Application of GIS and Remote Sensing in Disaster Vulnerability Modeling and Management: A Representation in Coastal Kerala

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Abstract:

Advent of high resolution satellite imaging technologies has improved the efficiency and accuracy of geoinformation applications in disaster management. The use of geospatial tools and technologies is still to be explored in disaster management scenario. The Indonesian Tsunami of December 26, 2004 brought up importance of advanced crisis informatics capabilities for natural hazards management. This paper highlights the multilevel application of disaster informatics in local geographic scales using geospatial data. Appropriate tracking of evacuation routes and modes of evacuation are developed in a matrix of geospatial components. Vulnerability of lowland areas and inland water bodies that are connected to sea through the coastal fresh water tidal creeks are priority mapped. Supported by GIS softwares, thematic layers are integrated, queried and geographically analyzed to derive supportive information on hazard proneness of the coastal settlements in the area. Interpreted data is used to produce maps for assessing vulnerability of areas, rescue routes and shelters. A shortest evacuation route finder application is developed in Map Objects and VB.NET that is capable of assisting the first responders to help public in reaching the nearest evacuation shelter quickly. The paper also highlights the need of implementation of Public Participatory Geographic Information System (PPGIS) for community preparedness and mitigation activities at local level using Open Source Geographic Information System (OSGIS).

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Introduction

Use of geospatial technologies in disaster management applications is evident from the multi-tier decision making process and participation during a disaster. The significance of the spatial components in disaster vulnerability modeling is emphasized from the hallucination capabilities of Geoinformation technologies. In a recent document published by the United Nations Development Programme (UNDP) in the Americas, a disaster is defined as 'a social crisis situation occurring when a physical phenomenon of natural, socio-natural or anthropogenic origin negatively impacts vulnerable populations causing intense, serious and widespread disruption of the normal functioning of the affected social unit'.(Wattegama, 2007). Natural disasters have their greatest impact at local level, especially on the lives of common people. As most of the populated areas in the world are situated near coasts around the world, vulnerability of such coastal settlements to disasters like storm surge and tsunami is a matter of great concern. Disaster management can be defined as the discipline and profession of applying science, technology, planning and management to deal with extreme events, that can injure or kill large numbers of people, cause extensive damage to property, and widespread distribution to society (Kreps, 1991). In developing countries, Disaster Management is limited to post-disaster recovery, rehabilitation and reconstruction. Developed countries concentrate towards disaster planning and preparedness measures which considerably reduce the overburden on post disaster activities, and also saves valuable lives. Impact of disasters on the society can be reduced by preparing communities to be more disaster resilient (Poland, 2010).

GIS is a valid tool in Disaster Management activities like Preparedness, Mitigation, Recovery, and Disaster Response (figure 1.). Most of the data requirements for disaster management are of a spatial nature and can be located on a map. GIS can be used effectively to achieve this objective. Using a geospatially linked information, it is possible to pinpoint hazard trends and start to evaluate the consequences of potential emergencies or disasters. When hazards are viewed with other map data, such as buildings, residential areas, rivers and waterways, streets, pipelines, power lines, storage facilities, forests, etc., disaster management officials can formulate vulnerability indices. More importantly, human life and other values (property, habitat, wildlife, etc.) at risk from emergencies can be quickly identified and targeted for protective action (Russ 2000). After potentially vulnerable locations are identified, risk is assessed and mitigation needs can be addressed. This process involves analysing the developments in the immediate aftermath of a disaster, evaluating the damage and determining what facilities are required to be reinforced for construction or relocation purposes. By utilizing a geographically referenced information system, agencies involved in response can share information through databases on computer-generated maps in one location. Most disasters do not allow time to gather these resources. Geospatial tools thus provide a mechanism to centralize and visually display critical information during an emergency. This would facilitate scientists and disaster managers in creating models that would simulate trends observed in the past, present and also assist with projections for the future (Wattegama, 2007).

Crisis Informatics is an emerging field showcasing the application of information communication technology (ICT) in Disaster Management. Crisis informatics concerns with the extended social arena of disaster response which includes preparation, warning, response and recovery. Utilizing modern techniques of geo-informatics such as, Remote Sensing, GIS and GPS actions can be solicited in more systematic and precise way to respond to disasters, mitigate their effect and to make a better preparedness plans. High resolution satellite image is imperative for disaster management as it provides a cost effective solution for remote area coverage needed to support emergency preparedness efforts. Satellite image taken after a catastrophe reveals the secondary hazardous areas like low lands and creek connected water bodies near to the coast line, existing vegetation states, new access roads and vulnerable areas, settlements at risk, shelter proximity and alternative evacuation routes the settlements that need immediate attention can be located and emergency personnel can be re directed to that area. Pre disaster and post disaster images can be used for change detection and damage assessment effectively and quickly. It provides vital information to disaster managers for strategic planning.

This paper is an attempt to demonstrate the application of geospatial tools and technologies in vulnerability mapping of natural hazards including the spatial analysis of the landscapes in terms of its geographical settings and the patterns of human inhabitations. Capabilities of remote sensing and GIS as modeling tools enhances the interpretation of geographical trends and spatial patterns of risks of a natural disaster like storm surge or tsunami in a coastal scenario.

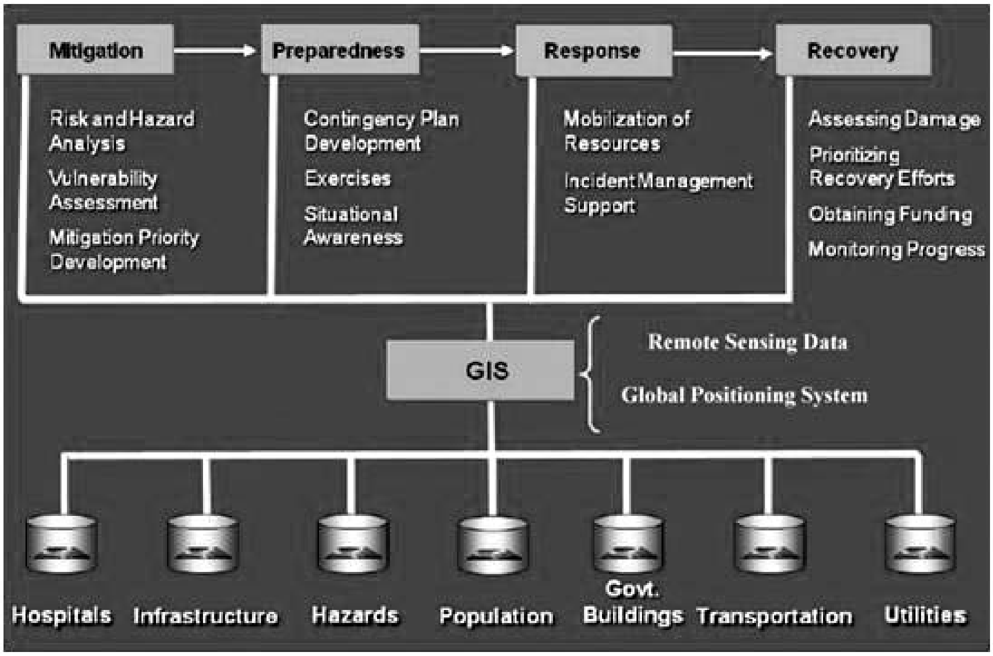

Figure 1. GIS in Disater Management

Source: ESRI White paper May 2000

Study Area

Study area is a coastal district with vast networks of backwaters, lagoons and tertiary geological plains situated in the south western corner of Indian Peninsula. Alleppey is the smallest district in Kerala considering the area but it has the highest density of population (1492 /Sq.Km). The district has a coastline of 82 Kms (Panchayat Level Statistics 2006, Alleppey). The Alleppey municipality is full of manmade canals and bridges. The coastal wards in Alleppey municipality were selected to demonstrate the application of Geospatial technologies in disaster management. The study area lies between 9°27'46''and 9031'19'' north latitude, 76°18'41''and 76°20'05''east longitudes. It is bounded on the north by Aryad South panchayat, east by Aryad South and Punnapra North panchayats, south by Punnapra North panchayat and on the west by Arabian Sea. The Alleppey municipality at present consists of 50 wards of which 8 are coastal wards. In the 8 wards there are a total of 6150 houses which contain 29,573 people. For conducting vulnerability study of the settlements in a coastal district with very high population density, a small area of Alleppey Municipal town with comparatively high risk with its proximity to seafront and continuous inland water body network and a lake was selected on the basis of its socio environmental settings.

Methodology

To demonstrate the application of geomatics in disaster management, a study was conducted which focuses along the coastal belt of Alleppey municipality in central Kerala. Coastal areas in Kerala are highly populated and vulnerable to maritime and climatic disasters. In this area coastal plain is undulated with sandy beach ridges and low lying swales. Inland micro wetlands which run along the plains are opened to coastline to discharge into sea. High density of population, important utilities and public installations along the coastal stretch warrants mitigative measures against natural calamities like tsunami and storm surge. With the help of QuickBird images of 0.6m resolution, high quality geospatial inventorying and mapping of disaster vulnerability of the coastal settlements is attempted. Depiction of geographical trend and spatial pattern of natural disasters like storm surge and tsunami is modulated in a geographically referenced frame work. Vulnerability mapping and risk assessment of the area includes identification of coastal locations in terms of its nature and human settlements. Appropriate tracking of evacuation routes and modes of evacuation is done in a spatial context. Locations for safe rehabilitation of the evacuated people are spatially represented. Vulnerability of lowlands and inland water bodies that are connected by creeks that are tidally active proximal to the coast line are mapped. Thematic mapping of the area from satellite data is done with perspective of disaster preparedness and response planning. The tsunami of Dec 26 2004 has already revealed its grip on the coastal dwellings of the municipality. The main concern in developing a disaster preparedness and response mapping system includes the identification of each and every settlement at risk and assigning them varying vulnerability weighatges depending upon their proximity to the coast line, proximity to a creek or lowland area. Quick Bird images of resolution 0.6meter were used to extract the settlements, roads, water bodies, lowlands and vegetation. The Quick Bird imagery is geo-referenced using the GPS values from field observation and this geo coded image is used as the base data. Other data collected from the local bodies like cadastral maps, resource maps etc. were also georeferenced with respect to the base data using image processing software. Related non spatial databases are integrated into a common frame work. According to feature geometry, shape files are generated in GIS platform. Thematic layers are extracted from the image and location of individual households, roads, land use and the individual parcels are extracted from the Cadastral maps.

Thematic layers and cadastral datasets are integrated and geographically analyzed to derive meaningful data on vulnerability of the coastal settlements. The secondary hazard area like lowlands and creek connected water bodies near coast line are also mapped. The land use and land cover of the area was digitized using satellite image.

Using this digital database, Coastal Regulation Zone (CRZ) is demarcated; the 200m and 500m regulation lines were drawn uniformly along the coast from the High Tide Line (HTL). The Coastal Regulation Zone (CRZ) was delineated by creating a buffer of 200m from the High Tide Line (HTL) which is the No Development Zone (NDZ) and another buffer of 500m was created from the HTL as per the government of India CRZ standards. The settlements in CRZ zones were identified from image and digitized in GIS. The risk zone mapping includes identification of the settlements with high hazard vulnerability near coast line including Coastal Regulation Zones (CRZ).

The second part includes marking of evacuation routes and modes of evacuation in terms of the geographical context, air lift and supply capabilities by means of helicopters need to be used in areas that are not directly accessible after the catastrophe, two Indian Air Force using emergency landing helipads- the Police Ground and the SD college ground were identified with reference to the coast and town of Alleppey which can be used in rapid response activities operating from remote. The next is mapping locations where evacuated people can be safely kept, which include open spaces, public and community assets with sufficient capacity, situating at a safer distance from vulnerable coastline. The LEO XIII School, SDV School and the ST. Michel School were identified.

Techniques to measure vulnerability have varied according to the discipline assessing the vulnerability and "what" is "vulnerable to what". Depending on the perspective of the analysis, there can be social vulnerability (Carmen *et al.* 2003), which addresses the capacity of human populations to respond to an event.

A coastal disaster vulnerability mapping of settlements for tsunami hazard is attempted against risk of the area. Study area was divided into grids of 12.5m interval and based on these grids, different vulnerability ranks were assigned to these grids depending on criteria like presence or absence of settlements in a grid, road connectivity to a grid, coastal proximity of the grids and proximity to inland water bodies. Different index values were set to sum up the vulnerability index of the area. These ranked grids were intersected into the centroids of the grids and based on the Inverse Distance Weighted interpolation technique using the 3D Analyst extension of ArcGIS a 3D raster model is developed in GIS (figure 2).

It can be done by the assumption that grids containing features which are not settlements or any other human or living establishments can be omitted as zero vulnerable and the 12.5 m grids containing adjacent or contiguous settlement patterns can be further included in a comparatively larger vulnerability rank. The priority will be given more to the settlements which are within 200m from the shoreline and other criterion which increases the vulnerability value is the proximity to creeks and low lying areas (figure 3). Further for this beach profile, only roads are the obstructions to tidal intrusions with reference to the local level field experience. The grids which intersect the roads and settlements in the West side will be given priority more than those which intersect grids in the East. The concentration of raster colors representing high vulnerability can be mapped as the areas which need preference in the time of information, orientation and rescue. The strategy implemented to address coastal disasters vulnerability of the settlements in the region aim to attend to emergencies rather than plan for prevention. This study will help non geospatial groups in multi dimensional visualization of vulnerability while participating and responding in a disaster scenario.

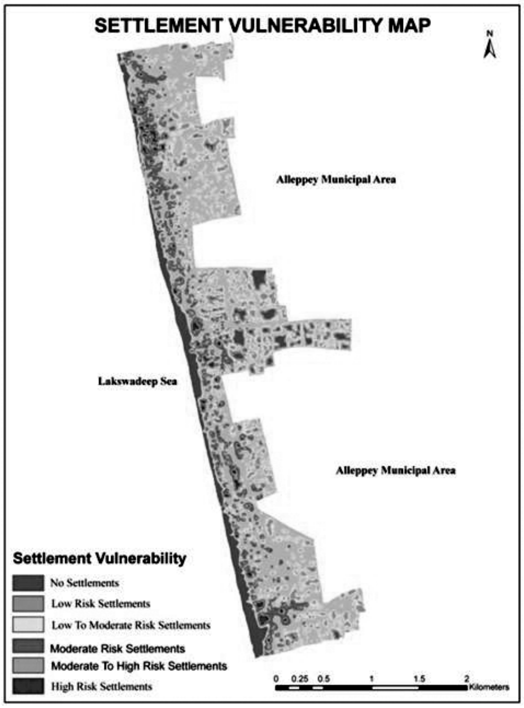

Figure 2. Settlement vulnerability map

Figure 3. Settlement vulnerability mapping using QuickBird image of 0.6m spatial resolution.

Using GIS software platform, thematic layers are integrated, queried and geographically analyzed to derive conclusive information on vulnerability of the coastal settlements in the study area. The entire road network of the municipality was digitized from quick birb imagery and was projected into UTM 43N, WGS84 coordinate system. Resultant data set was used to develop a decision support system (figure 4) using Map Objects and VB.NET which could be used by the emergency responders that provides information on the route events and shortest route to the settlement areas at risk, alternative rescue routes to the nearest evacuation shelters are associated with complete spatial control. Finding the shortest route is exceedingly important especially during a crisis situation. This system will help the first responders like police, fire force, emergency medical personnel and the local authorities during an emergency response as they might be unaware of the roads in an area. Spatially referenced accurate information allows the command and response units to work more efficiently and coordinate regional disaster response more effectively with the spatial location known and with a proper plan figured out, people will still have a chance to stand to the disaster.

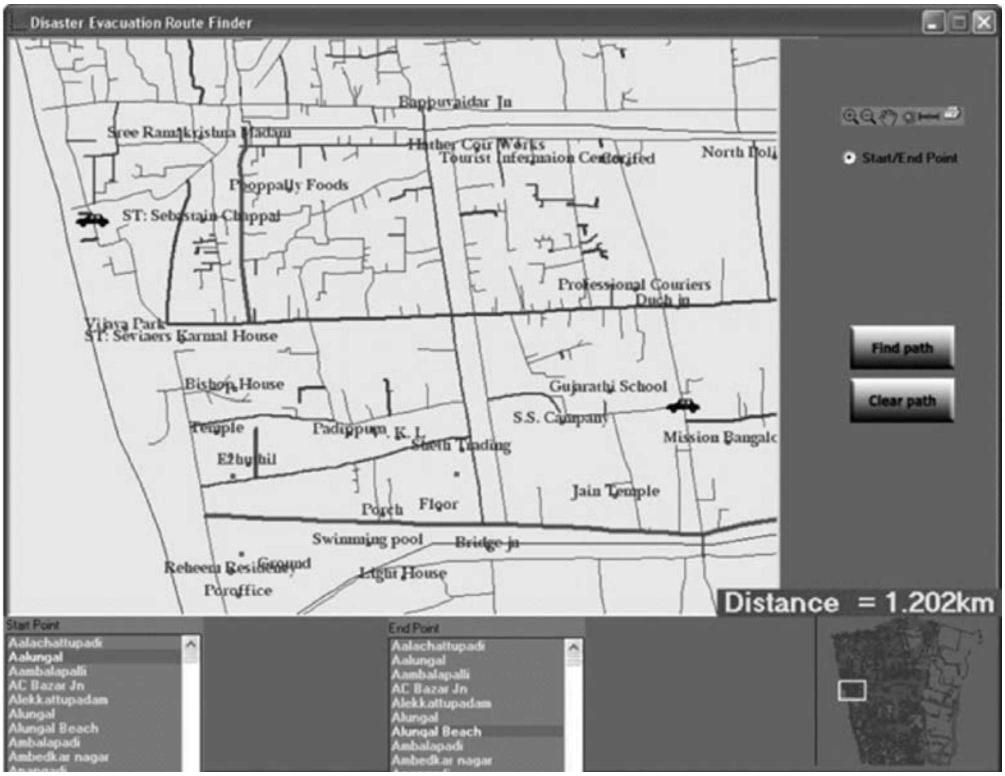

Figure 4. Shortest evacuation route finder

Results and Discussions

In many countries like India, risk analysis is limited to hazard mapping, showing areas where different levels of hazard can be expected. The available risk information is usually at too limited in spatial and temporal resolution to provide useful information on increasingly complex and dynamic risk patterns. Even where risk analysis takes into account vulnerability, this is normally restricted to the physical aspects. In most countries it is extremely rare to find risk analysis to take account of the social, economic, institutional and cultural aspects of vulnerability (Srivastava *et al.* 2004).

During the preparedness and response phases, GIS can accurately support better response planning in areas such as determining evacuation routes or locating vulnerable infrastructure and vital lifelines, etc. It also supports logistical planning to be able to provide relief supplies by displaying previously available information on roads, bridges, airports, railway and port conditions and limitations. Apart from this, activities such as evacuee camp planning can also be done using GIS. It can also provide answers to some of the questions important to disaster management, such as the exact location of the fire stations if a five-minute response time is expected or the number and locations of paramedic units required in a specific emergency. Based on the information provided by GIS, it is also possible to estimate what quantity of food supplies, bed space, clothes and medicine will be required at each shelter based on the number of expected evacuees.

Further this paper also discusses the need for implementation of Geographic Information System (GIS) at the local level through qualified local body officials by the use of Open Source Geographic Information System (OSGIS).

Open Source GIS promotes the use of geo-information for community participation in disaster mitigation. Quantum GIS (QGIS) is free GIS software (figure 5) that supports Linux, Windows and Mac operating systems. Ward leaders could be trained in using QGIS software, the objective is to bridge the gap between several levels of local administration and common people through an extensive knowledge workshop that ensured public participation for preparedness activities by defining roles and responsibilities of community leaders and task forces which include assigning 10 houses for a team leader who in turn will be monitored by the area leader who will be reporting directly to the ward official and training task forces and above all simulation of a crisis situation to evaluate both preparedness and post disaster response effectiveness, using evacuation route print outs generated by QGIS for mock drills. Also response initiatives like relief coordination, search and rescue and first aid training should also be discussed. The local knowledge on disasters is highly important; OSGIS helps in taking technology to the common people. It suggests a way to mobilize available human and technical resources in order to strengthen a good partnership between local communities and local officials. More efforts should be made towards capacity building of local people by use of available resources. It will help in developing their own knowledge base, and to develop methodologies like public participatory GIS, that promotes activities for reducing risks in a sustainable way thereby increases disaster resilience of the community by making people think spatially there by helping them better understand the area they live in and the risk they are exposed to.

The ward leaders could be trained in using Quantum GIS (QGIS) software. The objective was to bridge the gap between several levels of local administration and common people through an extensive knowledge workshop that ensured public participation for preparedness activities. Greater efforts should be made to strengthen the capacity of local people for developing their own knowledge base, and to develop methodologies like Public Participatory Geographic Information System (PPGIS), that promote activities for reducing risks in a sustainable way which results in community capacity building.

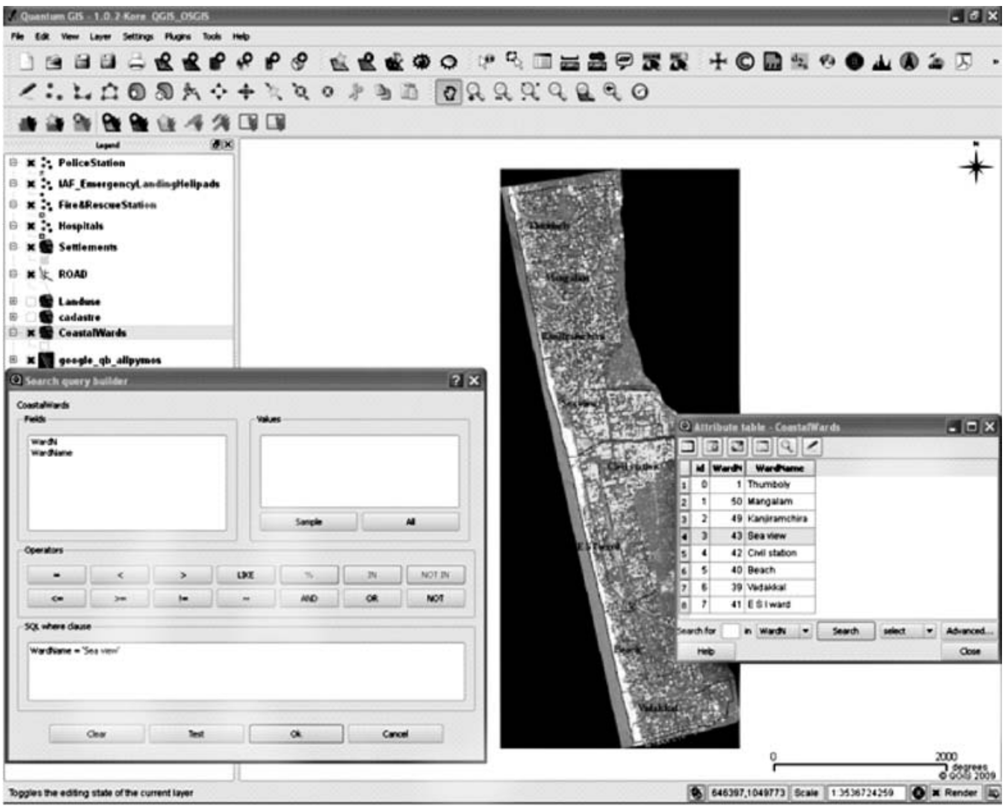

Figure 5. Use of OSGIS for Public Participatory Preparedness Initiatives

Conclusion

This study gives an idea on the advantage of using high resolution satellite imagery in disaster management; the 0.6 m resolution QuickBird imagery is extremely valuable as a means of providing local level and large scale mapping capability in disaster management. The present study delineates the purpose of an assessment of the area during a coastal disaster like storm surges or tsunami, with special preference given to early evacuation routing and community preparedness and an information system developed in GIS platform. The ultimate aim of this study is to achieve the task-specific delivery of geographic information to those in the field who are actually facing or responding to a disaster. The quality and timeliness of response services during a disaster can be improved using this system. Use of OSGIS is a cost effective method for local level community preparedness and public participatory geographic information sharing, it can be used for organizing mock drills and community preparedness plans, GIS makes people think and act spatially. Accurate information allows the command and response units to work more efficiently and coordinate regional disaster response more effectively with the spatial location known and with a proper plan figured out, people will still have a chance to stand to the hazard. Disaster management plans are to be integrated within the mainstream planning and development activities of local authorities and GIS needs to be deliberately infused into these activities for a better disaster resilient society. The local authorities can develop a crisis informatics unit by implementing this methodology and can make this system available to other local bodies and by equipping these units with the best technology and crisis informatics available, a high standard of State disaster response team could be developed in a responsible manner.

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