Applications of geographic information systems in disaster management: a promising future

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Introduction

As public health workers and researchers, we have a significant role to play with regard to disasters. As Bradt elegantly illustrates (see Figure 1), disaster response involves the overlapping fields of public health, clinical medicine, and disaster management. (1) In light of the recent (2005) Indian Ocean tsunami that devastated several surrounding countries, this is an opportune time to examine our previous approaches to disaster management and prevention and to consider future public health contributions to disaster work. The grounds for such a review are obvious: disasters are frequent events (when quantified on a world-wide basis) that are extremely difficult to manage. According to the International Federation of Red Cross and Red Crescent Societies (IFRC), arguably the most internationally-recognized disaster relief organization, disasters are not only frequent, but also their incidence has been increasing in recent years. Between the years 1994 and 1998, the IFRC counted an average of 428 worldwide disasters per year, whereas, that average skyrocketed to 707 disasters per year for the years 1999 through 2003. (2) Clearly, disasters are not rare events.

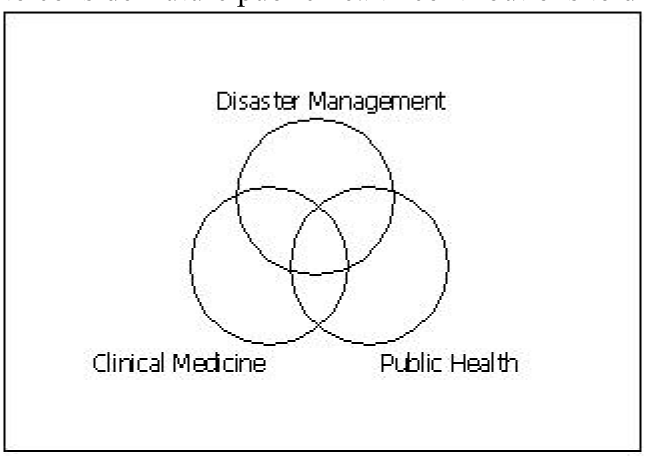

Figure 1

To put these numbers in better perspective, it is important to note how the IFRC defines disaster. According to the IFRC, all disasters, "regardless of cause," have the following characteristics in common:

- A great and sudden misfortune
- Beyond the normal capacity of the affected community to cope, unaided
- The interface between vulnerable human conditions and a natural hazard. (3) [direct quote]

Bradt and Drummond point out that the IFRC provides an even more precise definition of disaster when one speaks of this word from a surveillance perspective. In this specific case a disaster is any event "…meeting at least one of the following criteria: kills 10 or more persons; affects 100 or more persons; leads to a declaration of state of emergency; or leads to call for international assistance." (1) Other authors use various terms as synonyms for the word "disaster." For instance, Kaiser prefers to use the term "humanitarian emergency," (4) Benini and colleagues chooses to refers to these events as "humanitarian actions," (5) and Garthe and Mango speak of "mass casualties." (6) For the purposes of this review, we will group all these events under the umbrella word "disasters." Once we define the word disaster, we may categorize the types of disasters several ways; however, the most natural schema is to subdivide disasters into two main categories: those triggered by human action (e.g., war, chemical spills, terrorist acts) and those caused by nature (e.g., hurricanes, tornadoes, mudslides, etc.). (7) The main feature that distinguishes these two categories is the type of prevention strategies that one may employ in each case. For example, sociological approaches to prevention (such as diplomacy in the case of armed conflict) would be more relevant to human-triggered disasters as opposed to natural disasters.

The enormous impact of disasters on public health is due not only to the their high frequency, but also to the challenges that disasters pose to relief workers. There are at least three characteristics of disasters that lead to significant managerial challenges. First, timing is extremely important in disaster management. Effective disaster management requires rapid decisions and actions on behalf of relief workers. (7) Second, by definition, the scope of disasters is large (in terms of the number of people affected). Finally, and possibly most importantly, there is usually a lack of resources to manage disasters. Often, disasters destroy local resources (e.g., when a hospital collapses due to an earthquake) or render outside resources inaccessible (e.g., when roads are destroyed by a flood or the dangers of war prevent transportation). Although these three features of disasters are typical of most public health issues, the magnitude of these factors is often greater during a disaster.

Information is usually the best means to prevail over these disaster challenges. Thus, the application of health informatics (and specifically public health informatics) is likely to improve the management and prevention of disasters. (Indeed, the National Library of Medicine, the leading funder of health care informatics research, appears to agree with this contention since the agency offers specific grants targeted at disaster management.) In the recent past public health researchers and workers have usually turned to geographic information systems (GIS) to address their information needs during disaster management projects. As such, this essay will focus on previous research and development efforts to apply GIS to disasters as well as future trends in the field.

Principles of Disaster Management

Before we review the use of GIS during disasters, it is important to identify the guiding principles of disaster management. Campbell organizes disaster response into four phases [originally identified by Tailhades and Toole (8)]: preparedness, alert, response and recovery. Preparedness involves activities such as risk-assessment, strategic planning, and training/education (for example, first-aid instruction or earthquake drills in schools). The alert phase is the time-period immediately preceding a disaster in which early-warning systems may detect the imminent catastrophe. This phase is non-existent for some types of disaster (e.g., earthquakes), short for others (e.g., volcanic eruptions), and relatively long for the remaining (e.g., armed conflicts). During this phase, "information dissemination" is a crucial role of disaster responders, since the public should review contingency plans during this phase and/or may need to evacuate to a safer location. The third phase, response, begins with assessment. Within one to two days, disaster responders should determine the magnitude of the impact on the victimized community and measure the availability of local resources to respond to the emergency. Medical and public health personnel should begin immediately the provision of health care services (including psychosocial aid) for those harmed by the disaster. At this point in the disaster management process, epidemiological surveillance should also be initiated with the intent of preventing disease outbreaks (such as a dengue fever epidemic) as well as other complicating events (for instance, mortalities due to famine or exposure). The goal of the recovery phase, which is the longest of the four phases and may last for years, is to return the community to its pre-disaster state. (7)

In contrast to Campbell's description of the disaster management process, Eric Noji has described a slightly different approach to the task. Noji asserts that from the public health perspective, the goals of disaster management are to:

> assess the needs of disaster-affected populations, match available resources to those needs, prevent further adverse health effects, implement disease control strategies for well-defined problems, evaluate the effectiveness of disaster relief programs, and improve contingency plans for various types of future disasters. (9)

As one can readily see, Noji's goals and Campbell's phases overlap significantly, and where they differ, they are complementary rather than conflicting. One must also note that information, as Noji himself declares, is at the heart of good disaster management. Thus, given that disasters fall within the realm of public health (because they affect population health and well-being) and that they require accurate and easily accessible information, there appears to be an obvious role for public health informatics in improving disaster management and prevention.

Past and Current GIS-Disaster Projects

A relatively new, but increasingly popular public health tool is the geographic information system. GIS are software programs that allow the user to code and then spatially display various forms of data in a geographic context such as a neighborhood, city, country, etc. The end result of a GIS project is a multi-layer map that displays not only geographical landmarks (such as roads, political boundaries, etc.) but also relevant public health data (for instance, the locations of homes containing lead paint or the sites of local hospitals).

The public health literature abounds with articles extolling the many uses of GIS from assessing public health practices to planning structural modifications of public health organizations. (10) The public health literature related to disasters is no exception (several articles have been published concerning the use of GIS as a means of preventing and/or managing disasters). The principal benefit of GIS as a public health instrument is that it allows data to be gathered quicker, better and cheaper (after initial investment) than was previously possible. (4), (11) In fact, Kaiser claims that GIS leads to better data procurement because "GIS methods may increase accuracy (through improving random sample selection) and precision (time-saving methods may allow increasing sample size)." (4)

The range of uses of GIS in disaster management is very wide. Bradt provides the following broad overview of these uses:

> Geographic information systems tools have found applicability in many aspects of emergency management including selection of evacuation routes, placement of emergency shelters and population exposures to environmental toxins and sentinel disease surveillance. Geographic information systems can contribute to real-time assessments of hazard emergence (clustering of

> cases in syndromic disease surveillance as proxy indicator for bioterrorism) or hazard persistence (toxic plume dispersion and particulate fallout). (1)

Here we see GIS being used in two of Tailhades and Toole's disaster phases. Selecting evacuation routes is a primary function of the alert phase. The other uses described by Bradt would naturally fall into the response phase. One can easily imagine the usefulness of GIS during the other two disaster phases, preparedness and recovery. For example, in preparing for a potential flood, GIS could be used to assess the risk of floodwaters destroying various disaster relief resources (e.g., hospitals, public health agencies, etc.). To continue with the flood example, GIS would be useful during the recovery phase for planning where to rebuild destroyed resources or where to construct floodwalls to prevent future catastrophes.

Currently, the US government (through the United States Agency of International Development [USAID]) is sponsoring a large disaster project called the Famine Early Warning Systems (FEWS) Network, a system whose purposes straddle the preparedness and alert phases of disaster management. FEWS uses both GIS and satellite technology to monitor predictors of future famines in Africa. One of these predictors is the health of vegetation. FEWS continually tracks the Normalized Difference Vegetation Index (NDVI), which essentially measures the amount of photosynthesis occurring in the observed region. Interestingly, this data is collected via satellite by one US government agency (the National Oceanic and Atmospheric Administration) but is processed via a GIS by a different agency (the National Aeronautics and Space Administration). (12) Another early warning predictor tracked by FEWS is rainfall. FEWS estimates rainfall by combining data from a number of sources including infrared data and microwave satellite observations. (12) The FEWS system has been used extensively to prevent food insecurity, most recently with regard to the crisis in the Darfur region of Sudan. By predicting the start of the rainy season, which isolates many of the remote communities in the region, FEWS was able to alert relief workers to "preposition relief supplies" near these communities. (13)

In a recent article, Melanie Gall describes a project involving the use of GIS during the response phase of a disaster in Mozambique. The purpose of Gall's work was to evaluate and ultimately to prevent vulnerability (e.g., malnutrition, disease, etc.) among the Mozambiquan disaster victims. Gall argues that emergency shelters are "of key importance for vulnerability reduction in Mozambique because shelters serve dual purposes: accommodation provision and a venue for aid distribution. They ensure basic assistance by providing survival necessities to homeless and affected people, who may then remain in their home area." Thus, identification of the best locations for the proposed shelter sites is of paramount importance to disaster management in Mozambique. During the floods that inundated Mozambique in 2000, Gall conducted a survey among relief workers to ascertain the "…factors that enhance the suitability of shelter sites." The results of the survey revealed that factors such as the "proximity to roads" and "the availability of potable water" were the most important determinants of shelter site appropriateness. Gall then used GIS to map actual areas of Mozambique that met the criteria determined by the survey. The author was able to identify eight sites within the study area that were suitable for placement of emergency shelters. Gall concluded that GIS was an effective tool for disaster workers seeking to mitigate vulnerability in Mozambique. (14)

The work described by Benini et al. is a good example of an informatics application during the recovery phase of a disaster. Using GIS techniques, this project combined data on Lebanese land that has yet to be demined (following the cessation of approximately 25 years of armed conflict) with agricultural data (such as land use for agricultural purposes and the amount of irrigation applied to "actively used land.") The many years of war devastated Lebanon's rich agricultural industry. One of the goals of the project was to test the claim, put forward by Ahmed (15), that landmines that have not been removed inhibit a return to agricultural activity. The authors discovered that indeed landmines did inhibit agricultural activity, but only in communities predisposed to high levels of activity. Landmines did not affect those communities that were not predisposed to high agricultural activity (due to factors such as climate.) Thus, as Benini explains, “Ahmed’s observation that landmines created a lack of farm land…is not tenable as an across-the-board claim.” Another surprising result of this project was that communities who only recently exited the armed conflict (e.g., southern Lebanon, which was occupied by Israel until the Israeli withdrawal in May 2000) had “higher active land-use levels” than those communities who exited the conflict earlier. This finding would seem counterintuitive if Ahmed’s observation were correct since there would be less time to complete demining efforts in these communities. Thus, Benini and colleagues assume that factors besides landmines affect whether or not a community returns to agricultural activity. The authors conjecture that those communities who exited the conflict earlier have, over the ensuing years, shifted from an agricultural to a service-based economy due to various market forces, whereas late-exiting communities have not had sufficient time to make this shift and thus fall back on their agricultural roots. This project demonstrates well the power of GIS: its ability to combine data from various sources to analyze complex situations such as disaster recovery. (5)

Future GIS/Disaster Research

As noted above, a number of researchers and workers have employed GIS in their management and prevention of disasters. Based on the published literature, it appears that disaster relief workers will increasing rely on GIS in the future. In fact, several authors have published their visions of the future of GIS in disaster relief. For instance, Bradt and Drummond anticipate the use of GIS and other informatics tools on the front lines of disaster relief:

> In the future, it is envisioned that technicians with laptops, GIS software, and plotters will appear at the disaster site as information first responders — just as quickly as conventional first responders. Moreover, advances in telecommunications will enable rapid digital transmission of these findings via portable handheld units and wireless application protocols to facility-specific end users. (1)

Kaiser et al. describe an equally compelling glimpse of the future. They claim that combining GIS with remote sensing (such as thermal imaging to detect campfires) could allow disaster managers to assess population movements in situations where data gathering on the ground is too dangerous (for instance, during armed conflicts). (4)

Other authors have proposed more sober scenarios for the future application of GIS in disaster relief and prevention. For example, Ruiz and colleagues have called for increased use of GIS in surveillance to prevent bioterrorism, a disaster scenario that has garnered significant press in recent years. Currently, GIS is being incorporated into the National Electronic Disease Surveillance System (NEDSS), which is a system that standardizes disease reporting across states. Ruiz et al. argue that surveillance at a local level is extremely important and that NEDSS does not address local health department needs. Thus, GIS should also be incorporated into the workflow of local health departments.(16)

Conclusion

A quick Medline search would reveal the current enthusiasm for GIS in the public health research field (last year, no less than 219 articles were indexed under the MESH term “Geographic Information Systems.”) As evidenced by the articles referenced in this paper, GIS is particularly popular among disaster management/prevention researchers. It is difficult to deny the usefulness of GIS when applied to disaster management and prevention; however, one must be aware of this technology's pitfalls. One well-recognized problem is that users who do not possess standard research skills (such as a good grasp of epidemiological principles) may form erroneous conclusions when interpreting GIS maps. As Melnick astutely observes, an untrained user may assume that the geographical clustering of a given health condition (such as cholera) is due to an environmental factor (such as the location of a contaminated water source) when in fact the clustering is due to "underlying population characteristics" (such as the average age of the individuals in the cluster). (17) A second concern is the cost of adopting GIS technology. Use of GIS mandates significant software and hardware requirements (18) that may be too costly for the limited budgets that are characteristic of many disaster relief organizations.

Despite these and other potential drawbacks to the use of GIS, it is likely that disaster workers will increasingly use GIS. Careful integration of GIS into disaster relief and prevention processes will no doubt improve the outcomes of this work. Given the increasing incidence of disasters, it is fortunate that we have such a powerful tool at our fingertips.

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