulnerable and the construction standard might not be as important as the previous case. The following resources could be applied to model and predict the consequences of disaster scenarios:

1. Vulnerability level of urban infrastructure
    a. Residential and commercial structures
        - Public facilities
        - Private facilities
    b. Industrial complexes
        - Non-hazardous industries

- Hazardous industries
  - Chemical or nuclear complex

2. Vulnerability level of public services infrastructure
   a. Transportation infrastructure
      - Airports, train stations, bridges, tunnels, roads
   b. Critical facilities
      - Water supply system
      - Transmission line
      - Hospitals, firefighter station, police, army stations, banks

3. Vulnerability level of communities
   a. Accessibilities
   b. Acceptability of the ERMS plans

4. Vulnerability level of Social & Cultural demographic
   a. Population
   b. Age
   c. Income level
   d. Religion
   e. Visible minorities
   f. Cultural differences

5. Vulnerability level of Institutional organization
   a. Acceptability of the new ERMS
   b. Capacity and adoptability with new ERMS

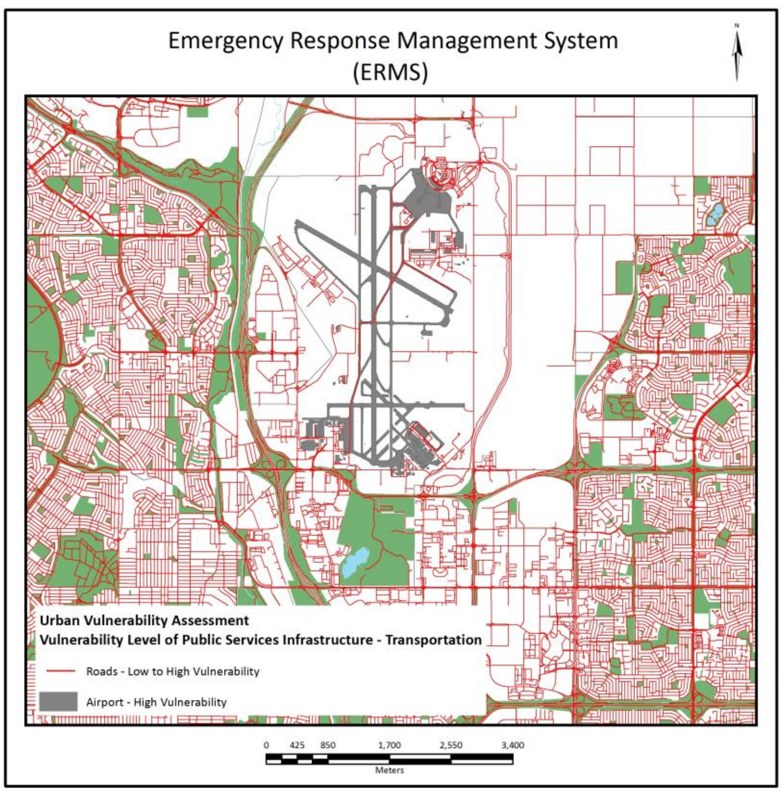

Fig. 3. Urban Vulnerability Assessment – Vulnerability Level of Public Services Infrastructure

The previous resources that could be applied to model and predict the consequences of disaster scenarios can be classified as follows:

- Infrastructural vulnerability
- Economical vulnerability
- Social and cultural vulnerability

Each type of vulnerability mentioned above and their subdivision can be integrated as a different GIS dataset and all the subsections are illustrated as different layers. An example of infrastructural vulnerability is shown in Figure 3.

3.3 Functionality of GIS as a vulnerability assessment tool

Using GIS software to represent various statistical data in a 3D format gives a better and clearer understanding of data. The benefit of a GIS based ERMS model is in its ability to capture new geo-referenced data and use it in a timely manner to assess the vulnerability of any geographic area based on multiple attributes. The considerations listed above can be entered into the GIS system as a series of layers that can be combined with other layers to represent a vulnerability risk factor. When these layers are combined, the result is a comprehensive and dynamic prediction model. Flexibility within the model is possible because each emergency scenario has specific risks associated with it. When the predictive model takes place, only the vulnerability layers relevant to that specific emergency will be added to provide comprehensive vulnerability assessment customized to each emergency scenario.

The analysis that is provided will be both spatial (patterns, trends and associated spatial statistics) and non-spatial (tabular data and associated statistics). Depending on the layers added to the model, interaction of the specific risk factors can be processed and visualized in the form of a map as well as quantified by the statistical capabilities of the GIS software. The higher quality the data layers used in the model the more detailed and specific the results of the model will be. Using different combinations of layers, the GIS based ERMS model will have the ability to predict the consequences of different disaster scenarios. The results of the analyses will also be saved as a layer that can be referenced in the event of an emergency to help assess where resources and aid is likely to be most needed.

A significant functional advantage will also be the ability for first responders to use the web based ERMS as a means of communication to update risks, needs, and requests in real time. Communication that includes a spatial element is essential in emergency response scenarios. The updates can be visualized on an interactive map which enables decision makers to better understand the challenged that need to be addressed.

4 Conclusion

The paper presents a GIS web-based interactive ERMS system that can be applied to many kinds of disasters across numerous environments. In response to the increasing frequency of “natural” and “manmade” disasters, the development of an Emergency Response Management System (ERMS) has been proposed. The ERMS includes vulnerability assessment, damage prediction, ERMS simulation, situation analysis, damage assessment and resource allocation which require real-time data, analysis, visual modeling and monitoring systems.

Advanced interactive capabilities of data capture, data management, analysis, modeling visualization, and real-time data exchange has made Geographic Information Systems (GIS) an effective information system for emergency response management. Increases to higher quality, real-time data coupled with easier connectivity between GIS and new communication technologies such as mobile and satellite phones, real time tracking systems and increased worldwide internet connectivity promotes the rapid improvement of emergency response.

The ERMS would include the ability to perform vulnerability assessment, damage prediction/assessment, situation analysis, and resource allocation tasks in both technical and non-technical levels. The proposed system would be web-based and leverage GIS technology to provide real-time data exchange, modeling, analysis, visualization and capture functionality as well as facilitate an effective form of communication. Leveraging new technologies, reviewing risk analysis factors, and inviting community participation are methods that can be used to develop response capacity for different types of disasters. Centralizing disaster related data and developing a vulnerability database will enable ERM teams to optimize resources and reduce response time after a disaster. Vulnerability assessment inputs are data regarding construction standards and vital public infrastructure but also include social, cultural and economic data. The GIS component of the ERMS enables users to combine the various data layers to produce a comprehensive and dynamic prediction model.

This system would be helpful for an ERM team to take proactive measures for effective emergency response planning and management by providing timely and valuable information. Professionals need to make informed decisions during a disaster response situation; this system will help them through real-time tracking and effective communication for effective emergency response management. Hence, this study is valuable for all professionals involved with disaster management.

Tapping on the real-time data exchange, modeling, analysis, visualization and capture functionality post-disaster scenarios, the ERMS provides a wealth of pertinent and useful information for decision makers and will eventually enhance collaborative ventures. By having the ERMS and a systematic way to make well-informed decisions, the efficiency of project team and the likelihood of strong coordination and eventually successful emergency response should increase. The study would assist professionals from academia and industry involved in research and reconstruction and disaster management. The system would be helpful for them to take proactive measures for reducing uninformed decisions related to team building and project coordination processes undertaken by disaster response management agencies. Professionals need to work in close cooperation with each other to give rise to a better and more efficient system. Hence, the study is valuable for all the professionals involved with research and development in the domain of reconstruction and disaster management.

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