Application of Remote Sensing and GIS in Disaster Management : A General Discussion

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1 Introduction

Disasters have become an issue of growing concern throughout the world. They have strong negative implications on sustainable development through social, economic and environmental impacts. Various disasters like earthquakes, landslides, floods, fires, tsunamis, volcanic eruptions and cyclones are natural hazards that kill lots of people and destroy property and infrastructures every year. In addition to these natural disasters, several man-made disasters like warfare, terrorist activities are also increasing major concerns nowadays. Geoinformation data and tools like Remote Sensing, Geographic Information Systems (GIS) and Global Navigation Satellite Systems (GNSS) have increasingly been used world over in pre, during and post disaster phases for generating updated maps, integrating information, visualizing scenarios and identifying and planning effective solutions.

2 Disaster Management Cycle

Disaster management planning is structured around the disaster management cycle model (Figure 1). Many nations now plan using a variation of the Disaster Management Cycle, an integrated, four–phase planning system. Although the cycle can be considered as a continuum, traditionally the first phase of the cycle is considered to be reduction, followed by readiness, response, and recovery.

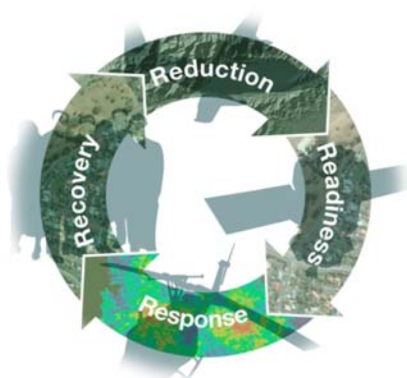

Figure 1 Disaster management cycle model

Reduction—Activities that actually eliminate or reduce the probability of a disaster. It also includes long-term activities designed to reduce the effects of unavoidable disasters.

Readiness—Activities necessary to the extent that mitigation measures have not, or cannot, prevent disasters. In the readiness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster damage.

Response—Activities following an emergency or disaster. These activities are designed to provide emergency assistance to the victims.

Recovery—Activities necessary to return all systems to normal or better.

3 Remote Sensing and GIS—The Foundation for Disaster Management

All phases of disaster management depend on data from a variety of sources. The appropriate data has to be gathered, organized, and displayed logically to determine the size and scope of disaster management programs. During an actual emergency it is critical to have the right data, at the right time, displayed logically, to respond and take appropriate action.

Emergency personnel often need detailed information concerning pipelines, building layout, electrical distribution, sewer systems, and so on. By utilizing a GIS, all departments can share information through databases on computer-generated maps in one location. Without this capability, emergency workers must gain access to a number of department managers, their unique maps, and their unique data. Most disasters do not allow time to gather these resources. This results in emergency responders having to guess, estimate, or make decisions without adequate information. This costs time, money, and—in some cases—lives. GIS provides a mechanism to centralize and visually display critical information during an emergency. Remote sensing can provide timely information about the current and historical status of the earth resources within a GIS system.

Most of the data requirements for emergency management are of a spatial nature and can be located on a maps and remote sensing imageries. The remainder of this section will illustrate how remote sensing and GIS can fulfil data requirement needs for planning and emergency operations; and how they can become the backbone of disaster management. Disaster management activities are focused on three primary objectives. These objectives are protecting life, property, and the environment. Using remote sensing and GIS, officials can pinpoint hazards and begin to evaluate the consequences of potential emergencies or disasters. When hazards (earthquake faults, fire hazard areas, flood zones, shoreline exposure, etc.) are viewed with other map data (streets, pipelines, buildings, residential areas, powerlines, storage facilities, etc.), disaster management officials can begin to formulate reduction, readiness, response, and possible recovery needs. Lives, property, and environmental values at high risk from potential emergency or disaster become apparent. Public safety personnel can focus on where reduction efforts will be necessary, where readiness efforts must be focused, where response efforts must be strengthened, and the type of recovery efforts that may be necessary.

3.1 Reduction

As potential disaster situations are identified, reduction needs can be determined and prioritized. In the case of an earthquake, what developments are within the primary impact zone of earthquake faults? Based on the expected magnitude of an earthquake, characteristics of soils, and other geologic data, what damage may occur? What facilities require reinforced construction or relocation? What facilities are in high hazard areas (key bridges, primary roads, freeway overpasses, hospitals, hazardous material storage facilities, etc.)? Reduction may include implementing legislation that limits building in earthquake or flood zones. Other reduction may target fire-safe roofing materials in wildland fire hazard areas. Values at risk can be displayed quickly and efficiently through remote sensing and GIS. Utilizing existing databases linked to geographic features in GIS makes this possible. Where are the fire hazard zones? What combination of features (for example, topography, vegetation, weather) constitutes a fire hazard? Remote sensing and GIS can identify specific slope categories in combination with certain species of flammable vegetation near homes that could be threatened by wildfire. A GIS can identify certain soil types in and adjacent to earthquake impact zones where bridges or overpasses are at risk. Remote sensing and GIS can identify the likely path of a flood based on topographic features or the spread of a coastal oil spill based on currents and wind. More importantly, human life and other values (property, habitat, wildlife, etc.) at risk from these emergencies can be quickly identified and targeted for protective action.

3.2 Readiness

Readiness includes those activities that prepare for actual emergencies. GIS can provide answers to questions such as where should fire stations be located if a five-minute response time is expected? How many paramedic units are required and where should they be located? What evacuation routes should be selected if a toxic cloud or plume is accidentally released from a plant or storage facility based on different wind patterns? How will people be notified? Will the road networks handle the traffic? What facilities will provide evacuation shelters? What quantity of supplies, bed space, and so forth, will be required at each shelter based on the number of expected evacuees? GIS can display real-time monitoring for emergency early warning. Remote weather stations can provide current weather indexes based on location and surrounding areas. Wind direction, temperature, and relative humidity can be displayed by the reporting weather station. Wind information is vital in predicting the movement of a chemical cloud release or anticipating the direction of wildfire spread upon early report. Earth movements (earthquake), reservoir level at dam sights, radiation monitors, and so forth, can all be monitored and displayed by location in GIS. It is now possible to deliver this type of information and geographic display over the Internet for public information or the Intranet for organizational information delivery.

3.3 Response

Response GIS can provide one of the primary components for computer-aided dispatch systems. Emergency response units based at fixed locations can be selected and routed for emergency response. The closest (thereby quickest) response units can be selected, routed, and dispatched to an emergency once the location is known. Depending on the emergency, a GIS can provide detailed information before the first units arrive. For example, during a commercial building fire, it is possible to identify the closest hydrants, electrical panels, hazardous materials, and floor plan of the building while en route to the emergency. For hazardous spills or chemical cloud release, the direction and speed of movement can be modelled to determine evacuation zones and containment needs. Advanced vehicle locating (AVL) can be incorporated to track (in real time) the location of incoming emergency units. AVL can also assist in determining the closest mobile units (law enforcement) to be dispatched to an emergency, as they are located on the map through GNSS transponders. During multiple emergencies (numerous wildfires, mud slides, earthquake damage) in different locations, a GIS can display the current emergency unit locations and assigned responsibilities to maintain overall situation status.

3.4 Recovery

Recovery efforts begin when the emergency is over (immediate threat to life, property, and the environment). Recovery efforts are often in two phases, short term and long term. Short-term recovery restores vital services and systems. This may include temporary food, water, and shelter to citizens who have lost homes in a hurricane or large wildfire, assuring injured persons have medical care, and/or restoring electrical services through emergency generators, and so forth. The effects of the disaster may be continuous and ongoing, but the immediate threats are halted and basic services and vital needs are restored. A GIS can play an important role in short-term recovery efforts. One of the most difficult jobs in a disaster is damage assessment. A GIS can work in collaboration with GNSS to locate each damaged facility, identify the type and amount of damage, and begin to establish priorities for action. Laptop/Palmtop computers can update the primary database from remote locations through a variety of methods. GIS can display (through the primary database) overall current damage assessment as it is conducted. Emergency distribution centres' supplies (medical, food, water, clothing, etc.) can be assigned in appropriate amounts to shelters based on the amount and type of damage in each area. GIS can display the number of shelters needed and where they should be located for reasonable access. A GIS can display areas where services have been restored in order to quickly reallocate recovery work to priority tasks. Action plans with maps can be printed, outlining work for each specific area. Shelters can update inventory databases allowing the primary command center to consolidate supply orders for all shelters. The immediate recovery efforts can be visually displayed and quickly updated until short term recovery is complete. This visual status map can be accessed and viewed from remote locations. This is particularly helpful for large emergencies or disasters where work is ongoing in different locations.

Long-term recovery restores all services to normal or better. Long-term recovery (replacement of homes, water systems, streets, hospitals, bridges, schools, etc.) can take several years. Long-term plans and progress can be displayed and tracked utilizing a GIS. Prioritization for major restoration investments can be made with the assistance of GIS. As long-term restoration is completed, it can be identified and visually tracked through GIS. Accounting for disaster costs can be complicated. As funds are allocated for repairs, accounting information can be recorded and linked to each location. Long – term recovery costs can be in the millions (or more) for large disasters. Accounting for how and where funds are allocated is demanding. A GIS can ease the burden of this task.

4 Appropriate Remote Sensing Imagery for Disaster Management

In order to successfully use Remote Sensing and GIS techniques for disaster management, physical indicators of features or attributes within the disaster management cycle need to be identified. This identification requires selection of appropriate remote sensing imagery. This selection is primarily based on spatial, spectral, temporal and radiometric properties of the image.

Geostationary satellites provide data over a large area, but with minimal spatial detail, and are appropriate for monitoring weather patterns (readiness) and volcanic ash and gas distribution (response). Conversely, very high spatial resolution data (e.g. aerial photography, Quickbird, Ikonos, Worldview) are appropriate for targeting relatively small areas where they can provide a great deal of detail. Examples of their use include baseline infrastructure mapping for scenario development and model validation (reduction and readiness), building damage (response), and observations of debris removal and reconstruction (recovery).

Optical imageries are most widely used in remote sensing applications because they are simple to interpret. Consideration should be primarily given to the spatial and temporal resolution of the sensor. These factors will differ depending on the disaster management activity. For example, during the response phase, rapid acquisition of data following the event is crucial. During the recovery phase, the speed of acquisition is less important than repetition on a consistent basis. In the early stages of recovery, imagery may be useful on a monthly basis, though as time passes, an annual acquisition may be sufficient.

Optical data can be used for activities in all stages of the disaster management cycle, however the greatest potential contributions are for monitoring recovery, and helping to plan for reduction and readiness. The greatest limitation of optical sensors is the inability to obtain imagery through clouds, smoke or haze. Events such as forest fires, volcanic eruptions, and tropical cyclones or other severe storms are characterised by cloud and smoke, which can effectively obscure damage on the ground both during and immediately after an event.

The amount of energy decreases in the thermal bands. As a result the spatial resolution becomes coarser in thermal images. Despite that, thermal imagery provides a valuable source of temperature sensitive information such as volcanic eruptions and the forest fires. Higher spatial resolution thermal imagery can be obtained from ASTER or Landsat TM/ETM+, though neither of these sensors have the ability to provide imagery of rapidly changing thermal features. They are useful for tracking longer term temperature fluctuations, such as the warming and cooling cycles of volcanic lakes, global warming, etc.

Active microwave sensor is capable of acquiring data in harsh weather conditions, such as dense cloud or smoke coverage. The precise interpretation of microwave data is complicated because of its dependence on the phase, dielectric properties of the reflecting material, surface roughness, sensor wavelength, etc. But, at the same time variety of useful information can be easily observed by the microwave sensors. The analysis of backscatter intensity by determining thresholds associated with certain features can be performed in standard GIS or image processing software.

Therefore, choosing of appropriate data for a specific disaster or a specific phase of disaster management cycle is crucial. Knowledge of image analyst is equally important because image interpretation requires special skills and experience in analysing different types of remote sensing imageries. Table 1 is furnished here to provide a guidance for different types of disaster and different phases of management cycle.

5 Conclusions

Techniques like remote sensing imagery, GNSS and GIS help to identify areas that are disaster prone, zoning them according to risk magnitudes, inventory populations and assets at risk, and simulating damage scenarios. These tools are even useful in managing disasters as they provide instant access to information required in management decisions. Modern communication systems have also proved very useful, particularly in search and rescue operations. However, appropriate planning, selection of data and skillset of analyst is highly important in every stages of disaster management cycle.

Table 1 Appropriate sensors for different disaster management applications

Type of information	***Data required***	***Sensor example***	***Application example***
Location of fault traces and rupture zones	High resolution DEM	Airborne LiDAR, SAR	Use for land use planning around active faults to reduce risk from future development in fault hazard locations
Fault displacement	Interferometric SAR	ENVISAT ASAR, ALOS PALSAR	Knowledge of fault displacement rates are used in numerical models in order to forecast the magnitude of possible earthquakes
Flood plain mapping	DEM	Airborne LiDAR, 1/2, ENVISAT ASAR, ALOS PALSAR	Identification of flood plains can help inform changes in land use, and identify areas developing protective measures (e.g. stopbanks)
Land cover / land use	Optical and polarimetric SAR	IRS, ASTER RADARSAT-2	Used for catchment management planning to reduce flood and landslide risk
Vegetation change	Consistent time series of data	SPOT, ASTER RADARSAT-2	Determine drought zones, inform fire hazard mapping
Determining lahar and lava flow paths	DEM, high resolution optical imagery	SAR, Airborne LiDAR, , AVNIR-2, ASTER	Hazard zonation, public awareness, determining location of safety shelters
Locating potential and actual unstable slopes	DEM, Interferometric SAR, high resolution stereo optical imagery	Airborne LiDAR, 1/2, ENVISAT ASAR, ALOS PALSAR, aerial photography	Hazard mapping for infrastructure planning
Baseline infrastructure maps	Very high resolution optical imagery	Aerial photography, Quickbird, Ikonos, Worldview	Assist with hazard mapping to identify key infrastructure at risk - the risk can then be addressed through mitigation or built in redundancy. Can also be used for later damage assessment post-disaster
Baseline topographic data	Moderate to high resolution optical imagery	AVNIR-2, Aerial photography, Quickbird, Ikonos, Worldview	Hazard modelling

Severe weather warnings	RADAR, broadscale visible and infra red imagery	GOES, NOAA, Meteosat	Provide valuable advanced warning of severe events to the public and emergency planners via meteorologists
Movement and ground deformation	InSAR and PS-InSAR	ENVISAT ASAR, ALOS PALSAR	Rate of movement for slow moving landslides. Often acceleration of deformation rates means that a large event is about to follow. Early detection of deformation in volcanic regions is used for forecasting of possible eruptions
Soil moisture	Long wavelength SAR	SMAP	Water shortage leading to drought and agricultural productivity decline, ability of soils to retain water to indicate flood and landslide potential
Ground temperature variability	Thermal imagery, or SWIR in the case of very hot features	ASTER, MODIS, AVHRR	Monitoring heating and cooling cycles of volcanoes to understand pre-eruptive characteristics for forecasting purposes
Coastal and bathymetric mapping	SONAR, Laser depth ranging	LADS, Topex Poseidon / Jason	Tsunami hazard modelling
Display and advertisement of potential hazards	Moderate to high resolution optical imagery, often overlaying a DEM	Aerial photography, Quickbird, Ikonos - usually using black and white or true colour composites for ease of understanding	For use in public education about hazards and risks to foster greater readiness of individuals, households and organisations Use in civil defence emergency management exercises to provide realistic scenarios that will assist with staff professional development and planning
Detecting sea temperature or atmospheric pressure change in cyclone/hurricane/ typhoon generating latitudes	Broad scale thermal imagery, geostationary	MODIS, GOES, AVHRR	Advance warning of severe weather approaching to commence
Inundation	SAR, optical	Radarsat, , ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts. Use SAR when cloud cover is still problematic

Widespread storm or earthquake induced landslides	SAR, moderate - high resolution optical	Radarsat, , ASTER Quickbird, Ikonos	Determine magnitude, location and duration of impacts.
Volcanic ash and gases	Shortwave infra red, thermal infrared	GOES, TOMS/ , MODIS	Highly temporally variable, so minimum of daily imagery required. Used for volcanic ash advisories and to warn airlines of hazardous flight paths
Public information during events	High resolution optical imagery	Quickbird, Ikonos	Assist those at risk to personalise hazard threat
Ship location	SAR	Terra SAR-X, Cosmo Sky-Med	Locating ships in the ocean during storm
Co-seismic and post-seismic deformation	InSAR	ENVISAT ASAR, ALOS PALSAR	Confirming magnitude of earthquake and forecasting possible aftershocks
Rate of recovery e.g. debris removal, vegetation regrowth, reconstruction	Moderate to very high resolution imagery in a continuous time series	Aerial photography, Quickbird, Worldview, Ikonos	Compare the effectiveness of different recovery strategies; Determine if aid funding is being used appropriately; Wildlife habitat recovery (eg after fire); Identify "eresidual risk" - areas not recovered are more vulnerable to future events
Infrastructure and facilities locations	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Create new baseline maps
Revised DEM	InSAR, LiDAR	ENVISAT ASAR, ALOS PALSAR	Necessary after large earthquake or volcanic eruption if the local and regional elevation changes
Status Quo	Very high resolution imagery	Aerial photography, Quickbird, Worldview, Ikonos	Plan areas for funding allocation