Guidelines for Developing an Open Geospatial Response to Emergencies (OGRE)

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Disaster response typically requires high levels of coordination, necessitating effective communication and information management. Geographical Information Systems (GIS) are useful tools that are constantly being developed and used in many fields, including emergency and disaster management. They are useful in all four stages of the disaster management cycle (mitigation, preparation, response, and recovery) and they have the potential to become even more important to disaster response. This paper considers how GIS is used in emergency management, then suggests guidelines for developing a GIS-based, networked disaster response platform that includes public participation. This could allow visualization and management of the response to events (resources, personnel, hazards, incidents, evacuation routes, shelters). Additionally, it could facilitate communication between officials, members of the public, and other responders. The conclusion of this paper discusses factors relevant to development of this system, including information infrastructure, social media, and crowdsourcing, and considers basic guidelines for developing an Open Geospatial Response to Emergency (OGRE).

Introduction

This paper shows that computerized mapping systems already play an important role in emergency and disaster response, and argues that using these systems as platforms for public participation could have important benefits. Disasters are increasing in frequency and severity (Mitchell & van Aalst, 2008). Almost one million people were killed by disasters in the past decade, 2.6 billion people were affected, and over one half trillion US dollars in damage was done (Madry, 2015). Fortunately, developing tools such as Geographical Information Systems (GIS), satellites, handheld devices, and the Internet create new options for responding to disasters. According to Madry (2015), GIS "are at the heart of disaster management data integration, analysis, and sharing," and many disaster organizations using these systems (p. 99). Furthermore, new communication devices, such as cell phones with internet access, enable medical professionals to coordinate rescue and relief work (Zhou, Shi, Mao, Tang, & Zeng, 2012), and space systems (e.g. satellites) are now a "key element in the improved response capabilities for all types of disasters" (Madry, 2015, p. 9). Disaster management is conceptualized as a cycle of mitigation, preparation, response, and recovery, and GIS is used during all four phases (Birkmann & Teichman, 2010). The focus here is on the response phase, and basic guidelines are suggested for a GIS-based platform that allows communication and information sharing with the public.

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The proposed system developed in this paper is referred to as an Open Geospatial Response to Emergencies (OGRE). The idea is that it could present layers of geospatial information about hazards, vulnerabilities, people, resources, infrastructure, and more in a network accessible to emergency management officials, stakeholders, and the public. The inclusion of the public is important because they respond regardless of official efforts, and this has changed recently due to the dynamic nature of social networking technology that allows knowledge sharing from all involved parties (Freeman, 2011).

Incorporating social media, GIS, and other new tools may be challenging because Emergency Management (EM) culture is highly structured and hierarchical and is often seen as conservative with regard to adoption of new technologies (Mandry, 2015; NRC, 2007). However, public participation is important because there is potential for it to improve disaster response, which naturally involves the public, and should not be approached in a command and control manner (Drabek & McEntire, 2002). The commonly held view that disasters cause chaos and disorganization is widely believed to be false in the disaster science community, and the emergency managers who emphasize coordination and communication instead of command and control are much more effective (Phillips, Webb, & Neal, 2011). Calling for change, one researcher says, "The organizational systems that respond to extreme events must be open systems that allow information to be gathered from and transmitted to the public and nongovernmental organizations in addition to standard governmental sources" (Harrald, 2006, p. 270). Some disaster researchers argue that public response to disaster is "inevitable, natural, neither necessarily dysfunctional nor conflictive, and cannot be eliminated by planning" (Stallings & Quarantelli, 1985, p. 98). Many of the prerequisites for increasing public participation already exist (technology, information infrastructure, software, social media), so research and policy should focus on the potential for increased effectiveness in responding to disaster. It may be that "most of the problems associated with the use of geospatial data and tools are institutional and not technical" (NRC, 2007, p. 146).

GIS & Disasters: Mitigation, Preparation, Response, and Recovery

According to the Federal Emergency Management Agency (FEMA), GIS is "a computer-based system to capture, store, retrieve, analyze and display spatial information and its associated attributes. It combines spatial and tabular information to produce maps and to perform spatial analysis" (FEMA, n.d.c). The four components of a GIS are hardware (desktops, handhelds, data storage, GPS, cameras, satellites, scanners, remote sensors), software (used for thematic mapping, labeling, geocoding, determining quantities, tracking), data (from GPS units, paper maps, photographs, addresses, satellite images), and users (FEMA, n.d.c). This tool's ability to provide easy, low cost access to multiple users is one of its most appealing features, and GIS can visually present large amounts of data from multiple sources in real-time, thereby facilitating coordination between individuals and organizations, which is a key factor in disaster response (Harrald, 2006; Santos-Hernández, Rodríguez, & Díaz, 2008).

Using a GIS to visualize and track disaster events, incidents, resources and emergency management personnel, relevant populations and vulnerabilities, and hazards and related damage can greatly improve a decision maker's ability to mitigate, prepare for, respond to, and recover from disaster events (Bernard et al., 2006; Intergraph, 2012; Santos-Hernández, Rodríguez, & Díaz, 2008). Fortunately, advances in GIS technology have increased the accessibility and mobility of GIS tools, which has created an unprecedented ability to visualize and manage disasters (Tran, Shaw, Chantry, & Norton, 2008). The following sections discuss GIS use throughout the disaster management cycle to both illustrate the tool and its potential, and provide relevant context for understanding an OGRE.

Mitigation

The mitigation phase of disaster management aims to reduce or prevent risk from hazards through social or physical intervention. An example of this kind of use of GIS is FEMA's development of hurricane and earthquake modeling software capable of estimating direct and indirect economic loss, shelter requirements, casualties, ground shaking, cost of building repairs, housing loss, quantity of debris and direct loss of function, as well as having special features for hospitals, schools and fire stations (FEMA, n.d.a). A second example is the US response to the 2011 Fukushima catastrophe in Japan, where a natural disaster caused a nuclear meltdown. Seismic risk assessments for nuclear reactors were conducted throughout the U.S., and web-based, interactive maps were created for the public, showing information about their risk from nuclear reactors (Sternberg, 2011). Like FEMA's software, this is a useful risk assessment tool for disaster mitigation.

Preparedness

GIS can also help during disaster preparedness, including evacuation planning, hazard tracking, and modeling. Evacuation can overload transportation infrastructure, so congestion can be problematic, regardless of infrastructure damage and driving conditions. An example of GIS use in evacuation planning comes from FEMA's dedicated Enterprise GIS servers, which host dynamic maps showing evacuation routes (FEMA, n.d.b). GIS can also model hazards, and an example is the Makai Voyager software, which is capable of visualizing 3D and 4D data anywhere on Earth, and can model large temporal environmental events in real time, such as hurricanes, with the help of remote sensors (Makai Voyager 1.1, 2012).

Response

A basic understanding of the role GIS plays throughout the disaster management cycle is important because the use of geospatial tools and data "must be habitual rather than exceptional" (NRC, 2007, p. 146). An ideal GIS-based disaster response system would be familiar to users, and, in addition to training and exercises, it could be beneficial to use the system in other phases of disaster management. This is why the other phases are discussed in this paper, but the focus is on disaster response. GIS already plays an important role in disaster response, and is the glue that brings data together, supporting situational maps, press briefings, and hundreds of additional uses (Madry, 2015). Some researchers say that:

> [T]he ability to synthesize information from multiple sources and to make available up-to-date maps and location information is of critical importance in ensuring a timely and effective response. Broader use of geospatial technologies, including Geographic Information System (GIS), Remote Sensing, and Global Positioning System (GPS), provide the key for doing so in the future. (Kawasaki, Berman, & Guan, 2013, p. 201)

For example, after the 2001 attacks on the World Trade Center, a variety of geospatial technologies (aerial imagery, light detection and ranging, satellite images, hand-held devices with GPS, internet, GIS) were used to enable a more comprehensive response to the tragedy (NRC, 2007). Another example is Intergraph Corporation's computer aided dispatch (CAD), which is used to coordinate police, fire, EMS, and search and rescue services for almost 10% of people worldwide (Intergraph, 2012). Intergraph's automated dispatch software integrates a range of functions (alerting, remote printing, paging first responders, managing records, resource optimization tools), which can facilitate record management (Intergraph, 2012). A third example is the Puerto Rico Disaster Decision Support Tool, which is an internet-based GIS used by various decision makers to assess geographically tagged information. This system only requires a basic computer and can be accessed through a web browser. It allows "first responders to channel aid more efficiently and effectively to the population groups with the greatest needs" (Santos-Hernández et al., 2008, p. 22). This less expensive system may be good for developing societies which have more trouble responding to disasters (Kahn, 2005).

One of the places GIS can play a critical role is emergency operations centers (EOCs), which are an important part of disaster response that bring multiple actors together to coordinate efforts (Drabek & McEntire, 2002). An EOC plays a central role in many disaster responses and "coordinates the multi-agency, intergovernmental response to an incident into an effective and efficient effort" (Perry, 2003, p. 151). Perry argues that accurate and timely information collection and delivery for officials, responders in the field, and members of the public is important in order to avoid issues arising from convergence, and most large EOCs use software to manage incidents, which includes GIS capabilities. For instance, after the attacks on the World Trade Center, the city EOC's GIS displayed maps of critical facilities and systems, but was destroyed when the building containing them collapsed. In a remarkable demonstration of resilience, local students, professors, and a company responded to the need for geospatial data, aiding the city's GIS specialists by providing equipment and support. This response created a "map production and distribution capability, much greater than existed at 7WTC [building where GIS was contained] and amounting essentially to a mapmaking factory" (Kendra & Wachtendorf, 2003, p. 47). This example illustrates convergence, which is relevant to an OGRE in the sense that volunteers collaborated to work with geospatial information and helped coordinate disaster response.

Recovery

GIS is also useful in the final phase of recovery. An example is the response to Hurricane Katrina in Gulfport, Texas, where local officials used an extant infrastructure GIS to create maps which allowed the user to locate assets under debris, and served as a damage report database. This information was also used by the town to demonstrate infrastructure damage, which helped them secure a FEMA grant worth over US$100 million, and by residents who sought federal and insurance aid (Government Engineering, 2009). A second example comes from the conflict in Kosovo during the 1990s, when the US State Department created a GIS database used by national government agencies and non-governmental organizations (NGOs) to address damage and track landmines and unexploded ordinance. The data was collected in simple ways (paper and pen) in order to avoid a steep learning curve and accommodate different data inputs (Smith, 2001). The cooperative efforts highlighted in this case make it an illustrative example of the utility of employing GIS as a collaborative platform.

GIS Limitations and Issues

Despite apparent benefits, some limitations and other issues related to GIS should be considered when developing a GIS-based OGRE. Lejano (2008) notes that although GIS does increase analytical power, it is limited to a spatial analysis and neglects important social factors. Systematic use focuses on problems in the digital world, which may result in missing real world issues, and GIS's reductionist quality simplifies representations of a much more complex reality. Thus, while GIS can handle physical ground-truthing fairly well (gathering proper objective data to determine truth), social ground-truthing is often lacking. Professionals are working in offices instead of on the ground where their decisions take effect. In his words, "In GIS, unlike the visual, what one sees has already been determined. You cannot come down from your elevated perch to see what's there in GIS, there is no 'there' there" (Lejano, 2008, p. 654). Nevertheless, Lejano sees great potential in GIS, as long as users and decision makers are mindful of the inherent limitations embedded in this tool. Alexander expresses similar concerns, saying that:

> In principle, any retreat from reality is likely to be damaging. The 'video game' view of hazards and disasters tends to reek of 'disaster pornography' and superficial attitudes to human suffering. The creation of an electronic elite will do little to ease the socio-economic disparities that are at the root of disasters. Truly, all that glisters is not gold. (2000, p. 150)

Put simply, when disaster managers are removed from direct work on the ground, they may be missing out on important parts of the reality they are trying to address. So, certain uses of GIS can influence EM by limiting scope, promoting information quantity rather than quality, substituting itself for intuition and good decision-making, and removing users from the social and physical context surrounding their choices (Quarantelli, 2007).

Guidelines for an OGRE System

With a basic understanding of GIS and EM in place, guidelines for developing an OGRE can be introduced. The purpose of an OGRE is to use developing technology to facilitate inclusion of stakeholders and the public in disaster response. A networked GIS-based platform with support for two-way communication would be the platform for this kind of system, and a range of tools could improve collaboration (social media, satellites, mobile devices, crowdsourcing). There is a need for public involvement and information exchange in emergency response, and many components needed for an OGRE already exist (Harrald, 2006). Some authors argue that "during large disasters, the use of the same framework and foundation data by responders in various parts of the country is vital for close coordination." (NRC, 2007, p. 103), which makes sense because the location of urgent requirements, the current situation (road closings, power outages, available airports and hospitals), and updates (resources, current efforts) is a "constantly changing matrix that requires frequent updates" (Madry, 2015, p. 15).

This kind of system would have several key aspects, including reliability, public participation, and the ability to layer geospatial information coming from multiple sources. Public participation would mean two-way communication with the public (deliver warnings, accepting input, responding to concerns and requests), and layers of information could include social media, base maps, traffic data, satellite readings, GPS tracking, and more. The actual design and implementation of an OGRE system would depend significantly on relevant context, and there are several factors that officials interested in developing an OGRE system should consider, including location, information infrastructure and technology, devices, collaboration, funding, and desired layers of information.

Location

The clear global trend towards urbanization may promote development of an OGRE (IPCC, 2012). Urban areas tend to have more extensive communication infrastructures and high population density, which may increase public participation because of their ability to network and the number of people impacted. With more than half the world's population living in urban areas, which might experience higher levels of destruction from traditional hazards in the future, regularly updated global urban maps that would help improve preparations for and response to natural disasters are needed, so information needed to support an OGRE may be more available in urban areas (Potere & Schneider, 2007).

Information infrastructure and technology

Emergency management officials often use tools such as satellites and digital radios that do not rely on terrestrial infrastructure, but the public is likely to use landline and cellular networks which are more vulnerable to hazards. An OGRE would require reliable and accessible communication for both officials and the public. Communication methods independent of terrestrial networks should be considered, including two-way radios, ad-hoc, mobile-to-mobile networks, and satellite telecommunication. During Superstorm Sandy's impact on one of the most developed and prepared places, mobile phone networks were frequently down, demonstrating why networks should be resistant to damage, redundant, diversified, and able to activate backup systems (Alonso, Schuck-Paim, & Asrar, 2014). A system designed for public participation should incorporate typical public communication options. Since the need to communicate with the public has been elevated by risks like terrorism and telecom infrastructure is necessary for many popular forms of communication, availability and reliability of landline and cell networks is important (Perry, 2003). However, infrastructures can be severely affected by disasters, and government capabilities become quickly saturated due to demands for assistance (Alonso et al., 2014). Communications systems are often disrupted during disasters, and people designing OGRE systems must consider the communication needs of various participants as well as communication methods' reliability (NRC, 2007). A challenge for EM organizations is to be sure that they are using the technologies used by citizens, including social media and other methods (Freeman, 2011).

Satellites and unmanned aerial vehicles

Satellite networks are already used in disaster response, and they can support interoperability and reliability (Madry, 2015). While they provide a reliable method of communication, they are also expensive (Alexander, 2000). There is a trend of government space agencies and private entities supplying satellite imagery during disaster response, and the wait between updates has been shrinking. For example, within five days of the 2010

Haitian earthquake, over 15 organizations from eight countries had provided satellite images. More than half were commercial entities, and responders used GIS systems based on these satellite images to coordinate their efforts. This type of high-resolution satellite imagery is imperative for comprehensive disaster response (Kawasaki et al., 2013). However, it should be noted that "the technology requires continued commitment and an ever-increasing scale of investment for benefits that tend to be eclipsed or overtaken by new developments in technology" (Alexander, 2000, p. 155). Thus, satellite systems provide disaster managers with powerful tools to respond to disasters, and, in addition to being a vital aspect of our global infrastructure, they are often the only systems providing communications, data, and imagery immediately after a disaster (Madry, 2015). Mandry (2015) notes that a full three weeks after Katrina, only 60% of the area's cell service was operating, but satellite services were fully functional, with over 20,000 satellite phones deployed and an over 3000% increase in traffic for one network. Satellite services are still growing at a significant rate, and many EM organizations provide their key members with satellite phones to ensure communications (Madry, 2015). Thus, "establishing a backup satellite communications system to transmit voice and geospatial data can be extremely useful to obtain reports quickly from the field and to transmit information to other locations around the state or the country" (NRC, 2007, p. 144).

A fascinating and developing new possibility for disaster response communication is the use of unmanned aerial vehicles (UAVs). According to Madry (2015), UAVs can provide excellent telecom, data, and remote sensing capabilities by loitering at very high altitudes for weeks at a time. He points out that they can provide excellent damage assessment at specific times and higher resolutions than satellites, and have been used for this purpose since 1994. The size of UAVs now range from small, hand-launched quadcopters which are useful for searching hazardous areas and delivering aid, to US military drones with long range and high-quality remote sensing systems. It is likely that these small aerial systems will be used more often in the future as the necessary technology continues to develop, so their use as part of an OGRE's infrastructure should not be overlooked (Madry, 2015).

Digital radio

While not a common public communication method, digital radio can play an important role in disaster response when more popular infrastructure systems are not available. One company's communication interface allows radio, digital radio, and telephone integration, in addition to recording information about the call, and having the ability to interface with external applications (Intergraph, 2012, p. 5). This is a good example of a system that integrates more dependable and popular methods of communication.

Devices

The devices used in an OGRE should also be considered because a network's reliability is inconsequential if it cannot be utilized. Mobility is generally desirable, desktop computers are rarely self-powered, and they generally use wired connections, so self-powered mobile devices with wireless capability are appealing. Mobile devices come in many forms such as laptops, tablets, and phones, and in some regions they have high market saturation (Blodget, 2012). Recognizing this, FEMA developed smartphone applications that provide maps with important locations and the ability to submit geotagged photo reports with disaster information (FEMA, 2014). If an OGRE user has a mobile connection, they can access information, communicate, and coordinate with other users. Additionally, satellite, GPS, GIS, and weather data can be integrated into real-time warning systems with maps, web data, and warnings output to specific geographic areas (Madry, 2015). Mobile phones have played an increasingly positive role in disaster relief and have proven to be extraordinary tools during these situations; however, care should be taken by disaster managers tempted to rely on this technology, especially given the likely collapse of terrestrial telecommunication infrastructure after disasters (Alonso et al., 2014).

Smartphones are self-powered, can connect to multiple networks, are capable of many types of communication, often feature a GPS chip, camera, and other sensors (allowing for data collection and reporting), are very portable, and may have additional benefits such as the ability to be used as flashlights. An ideal system could deliver a full-featured experience for users with more capable computers, and a smartphone-friendly version for mobile users. According to Business Insider, the US smartphone market is more than halfway penetrated, with over 110 million users nationwide, and 78% of 15-64 year olds owning a smartphone (Blodget, 2012). It is worth noting that the short battery life of smartphones can be a major limitation in emergencies, as electrical grids can be damaged during disasters. However, solar powered phones have already been used in disaster response (Alonso et al., 2014).

Collaboration: Social media, crowdsourcing, and citizen science

The utility of an OGRE is closely tied to adoption, thus making social factors an important consideration. According to a recent article published in Disaster, "opportunities for volunteers to assist in disaster response via mapping and spatial analysis have grown significantly in size and in scope. It is safe to assume that these trends will continue in the near future" (Kawasaki et al., 2013, p. 209). Indeed, social media and crowdsourcing can now play important roles in disaster response (Haddow & Haddow, 2014).

Social media

An intriguing developing technology, social media networks, can allow citizens to access information that is geographically-specific and searchable. The benefits of using social media "as a complementary means of providing information far outweighs the negative issues and this is why authorized emergency management organizations are starting to utilize the technologies" (Freeman, 2011, p. 77). McClendon and Robinson (2012, p. 2) argue that "geospatially-oriented social media communications have emerged as a common information resource to support crisis management.", so implying that incorporating social media in an OGRE is important. Receiving this kind of information from the public, especially field data collected with mobile devices that can take pictures and gather other information, could be useful for officials in need of information. Notably, this information could be gathered even in the absence of intentional public participation. That is to say, people share useful information about disasters on social media regardless of the presence of an OGRE system. However, two-way communication would be useful for many reasons, including warnings, responding to requests for information, and seeking specific input.

While social media technology has been considered an ideal technology for disseminating information about natural disasters, a major drawback is that "there is no quality of service regarding the transmission of posts" (Freeman, 2011, p. 71). Additionally, EM use of social media can be complicated by the digital divide (some people do not participate in these networks), potential loss of control as multiple sources of information are available to citizens, and loss of Internet connectivity (Freeman, 2011, p. 77). According to Madry (2015), there is active debate in the disaster management community about how these tools can be incorporated, but there may also be policy issues and drawbacks. Notably, an individual intentionally sent false information to responders during Superstorm Sandy, and approximately 9 out of 10 US government agencies have little or no budget to support or staff dedicated to social media activities (Madry, 2015, p. 118-119). Unknown cost to governments and information overload, including provision of redundant information are also worth addressing (Mandry, 2015; McClendon & Robinson, 2012).

Despite drawbacks, "future platforms developed with the volunteer community in mind will need to incorporate social media as one piece of an overall strategy to support situational awareness and response and recovery featuring effective two-way communications with citizens through social media" (McClendon & Robinson, 2012, p. 10). Many citizens have gained emergency information and say they would contribute emergency information through social media. With a billion and a half people using mobile devices to access the internet, "we can reasonably expect the use of social media in disaster response to increase in the future" (McClendon & Robinson, 2012, p. 2). An example of this came from Superstorm Sandy, when the city's emergency management office provided updates and evacuation orders via Twitter, and the governor of New Jersey used his account to relay relevant information. Twitter and Facebook were used "extensively by individuals, first responder agencies and utility companies to relay messages and information, share evacuation orders and provide updates on the storm" (Cohen, 2013).

Crowdsourcing

Crowdsourcing (non-skilled assistance) is being considered by a wide range of organizations at the national and international levels (Alonso et al., 2014). It "has rapidly become an essential source of data in disaster response," and its utility has been enhanced by maps based on extracted location data (McClendon & Robinson, 2012, p. 2). While it is new to the disaster community, it has great potential, and mobile internet should be used to collect bottom-up disaster information (Madry, 2015; Zhou, et al., 2012). Remote support operations can be very valuable in disasters and have been used several times toprovide a continuous operation as work shifts between time zones. Major players in this community include Crisis Mappers, The Humanitarian OpenStreetMap Team, Digital Humanitarian Network, and GISCorps. This rapidly evolving world will have a major impact on disaster response in the future (Madry, 2015, p. 121).

Social buy-in and collaboration are important, but relying on crowdsourcing can mean a loss of control and unexpected outcomes. An example of this is the New Delhi Disaster Management Cell's use of a call center designed as a one-stop hub for all disaster management operations. The intention was that members of the public would report incidents such as floods, transportation accidents, and terrorist attacks. The caller's information would be taken and the system would automatically deliver relevant contact information to the user and send out text messages to various stakeholders. Unfortunately, the center has been used improperly to report traffic incidents, complain to the municipality, and request information for children's homework (Sobhana, 2008). While this system may have the potential, it has not had the desired outcome because of the way the public perceives and responds to it.

Citizen science

Citizen science (using skilled workers as remote support), is similar to crowdsourcing in some ways, also has great potential, and there are many striking examples of remote support for disaster response (Madry, 2015). Tweak the Tweet and Ushahidi are applications that create crisis maps of content from social media during disasters (Okolloh, 2009; Starbird & Palen, 2011). Other efforts to use crowdsourced information during disasters include the Sahana platform and the Crisis Mappers Network (Currion, de Silva, & Van De Walle, 2007). After the 2010 Haiti earthquake, the Director of FEMA said the Ushahidi Haiti map was the most comprehensive and up-to-date map available (Heinzelman & Waters, 2010). It is likely that it saved lives, and even US Marines and Coast Guard responders used it (McClendon & Robinson, 2012; Ramirez, 2010).

In another example of a remote support response to this earthquake, 1,000-2,000 text messages a day were passed through an automated system, translated by volunteers, and filtered to determine location (Meier & Munro, 2010). A project was set up to provide assistance via cell phone calls and texts (with a peak volume of over 5,000 calls an hour), which were routed, translated, enhanced with appropriate data, and then reported in a standardized way to response organizations (Madry, 2015, p. 118).

An interesting example of citizen science and remote support came three weeks after the 2004 Chuetsu earthquake in Niigata, Japan which caused extensive economic, human, and topographical damage. A web-based GIS was opened to the public which included imagery from remote sensing, base maps, and an advanced data-creating trial using volunteers to support the development of datasets remotely over the internet. The groups that established the portal aimed to use the internet to "collect, integrate, and distribute information from outside of the damaged area, and to support response activities from within and without the disaster zone" (Kawasaki et al., 2013, p. 204). Another example of a GIS-based remote response to disasters emerged the next year when Hurricane Katrina struck, with some commentators arguing this demonstrated the coming of age of the online disaster response community (Laituri & Kodrich, 2008), and showed the importance of publicly available geographic data such as satellite images (Butler, 2006). Many people thought the federal response to the catastrophe was inadequate, so they set up their own donation locations, message boards, and maps of aid sites (Kawasaki et al., 2013). Google quickly updated satellite imagery of the affected area, showing the extent of damage (Hanke, 2006). Shortcomings of the official response prompted a spontaneous reaction from the broader population, with internet and mobile applications being supported and utilized by government, private and relief organizations, and members of the public who used mobile equipment to collect and disseminate information (Kawasaki et al., 2013).

A more recent example of a remote support came after earthquakes in China, Haiti, Chile and Japan from 2008-2011, when the Center for Geographic Analysis (CGA) at Harvard University set up portals to collect and distribute geospatial data. Their goal was to support swift integration and analysis of information during the disaster response after these events, and they made GIS data, remote sensing images and news reports freely available to all users in the short term, and as an archive for researchers in the long term. The site was open to all, but targeted at professionals, and user contributions were encouraged from the beginning (Kawasaki et al., 2013). Following the 2008 Sichuan earthquake in China, the Chinese government released live updates on response activities, including disaster inspection reports, maps, and videos. A great number of international organizations and teams conducted surveys and rescue activities, creating significant domestic and international demand for geospatial data. The CGA realized that many individuals and organizations wanted to help but lacked the geospatial data necessary to properly support their efforts. Furthermore, although a variety of government agencies and other organizations were publishing information, there was no initiative to coordinate the process. This led them to launch the China Earthquake Geospatial Research Portal, which offered downloadable datasets, over 100 online postings, and a collection of hundreds of related news articles.

Within hours of the 2010 earthquake in Haiti, CGA recognized the need for geospatial data in order to coordinate the disaster response. The following day they created base maps of the area and opened up a portal which made use of the Military Grid Reference System. The portal was publishing GIS layers within 2 days of the event, including high resolution satellite images and printable maps. CGA also set up a portal following the 2011 earthquake and tsunami in Japan, which was running by noon the next day, and emails were sent requesting data for the portal. Within the first weekend several dozen resources were available and nearly 100 emails were received offering or requesting data. One week after the event the portal received more than 20,000 visits every day. CGA received a letter from the US Geological Survey thanking them for their efforts on behalf the Japanese authorities (Kawasaki et al., 2013). These examples are far from exhaustive, but they clearly show that there is potential for collaborative responses to emergencies and disasters by connecting people and geospatial information. Importantly, the web-based, open nature of this kind of effort allows worldwide collaboration, as opposed to a response limited to officials in a particular region.

Funding

In addition to location, information infrastructure, devices, and collaboration, a primary factor that must be considered is the cost associated with the development, implementation, and maintenance of an OGRE system. A 2008 report from UN-Habitat, an organization focused on human settlement and environmental preservation, pointed out that there were roadblocks for developing countries trying to use technology, especially satellites, to manage disasters because the required financial investment often exceeds the budget of the countries most affected by disasters (UN-Habitat, 2008). Due to the correlation between low development and vulnerability to hazards, financial constraints leave more people at risk (Nicholls et al., 2008). Trends indicate this may get worse (Alexander, 2000). However, even these populations at risk could benefit from low-budget OGRE systems.

As has been shown, there is often collaboration between governments, the private sector, nonprofit organizations, and many individuals offering help in response to disasters. While owning satellites may not be feasible, there are many examples of companies and nations donating the use of their satellites during disaster response. Staffing in the form of highly trained professionals who are familiar with the disaster area may be limited, but professionals and laypeople will volunteer to help remotely in many cases. Disaster zones in less affluent countries can be mapped rapidly, and a global infrastructure can support at least a basic communication platform. At the least, information on aid requirements and vulnerability can be collected in the response phase, allowing more efficient aid during recovery (Kawasaki et al., 2013). Thus, even in areas where funding is limited, an OGRE could play an important role.

Layers

A final and important factor to be considered is the selection of layers to include in the OGRE system. The GIS portion of an OGRE system would be composed of geospatial layers superimposed over a base map, which could work in tandem with a communication system that facilitates warnings, field reporting, crowdsourcing, and other information exchange. Some layers could contain sensitive information such as the location of people and resources, official communications, and information on vulnerabilities. Therefore, the ability to restrict access to layers of the system or channels of communication could be important. On the other hand, some layers such as hazard tracking, evacuation routes, and location of shelters could be open to the public. A few potential layers are discussed here, including resources, personnel, social information, hazards, and evacuation routes, but these only highlight a few possibilities.

Resources

In order to get the most out of an OGRE, tracking resources should be a consideration. Not only would the ability to track resources be useful for officials, first responders, and other workers, but it would also allow members of the public to seek and offer various supplies or other assistance. An example of GIS used to track resources can be found in the India Disaster Resource Network (IDRN) which is an online inventory designed to support decision making by government administrators and emergency management officials. The inventory includes equipment and human resources, as well as details about NGOs and the private sector, including 5,000 corporate members and 33,000 builders, contractors, and construction companies (IDRN, n.d.). If this information was available as a layer in a GIS, it could help decision makers deliver aid effectively and in a timely manner.

Personnel

As with the CAD system developed by Intergraph, tracking the location of responders and other personnel can be important.and this GIS layer could be useful for officials. Toronto is an example of a city that already has the capability to track personnel in this way. For emergency managers, this ability to quickly visualize and communicate the "big picture [which] defines the very essence of disaster response" is important (Drabek & McEntire, 2002, p. 215).

Hazards

Just as one can superimpose a layer of real-time weather information on a GIS, an OGRE could include a layer that shows real time threat from hazards, such as information about a hurricane or tornado tracked by remote sensors. Flooding, tsunamis, storm conditions, and other hazard information could also be incorporated. An OGRE with the layers described so far would allow officials to track the location of their resources and personnel, while also gathering input from the public and tracking hazards and their impacts. This all leads to another important potential layer on an OGRE system, which is evacuation routes.

Evacuation routes

As mentioned previously, current technology has the potential to give officials and the public real-time, dynamic information on the best evacuation route based on their exact location, current traffic, and infrastructure information. Many smartphones can recalculate a user's route based on a wrong turn or automated traffic information, and it seems clear that using this same approach to get people out of danger would be useful. An OGRE could provide real time navigation assistance to both officials and the public, as mobile phones can enable rapid data collection and track real-time population movements (Alonso et al., 2014). Computer models can determine the most efficient evacuation routes for urban areas and could act as a starting point for navigation assistance (Chiu et al., 2008).

This discussion of the potential layers in an OGRE highlights only some information that could be managed by an OGRE system. The layers proposed here may be important parts of most OGRE systems, but there is no real limit on the number of layers or participants. Satellite, light detection and ranging information, radar, user photographs and videos, field reports, impact projections, and a wide range of other data could be included.

Warnings

An OGRE could be used to deliver warnings and target them based on user location. In addition to official warnings, unofficial warnings could play an important role. According to Parker and Handmer (1998, p. 45), "unofficial approaches to warning tend to be particularly well developed where there is no official activity; but, also, occasionally flourish in competition with government." Thus, the potential for unofficial warnings distributed through an OGRE system, via a social network such as Twitter or more directly, should not be overlooked.

Additional considerations

Use of standards and appropriate computer setup are also important factors relevant to the development of an OGRE system. Incorporating data from a range of sources could be important and using industry standards could facilitate collaboration, increase ease of use, and promote the integration of new data. Fortunately, there is movement toward developing international GIS standards. The Open Geospatial Consortium is a collaboration of 441 companies, government agencies, universities, and individuals. R.K. Srivastava, the joint secretary of the Disaster Management Division of the Ministry of Home Affairs in India, supports this idea, saying that "there is a need to enhance the data sharing protocols and mechanism at the national and state level" (Srivastava, 2011, p. 11).

A central server or group of servers that is managed by emergency management officials would be needed to host the software and data, thereby acting as a platform. Reliability would be critical, so a network approach, use of backups, and secondary power sources should be considered. Traffic would likely peak during events, so the system may need to handle a large number of connections and high volume of data, including secure information. A browser-based system would likely be the most accessible, but applications developed for specific operating systems might be more efficient and effective. Many kinds of GIS software are already available, and some are already used for coordination and communication, so there are frameworks that could be developed in order to support an OGRE.

Conclusions

Implementation of an OGRE system would require careful planning due to the many factors coming into play, and it could be expensive to develop and maintain, with dependability being just one potential problem. While these factors do not preclude development of a GIS-based communications platform for coordinating emergency and disaster response, any such system with the high level of functionality discussed here may be feasible in only relatively wealthy areas with the required infrastructure, technological saturation, and funding.

Looking ahead, emergency and disaster researchers and practitioners can expand upon the basic guidelines laid out in this paper. The abilities of various agencies and organizations to utilize GIS in disaster response and data sharing have already "been transformed into a more dynamic, more transparent, and decentralized form with a wide participation" (Kawasaki et al., 2013, p. 201). Planning should take public participation in disaster response into account (Stalling & Quarantelli, 1985), and this response "will be more effective to the degree that emergency managers successfully overcome the problems that emergent groups sometimes create while also harnessing their potential contributions" (Drabek & McEntire, 2002, p. 214). Indeed, "Society must plan in advance for disasters and cannot afford to wait until the next one happens, as it inevitably will. Investment in infrastructure is an important part of preparedness, and the kind of infrastructure represented by geospatial data and tools is a very important part of that investment" (NRC, 2007, p. 146).

A GIS-based, officially-supported platform that promotes public participation and incorporates information sharing is possible, and many of the prerequisites are already in place. This kind of open system could improve coordination among those involved in disaster response, saving lives while creating a foundation for recovery. A National Academy of Sciences workshop concluded that revolutionary leadership is needed to overcome challenges to incorporating advanced technologies in disaster management , and this may happen over time as a new generation of workers enter the EM community (Madry, 2015; NRC, 2005).

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