Use of GIS for disaster management and emergency response in developing countries

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Abstract: GIS is any information that integrates, stores, edits, analysed, shares and displays geographic information for informing decision making. This decision making can be when a disaster and or emergency response is needed. The objective of this paper is to examine the use of GIS in disaster management and emergency response in developing countries. Data for the study was generated through observations and secondary sources. The results show that there are several disasters that have occurred in developing countries in the last few years which include earthquakes, Tsunamis, volcanic eruptions, flooding, droughts, cyclones/typhoons etc. However, there is low use of GIS in managing these disasters and providing emergency response to the victims. There is urgent need for GIS as it is revolutionizing the way governments and other agencies manage disasters. The development of wireless technologies and web-based GIS applications has also enhanced the coordination of emergency relief efforts. It is therefore recommended that developing countries should focus on building their GIS capabilities through establishing the necessary infrastructures and training of manpower for effective use of GIS in disaster management and emergency response.

Keywords: GIS, disaster management, emergency response, developing Countries

1. Introduction

Geographical information system (GIS) is an integrated suite of systems for capturing, storing, validating, maintaining, analyzing, displaying and management of spatially managed data (Musa et al., 2010). This data is in form of maps, charts, satellite imageries, aerial photographs etc, the system can integrate these data from various sources into one and can be queried all in one to bring out unseen trends and processed information for planning or decision making (Labiye, 2008). GIS is thus any information that integrates, stores, edits, analyzed shares and displays geographic information for informing decision making.

GIS provide a technology and method to analyzed spatial data or information about the earth. The earth’s climate, natural hazards, population, geology, vegetation, soils, land use and other characteristics can be analyzed in a GIS using computerized maps, aerial photographs, satellite images, databases and graphs (USGS, 2005). By analyzing information about the earth’s hydrosphere, lithosphere, atmosphere, and biosphere, a GIS helps people understand patterns, linkages and trends about the earth (USGS, 2005). GIS facilities in form of scientific gadgets and satellite imagery and photographs are used a form early warning system that warns the people about an impending or unfolding disaster so that they evacuate to safety.

The decision making informed by the GIS can be when a disaster occurs and or emergency response is needed. A disaster is an event (natural or man-made) that causes serious loss, destruction to properties and infrastructures and unhappiness, hardship or even death to the people. Natural disasters can be atmospheric (e.g Hurricanes / Cyclones, Hallstorms, Windstorms etc), geologic (e.g landslide, Mudslide etc), Hydrologic (e.g floods, flash floods, Droughts etc), Seismic and Volcanic (e.g earth-quakes, Tsunamis, Volcanoes etc), and other natural disasters (e.g wind fire, Insect infestation etc) (USAFO, 2012). Disaster management is planned steps to minimize the effects of a disaster. This comprises actions taken to respond to an unexpected event that has adversely affects people and threatened their peaceful co-existence.

Emergency response are the aggregate of decisions and measures taken to contain or mitigate the effects of a disastrous event to prevent any further loss of life and/or property to restore order in its immediate aftermath and to re-establish normality through reconstruction and rehabilitation shortly thereafter (BUSD, 2012). Disaster management and emergency response are thus closely related, as when a disaster occurs it has to be managed and emergency response provided to the victims.

Developing countries are countries that are developing, growing evolving, that have a standard of living, level of industrial production or technological development well below that of the developed countries of North America, Europe, Australia, Japan, Koreas, and Singapore etc. The developing countries, by geography are those located in Central America, South America, Africa and Asia.

The aim of this paper is to examine the use of GIS in disaster management and emergency response in the developing countries of the world. GIS is a powerful tool that can provide excellent information for supporting many types of difficult decision making like during the occurrence of disasters and emergency response (Fadda et al., 2011).

2. GIS as a System for Disaster Management and Emergency Response

GIS provides a system for disaster management and emergency response that supports all facets of the mission including preparedness, mitigation, and response. The system consists of Desktop, Web, Mobile online maps and data and GIS saver.

i) Desktop: GIS spatial analysis and modeling power provide the tools necessary to perform a thorough risk and hazard assessment. GIS can quickly map and display critical infrastructure, populations and other community values exposed to...
natural hazards. It can also model potential events to determine consequence and loss. This type of work is typically performed by a GIS technician using the power of GIS for desktop technology (ESRI, 2011).

ii) **Web**: A web-based GIS enabled common operating picture (COP) which provides an essential geographic context of the jurisdiction with base layers of information (imagery, streets, critical infrastructure, evaluations etc). GIS can also consume and publish dynamic GIS data and services from other systems (weather, traffic cameras, video, global positioning satellite, distress calls etc). (ESRI, 2011). The web contain maps such as Google maps and OpenLayers which offer street maps, aerial/satellite imagery, decoding, searches and routine functionality which are vital component of the GIS system. These web based GIS applications enhanced the coordination of emergency relief efforts (Labiye, 2008).

iii) **Mobile**: Mobile GIS technology provide the capability to support a number of tasks within the emergency work. These capabilities include providing access to the COP in the field, the ability to provide updates to this data from the field in tactical and administrative operations and the ability to collect all type of GIS and non GIS data that can be transmitted to the COP for visualization within a geographical context. GIS for windows mobile is configured for use in the field with very little training required (ESRI, 2011). Field crew use mobile handheld devices in the field to map out points of interest which are instantly send across to the backend data base by GPRS connection which keep maps updated and information is shared and made available easily (Labiye, 2008).

iv) **Online maps and data**: GIS online can provide access to all types of GIS data, imagery and applications and is a key component of the system for disaster management and emergency response (ESRI, 2011). A variety of worldwide base maps are available including imagery, streets, topography and community base maps and more. Emergency personnel can create public or private groups to exchange map data, projects and presentations (ESRI, 2011).

In recent years there has been an explosion of mapping applications on the web such as Google maps and Bing Maps. These websites gives access to huge amounts of geographic data (Wikipedia, 2011). Other applications for publishing geographic information on the web include GeoBase, mapInfro’s Map Xfreme, Arc GIS Server etc. Web mapping services now adopt features more common in GIS services such as Google maps and Bing Maps which allow users to access and annotate maps and share the map with users (Wikipedia, 2011).

v) **GIS server**: This is the core component of the GIS system for disaster management and emergency response which can be deployed in the management facility or in the cloud and provided as a GIS service (ESRI, 2011). This provides the platform for the organization and management of GIS data available to the desktop for planning and analysis of enhanced decision support and analysis of unfolding events. It manages mobile communications to consume updates and edits which are stored in the data base and published to the COP. It also enables access to dynamic data, services and other online GIS data that is made available to all GIS users within the system (ESRI, 2011).

3. **Natural Disasters in Developing Countries**

There are many natural disasters that have occurred in the developing countries almost every month of the year in the last five years. According to Smara et al. (2004), large scale disastrous events continually occur and the magnitude and frequency of these disasters appear to be increasing.

A selection of the major natural disasters that have occurred in developing countries is presented on below on table 1.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Type of disaster and date</th>
<th>Location</th>
<th>Damages and casualties</th>
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</table>
|     | Tropical storm (October, 2010) | Philippines (Cyclone Megi) | - Over 10 people died  
- Damage to infrastructures and communication lines |
|     | Torrential rain (August, 2010) | Northern Nigeria | - Farmlands washed away  
- Destruction and damage to vital infrastructures e.g roads and bridges |
|     |  Hailstorm (July, 2010) | Northern Nigeria | - Over 200 car windscreen and roofs destroyed |
|     |  Landslides (April, 2010) | Brazil | - Over 250 dead  
- 50 buildings buried |
|     |  Mudslides (April, 2010) | Brazil | - 200 people buried in the mud  
- 147 people died  
- Damages to homes and  
- to homes/businesses |
|     |  Floods (July, 2010) | Northern Pakistan | - About 2,000 people died  
- 557,226 houses destroyed  
- Damage to roads, bridges |
|     |  Storm Surges | Trinidad and Tobago | - Damage to coastal infrastructures |
|     |  Drought | Niger Republic | - Crop failure  
- Millions starved for months  
- Spread of diseases. |
|     |  Earthquake (January, 2010) | Haiti | - 316 people died  
- 300,000 injured |

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<th>S/N</th>
<th>Type and date of disaster</th>
<th>Location</th>
<th>Impact</th>
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<td>India (Cyclone Thane)</td>
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<td>Torrential rain (December, 2011)</td>
<td>Tanzania</td>
<td>- Around 100 houses were destroyed</td>
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<td>Hailstorm (April, 2011)</td>
<td>China</td>
<td>- Several people killed</td>
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<td>Mudslides (January, 2011)</td>
<td>Brazil</td>
<td>- 480 persons killed</td>
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<td>Floods (October, 2011)</td>
<td>Thailand</td>
<td>- Disruption business activities in the capital Bangkok</td>
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<td>Storm Surge (September, 2011)</td>
<td>Philippines</td>
<td>- Houses washed into the sea</td>
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<td></td>
<td>Drought</td>
<td>East Africa</td>
<td>- Famine affected millions</td>
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<td>Earthquake (October, 2011)</td>
<td>Eastern Turkey</td>
<td>- 604 people died</td>
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<td>Volcanic Eruption (November, 2011)</td>
<td>DR Congo</td>
<td>- Contaminate water bodies</td>
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<td></td>
<td>Wild fire</td>
<td>Southern Chile</td>
<td>- 06 fire fighters killed</td>
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Table 2: Some selected major natural disasters in developing countries in the year 2011. Source; Wikipedia (2012, Aljazeera (2011)

<table>
<thead>
<tr>
<th>S/N</th>
<th>Type of disaster and date</th>
<th>Location</th>
<th>Damages/casualties</th>
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<td></td>
<td>Torrential down pours (2&lt;sup&gt;nd&lt;/sup&gt; January)</td>
<td>Northern brazil</td>
<td>- 16 people killed</td>
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<td>Landslides/Mudslides (13&lt;sup&gt;th&lt;/sup&gt; January)</td>
<td>Brazil</td>
<td>- 500 people died</td>
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<td>Landslides (24&lt;sup&gt;th&lt;/sup&gt; January)</td>
<td>Papua New Guinea</td>
<td>- 60 people died or missing</td>
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<td>Tropical cyclone Dando and Funso (18&lt;sup&gt;th&lt;/sup&gt; - 27&lt;sup&gt;th&lt;/sup&gt;, January, 2012)</td>
<td>Mozambique and Malawi</td>
<td>- 25 people killed</td>
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<td></td>
<td>Earthquake (21&lt;sup&gt;st&lt;/sup&gt; January)</td>
<td>Southern Mexico</td>
<td>- 02 people killed</td>
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<td></td>
<td>Torrential rain (23&lt;sup&gt;rd&lt;/sup&gt; January)</td>
<td>Fiji Islands</td>
<td>- 03 people died</td>
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Table 3: Natural disasters that have occurred in January, 2012. Source: BBC (2012), Aljazeera (2012)
From the tables it can be observed that different types of natural disasters have been occurring in the developing countries in the two years presented on the tables 1 and 2, and even in the first month of the year 2012.

Table 1 shows that cyclone mergi is one of the disasters that originate from the Indian Ocean causing damage to infrastructures. Northern Nigeria suffered as a torrential rains destroyed roads and vital bridges and destroyed farmlands and people houses. Also devastating is the Haiti Earthquake that killed, injured and displaced the entire population of the affected regions of the impoverished Caribbean nation. The impact of the Haiti earthquake is felt up till today as recovery, rehabilitation and reconstructions are still ongoing. Also felt up till today is the impact of the 2010 Mount Merapi (Indonesia) eruption as many victims are yet to be fully rehabilitated (Vaessen, 2011).

Table 2 shows the selected disasters of 2011. Earthquakes, floods, droughts, Tsunamis affected millions of people in the developing countries. The torrential rains in Tanzania are the heaviest rains the country has experienced since independence in 1961 (BBC News Africa, 2011). The Thailand floods of 2011 are the worst flooding experienced in 50 years in the country. The East Africa drought is one of the most devastating disasters affecting farmlands, farm animals and forcing thousands to migrate to camps in neighbouring countries. The Chile wild fire is another major disaster in the developing world. As a result of the disaster catastrophe zone was declared in three countries (Aljazeera, 2011). Series of earthquakes have occurred in Turkey, Chile, China, Burma etc with heavy casualties to the affected nations. The Turkey 7.1 magnitude quake in October is among the worst disasters in the history of the nation.

The year 2012 has started with some disasters occurring in the month of January. Flash floods, mudslide and landslide hit Brazil devastating several mountain towns near Rio de Janiero killing at least 257 people as water and mud swept the region burying families as they slept (Phillip, 2012). Tropical cyclones Dando and Funso swept coastal part of Mozambique and Malawi causing damage to coastal infrastructures. Torrential downpours hit Fiji islands submerging many houses and disrupting the Fijian tourist season. Also southern Mexico was hit by an earthquake of 6.2 magnitudes on 20th January, 2012.

From the tables and above discussions it could be observed that natural disasters occur continuously with increasing frequency and devastating impact. This situation necessitates the use of an information system to manage these disasters and respond quickly when they occur to save lives and reduce damage to properties. GIS is a viable tool that is be used for this purpose in both developed and developing countries.

4. Use of GIS for Disaster Management and Emergency Response in Developing countries

GIS plays an important role in planning for disasters and co-ordinating emergency response. Emergency response is based on the co-ordination of tremendous amount of data from multiple sources. Many governments and private agencies in developed countries rely on GIS to access real time information to make better decisions and respond more effectively to disasters (Ibrahim, 2008).

This paper examines the use of GIS for disaster management and emergency response based on the types of disasters with the aid of relevant practical documented examples of disasters from these countries and makes comparison with the developed countries where it is pertinent.

i) Atmospheric Disasters: Tropical cyclone Nargis that affected Burma in 2008 claimed many lives and destroyed properties worth millions. This is mainly due to the fact that there were no warnings issued to the people on the arrival and strength of the cyclone. In contrast there was the use of satellite imagery in warning the residence of gulf region of United States of the arrival and strength of hurricane Katrina in 2005; hence many people were able to flee for safety. The US has a hurricane warning centre that forecast storms before they make landfall (Masakayan, 2011). There were no powerful mapping and analysis capabilities to help plan ahead and be prepared when torrential rains cause havoc in Northern Nigeria in 2010 and the Tanzanian capital Dar-es-salaam in 2011. Though the Tanzanian Meteorological Agency were able to warn that the downpours are set to continue and told those living the city’s valleys to move (BBC News Africa, 2011). In Nigeria, the meteorological agency could not establish an early warning system to warn people about the occurrence of extreme weather events such as the hailstorm that affected Katsina metropolis, on 15th July, 2010 (Ladan, 2010).

ii) Geological Disasters: Flash floods, landslides and mudslides hit Brazil yearly during the rainy season with poor people mostly affected by the twin disasters of landslides and mudslides. The frequent occurrence of these disasters clearly shows that there is no warning system in place to alert the people of the disasters. The management of these disasters needs not only the application of GIS but favourable government policies on land acquisition and land use. However in Hong Kong,( China) the Technical Engineering Office operates the Land Slip Warning System in collaboration with Hong Kong Meteorological Agency. The warning system is a major component of the slope safety system that warns the public of landslides risk in times of heavy rainstorms. The public is advised to take precautionary measures when such a signal is in effect e.g staying at home and away from dangerous slopes (Chueng, 2008). In Hong Kong, GIS has for some time been used to determine the spatial distribution of maximum rainfall and landslides at various durations for major rain storms (Chueng, 2008).

iii) Hydraulic Disasters: The Philippines floods of September 2011 highlighted the insufficient information the damage potential of the flood disaster. The rains that caused the floods were forecasted but not as heavy as the one that falls and caused floods. Hence the weather department was criticized for not predicting the intensity of the rains. The same agency was also criticized for not predicting the severity of the storm that causes storm surge during the same month. However there was the use of GIS to obtain an aerial view of the damaged areas of the country. The
assessment of Jeddah floods 2009 shows the utility of GIS as a sophisticated technique spatial data analysis as ArcGIS 9.3 software which provides geo-spatial information from IKONOS satellite images that produced a comprehensive assessment of the Jeddah flood catastrophic event (Alsaud, 2011). The East African drought of 2011 is one of the most devastating in the recent year with millions of people, livestock and farmlands affected. Satellite pictures were taken to depict the situation in the region so that governments and donor agencies (e.g. Oxfam, UNICEF, save the children etc) could mobilize relief materials to the victims. However these warnings were largely ignored which increased the severity and impact of the disaster as the late response cost thousands of lives (BBC, World, 2012). The Sahel region of West Africa (Niger Republic in particular) could face severe food shortages if there is no emergency response.

iv) Seismic and Volcanic Disasters: Quick and realistic damage assessment is often the top priority a seismic event for quick and effective response activities. After the Kashmir earthquake, fine resolution images of IKONOS and quick bird were acquired from International Charter Space and Major Disasters for Muzaffarabad and Balakot cities of Pakistan. The cities were divided in zones and corresponding structural damage data was collected for emergency response (Shafique and Mejide, 2011).

After the 2010 Haiti Earthquake, a disaster response map (Post earthquake imagery) provided by Google on the Internet was provided to assist relief organizations to coordinate and plan their activities. The Haiti Earthquake disaster management and emergency response using GIS was largely possible with the assistance of the United States of America. During the February 2010 Chile earthquake an early warning was issued along the pacific areas to alert people of a possible coming of Tsunami. This shows that an early warning system is now in place along the Chilean Pacific coast. This however is not the case in Indonesia, the October 2010 Sumatra earthquake and Tsunami caused widespread destruction that displaced 20,000 people and 20 villages were hit by the waves. Officials say that the Tsunami warning system installed after the 2004 Indian Ocean Earthquake failed to function properly (Wikipedia, 2012b).

In Indonesia, Mount Merapi’s violent and destructive eruption in October and November 2010 volcanologists have now put in place an early warning system that will show the direction of the lava to alert local residents. The authorities have 30 minutes to warn people of the coming lava to evacuate for safety (Vaessen, 2011).

v) Other Disasters (Wild Fire): Wild fire is a major disaster that affects developing countries especially those with the tropical rain forest vegetation such as Brazil, Chile, DR Congo, Indonesia, Mexico, Costa Rica etc.

There is the use of GIS in fire detection and surveillance in some of these countries listed above. Scientists of Brazil's National Space Research Institute use satellite data to estimate the number of fires in the Amazon forest (Cunningham and Cunningham, 2004). In Mexico, there is satellite detection of fires that provides information on the region's fire hot spots via the internet (Dominguez and Trejo, 2004). In other countries with forests that were affected by wild fire they are yet to develop a GIS based remote sensing data for the prevention and management of fires. Besides natural hazards GIS is used to some extent in the management and emergency response to man-made disasters. Such as oil spillage, marine pollution, chemical pollution in oil producing countries of the tropics such as Nigeria, Algeria etc.

5. Challenges of Using GIS for Disaster Management and Emergency Response in Developing Countries

The use of GIS for disaster management and emergency response in developing countries is faced with challenges which are outlined below:

i) In the developing countries the availability of reliable computer network and internet connections is dependent on an overall well developed infrastructures such as regular electric power supply.

ii) The power of information and communication technology is at times not evidenced by their actual performance during a disaster. For example during the Kashmir earthquake of 2005, basic GIS data layers were not available and processed satellite images revealed little in way of damaged assessment (Laturi, 2010).

iii) In some developing countries such as Nigeria not much has been done in the area of effective mapping and provision of mapping data, different government agencies and states are doing their own mapping and surveying (Labiye, 2008).

iv) Maps and information needed for the local scale are often not available. This data is location specific, sensitive to scale and rarely has adequate coverage of the social landscape (Laturi, 2008).

v) Issues concerning data availability and access are copyrighted and classified data. Therefore such data may not be readily released or made available during emergencies. This is evident in both developing and developed countries. Moreover, information must be authentic and valid to be trusted by the users and affected populations (Laturi, 2008).

vi) GIS facilities such as Internet services and other communication facilities can be knocked down or damaged during disasters which limit their usage at a critical time.

6. Conclusion

Effective disaster management and response demands rapid utilization of information and data from many sources. The ability to integrate and distribute digital data into spatially explicit forms for rapid assessment and analysis during and after a disaster is a challenging undertaking (Laturi, 2008). Disasters reveal the need for integrated solutions that include on-the-ground emergency response informed by geospatial technologies and digital data bases. Visualization and spatial applications are critical in pre, during and in post disaster management and response (Laturi, 2008).
GIS has become an integrated well developed and successful tool in disaster management. This is because it allows for the combination of different kinds of spatial data with non-spatial data attribute data and uses them as useful information in the various stages of disaster management and emergency response (Smara et al., 2004). Developing countries are facing a lot of challenges to ensure effective use of GIS in disaster management and emergency response. These challenges have to be overcome to enable these countries to effectively use GIS in disaster management and emergency response to save lives, reduce damage to properties and minimize impact of disasters to the economy. It is therefore recommended that these countries should focus on building their GIS capabilities through establishing the necessary infrastructures and training of manpower for effective use of GIS in disaster management and emergency response.

References
BBC World 2012 GMT World News Wednesday 18th January, 2012
ESRI 2011 Public Safety and Disaster Management http://www.esri.com/industries/publicsafety (access date 4th December, 2011)
Ibrahim, Y. E. 2008 Concepts of Geographic Information System and its Significance in Geographical Analysis 2nd National Conference HUK Polytechnic, Katsina,