Remote Sensing and Geographic Information Systems for Natural Disaster Management

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Abstract
Natural disasters are extreme events within the earth's system that result in death or injury to humans, and damage or loss of valuable goods, such as buildings, communication systems, agricultural land, forest, natural environment etc. Disasters can have a purely natural origin, or they can be induced or aggravated by human activity. The economic losses due to natural disasters have shown an increase with a factor of eight over the past four decades, caused by the increased vulnerability of the global society, due to population growth, urbanisation, poor urban planning, but also due to an increase in the number of weather-related disasters.
The activities on natural disaster reduction in the past decade, which was designated by the UN as the "International Decade for Natural Disaster Reduction", unfortunately have not led to a diversion of this increasing loss trend. In future even more work has to be done in disaster management.
For the management of natural disasters a large amount of multi-temporal spatial data is required. Satellite remote sensing is the ideal tool for disaster management, since it offers information over large areas, and at short time intervals. Although it can be utilised in the various phases of disaster management, such as prevention, preparedness, relief, and reconstruction, in practice up till now it is mostly used for warning and monitoring. During the last decades remote sensing has become an operational tool in the disaster preparedness and warning phases for cyclones, droughts and floods. The use of remote sensing data is not possible without a proper tool to handle the large amounts of data and combine it with data coming from other sources, such as maps or measurement stations. Therefore, together with the growth of the remote sensing applications, Geographic Information Systems have become increasingly important for disaster management. This chapter gives a review of the use of remote sensing and GIS for a number of major disaster types.

1. Introduction

Natural disasters are extreme events within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differs substantially from the mean, resulting in death or injury to humans, and damage or loss of valuable good, such as buildings, communication systems, agricultural land, forest, natural environment. They are a profound impact of the natural environment upon the socio-economic system (Alexander, 1993). This impact may be rapid, as in the case of earthquakes, or slow as in the case of drought.
It is important to distinguish between the terms *disaster* and *hazard.* A potentially damaging phenomenon (hazard), such as an earthquake by itself is not considered a disaster when it occurs in uninhabited areas. It is called a disaster when it occurs in a populated area, and brings damage, loss or destruction. Natural disasters occur in many parts of the world, although each type of disaster is restricted to certain regions. Figure 1 gives an indication of the geographical distribution of a number of major hazards, such as earthquakes, volcanoes, tropical storms and cyclones. As can be seen from this figure earthquake and volcanoes, for example, are concentrated mainly on the earth's plate boundaries.
Disasters can be classified in several ways. A possible subdivision is between:

- *Natural disasters* are events which are caused by purely natural phenomena and bring damage to human societies (such as earthquakes, volcanic eruptions, hurricanes);
- *Human-made disasters* are events which are caused by human activities (such as atmospheric pollution, industrial chemical accidents, major armed conflicts, nuclear accidents, oil spills), and

Human-induced disasters are natural disasters that are accelerated/aggravated by human influence.

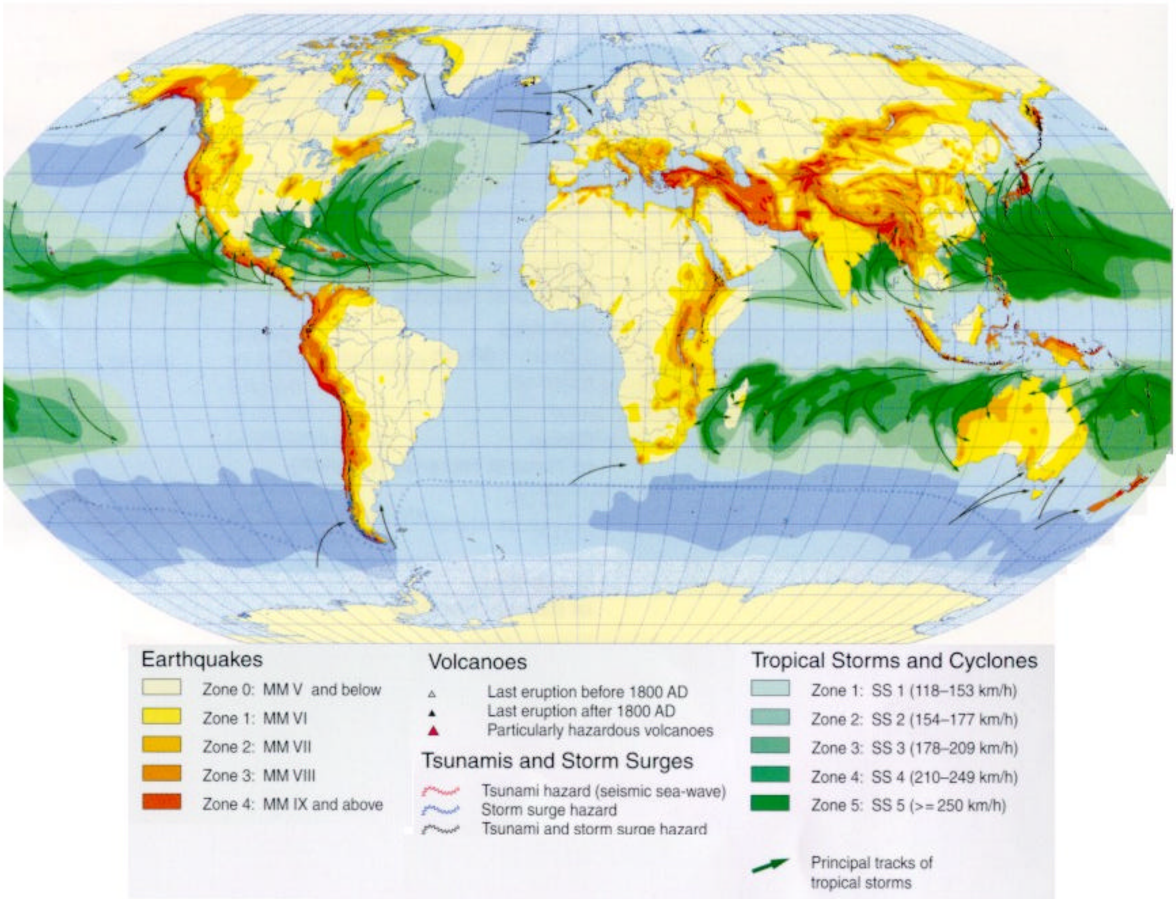

Figure 1: World map of natural disasters (Source: Munich Re., 1998a)

In table 1 the various disasters are classified according to this classification, using some intermediate classes. A landslide, for example, may be purely natural, as a result of a heavy rainfall or earthquake, but it may also be human induced, as a result of an oversteepened roadcut.

Natural	**Some human influence**	**Mixed natural /human influence**	**Some natural influence**	**Human**
Earthquake	Flood	Landslides	Crop disease	Armed conflict
Tsunami	Dust storm	Subsidence	Insect infestation	Land mines
Volcanic eruption	Drought	Erosion	Forest fire	Major (air-, sea-, land-) traffic accidents
Snow storm / avalanche		Desertification	Mangrove decline	Nuclear / chemical accidents
Glacial lake outburst		Coal fires	Coral reef decline	Oil spill
Lightning		Coastal erosion	Acid rain	Water / soil / air pollution
Windstorm Thunderstorm		Greenhouse effect	Ozone depletion	Groundwater pollution
Hailstorm Tornado		Sealevel rise		Electrical power breakdown
Cyclone/ Hurricane				Pesticides
Asteroid impact				
Aurora borealis				

Table 1: Classification of disaster in a gradual scale between purely natural and purely human-made.

Another subdivision is related to the main controlling factors leading to a disaster. These may be meteorological (too much or too little rainfall, high wind-speed), geomorphological/geological (resulting from anomalies in the earth's surface or subsurface), ecological (regarding flora and fauna), technological (human made), global environmental (affecting the environment on global scale) and extra terrestrial (See table 2).

Meteorological	**Geomorphological/ Geological**	**Ecological**	**Technological**	**Global environmental**	**Extra terrestrial**
Drought	Earthquake	Crop disease	Armed conflict	Acid rain	Asteroid impact
Dust storm	Tsunami	Insect infestation	Land mines	Atmospheric pollution	Aurora borealis
Flood	Volcanic eruption	Forest fire	Major (air-, sea-, land-) traffic accidents	Greenhouse effect	
Lightning	Landslide	Mangrove decline	Nuclear / chemical accidents	Sealevel rise	
Windstorm	Snow avalanche	Coral reef decline	Oil spill	El Niño	
Thunderstorm	Glacial lake outburst		Water / soil / air pollution	Ozone depletion	
Hailstorm	Subsidence		Electrical power breakdown		
Tornado	Groundwater pollution		Pesticides		
Cyclone/ Hurricane	Coal fires				
	Coastal erosion				

Table 2: Classification of disasters according to the main controlling factor.

The impact of natural disasters to the global environment is becoming more and more severe over the last decades. The reported number of disaster has dramatically increased, as well as the cost to the global economy and the number of people affected (see table 3 and figure 2).

	Decade 1960 - 1969 US $ billion	**Decade 1970 -1979 US $ billion**	**Decade 1980 - 1989 US $ billion**	**Last10 years 1988 - 1997 US $ billion**	**Factor Last 10 : 60s**
Number of large disasters	**16**	**29**	**70**	**48**	**3.0**
Economic losses	**50.4**	**96.9**	**153.8**	**426.7**	**8.5**
Insured losses	**6.7**	**11.3**	**31.0**	**93.5**	**14.0**

Table 3: Statistics of great natural disasters for the last four decades (source: Munich Re, 1998b)

Earthquakes result in the largest amount of losses. Of the total losses it accounts for 35%, ahead of floods (30%), windstorms (28%) and others (7%). Earthquake is also the main cause in terms of the number of fatalities (47%), followed by windstorms (45%), floods (7%), and others (1%) (Munich Re., 1999).
The strong increase in losses and people affected by natural disasters is partly due to the developments in communications, as hardly any disaster passes unnoticed by the mass media. But it is also due to the increased exposure of the world's population to natural disasters. There are a number of factors responsible for this, which can be subdived in factors leading to a larger risk and factors leading to a higher occurrence of hazardous events. The increased risk is due to the rapid increase of the world population, which has doubled in size from 3 billion in the 1960s to 6 billion in 2000. Depending on the expected growth rates, world population is estimated to be between 7 and 10 billion by the year 2050 (UNPD, 1999).
Another factor related to the population pressure is that areas become settled that were previously avoided due to their susceptibility to natural hazards. Added to this is the important trend of the concentration of people and economic activities in large urban centres, most of which are located in vulnerable coastal areas. Mega-cities with a very rapid growth mostly experience the occupation of marginal land, susceptible to disasters, by the poor newcomers.
Another factor related to the increasing impact of natural disasters has to do with the development of highly sensitive technologies and the growing susceptibility of modern industrial societies to breakdowns in their infrastructure. Figure 2 shows the distribution of economic and insured losses due to natural disasters during the last 4 decades.
It is also clear that there is a rapid increase in the insured losses, which are mainly related to losses occurring in developed countries. Windstorms clearly dominate the category of insured losses (US $90 billion), followed by earthquakes (US $ 25 billion). Insured losses to flooding are remarkably less (US $ 10 billion), due to the fact that they are most sever in developing countries with lower insurance density.

However, it is not only the increased exposure of the population to hazards that can explain the increase in natural disasters. There is also a clear trend that the frequency of destructive events, related to atmospheric extremes, such as floods, drought, cyclones, and landslides is increasing. During the last 10 years a total of 3,750 windstorms and floods were recorded, accounting for two-thirds of all events. The number of catastrophes due to earthquakes and volcanic activity (about 100 per year) has remained constant (Munich Re., 1998). Although the time-span is still not long enough to indicate it with certainty, it is a clear indication that climate change shows a clear negative trend in relation with the occurrence of natural disasters, which only will be become more severe in the near future.

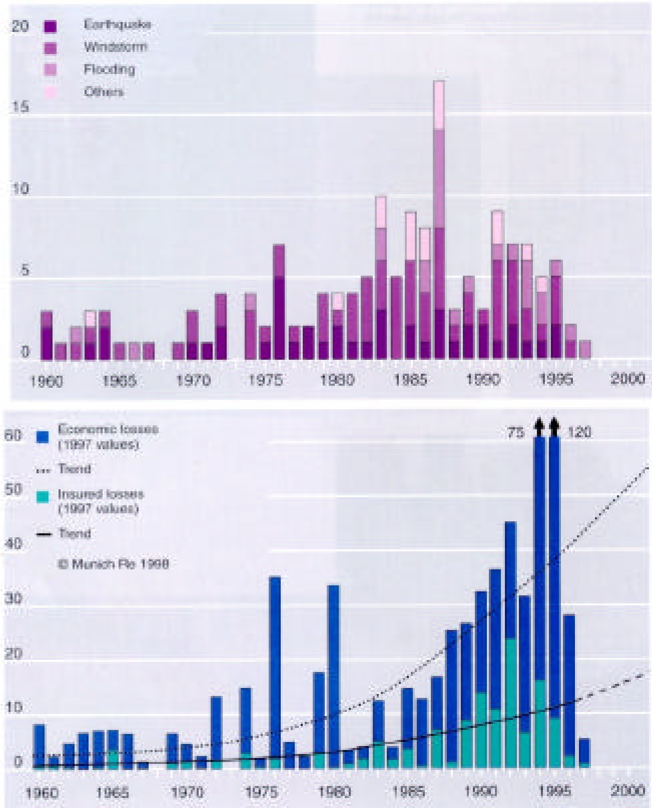

Figure 2: Above: number of large natural disaster per year for the period 1960-1998. Below: economic and insured losses due to natural disasters, with trends (Source: Munich Re., 1998b)

There seems to be an inverse relationship between the level of development and loss of human lives in the case of a disaster. About 95 percent of the disaster related casualties occur in developing countries, where more than 4.200 million people live. Economic losses attributable to natural hazards in developing countries may represent as much as 10% of their gross national product. In industrialised countries, where warning -systems are more sophisticated, it is more feasible to predict the occurrence of certain natural phenomena, and to carry out massive evacuations. The application of building codes and restrictive zoning also accounts for a lower number of casualties in developed countries.

These statistics illustrate well the importance of hazard mitiga tion. The International community has become aware of the necessity to increase the work on disaster management. The decade 1990-2000 was designated the "International Decade for Natural Disaster Reduction" by the general assembly of the United Nations. Ho wever, now that we are at the end of the IDNDR, we must conclude that the efforts for reducing the effects for disaster reduction during the last decade have not been sufficient, and have to be enhanced in the next decade.

2. Disaster management

One way of dealing with natural hazards is to ignore them. In many areas, neither the population nor the authorities chooses to take the danger due to natural hazards seriously, due to many different reasons. The last major destructive event may have happened long time ago, and is only remember as a story from the past. People may have moved in the area recently, without having the knowledge on potential hazards. Or it may be that the risk due to natural hazards is taken for granted, given the many dangers and pro blems confronted with in people's daily lives. Cynical authorities may ignore hazards because the media exposure for their aid supply after the disaster has happened has much more impact on voters than the quit investment of funds for disaster mitigation.
To effectively reduce the impacts of natural disasters a complete strategy for disaster management is required, which is also referred to as the disaster management cycle (see figure 3).

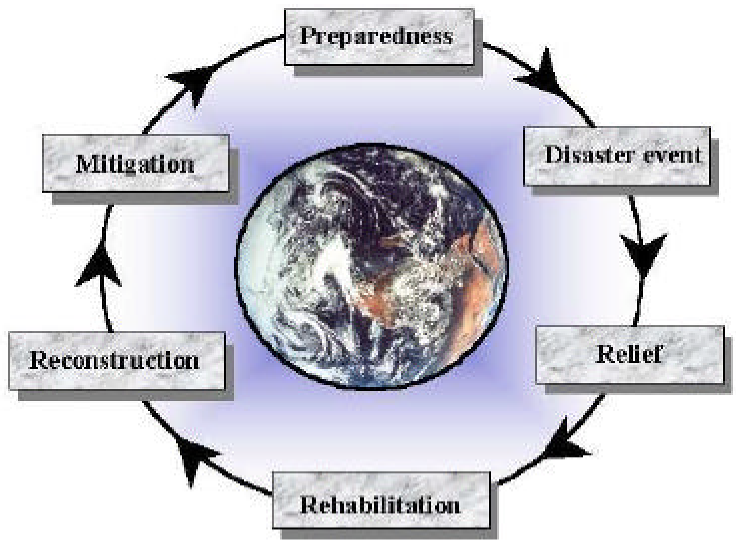

Figure 3: The Disaster Management cycle

Disaster management consists of two phases that take place before a disaster occurs, ***disaster prevention*** and ***disaster preparedness***, and three phases that happen after the occurrence of a disaster, ***disaster relief***, ***rehabilitation*** and ***reconstruction*** (UNDRO, 1991).
Disaster management is represented here as a cycle, since the occurrence of a disaster event will eventually influence the way society is preparing for the next one.

Disaster prevention

Disaster prevention is the planned reduction of risk to human health and safety. This may involve modifying the causes or consequences of the hazard, the vulnerability of the population or the distribution of the losses. The following activities form part of disaster prevention:

- ***Hazard assessment***: determining the type of hazardous phenomena that may affect the area, their frequency and magnitude, and representing on a map which areas are likely to be affected;
- ***Vulnerability assessment***: assessing the degree of loss that these events will cause to population, buildings, infrastructure, economic activities, etc. ;
- ***Risk assessment***: quantifying the numbers of lives likely to be lost, the number of persons injured, the cost of damage to property and disruption of economic activities caused by the events, and preparation of maps indicating the risk areas.
- ***Restrictive zoning***: implementation of the risk maps in development plans, and development of laws to enforce these plans. Public acquisitions of hazardous areas; alternative land use designation for hazardous areas; removal of unsafe structures; obligatory informing potential buyers of real estate on hazardness of the site; include hazardness in insurance policies of real estate;
- ***Protective engineering solutions***: the construction of engineering works to protect the elements at risk from a potentially disastrous event. For example: dikes, floodwalls, slope stabilisation works, erosion control works, cyclone shelters, etc.;
- ***Building codes***: the definition of standards for the construction of buildings and infrastructure, so that they are able to withstand a disastrous event of a certain magnitude/intensity. For example: earthquake resistant building codes.

- ***Informing population***: public information and education on hazards and risks in the area. Involvement of communities, schools, offices in disaster management.

Disaster preparedness

Disaster preparedness involves all those activities that are intended to be prepared once a disastrous event is going to happen, so that people can be evacuated, protected or rescued as soon as possible. It involves the following activities:

- ***Preparation of a disaster plan***: co-ordination with all emergency services, governmental organisations and the public. Establishing an organisation for emergency operations;
- ***Anticipating damage to critical facilities***: construction of a number of disaster scenarios, in which damage to critical facilities (main roads, hospitals, buildings of emergency organisations, etc.) is anticipated, and the consequences evaluated;
- ***Damage inspection, repair, and recovery procedures***: setting-up procedures for post-disaster damage inspection, and make sure that enough trained personnel are available and that there is a supply of materials to be used in emergency situations;
- ***Communications and control centre***: establish procedures for communication during and after the disaster, with all emergency services, press, and government. Make sure there is enough equipment, and that the equipment will function after the event. Setting up a disaster co-ordination command centre;
- ***Disaster training exercises:*** training of personnel of disaster emergency services. Rehearsal of disaster plan with all people involved;
- ***Prepare evacuation plans:*** establishing safe sites for disaster shelters, evacuation routes, and the preparation of evacuation maps, in close co-operation with the local population;
- **Informing /training population**: public information and education on hazards and risks in the area; information about how to prepare for a disaster, and how to react when it happened; information on evacuation procedures;
- ***Forecasts/warning/prediction of disasters***: establishing a natural hazards observatory, a technical centre receiving all kind of scientific data, and whose task it is to do real-time data processing and give forecasts and status reports on disasters to emergency organisations and the public;
- **Monitoring**: evaluating the development through time of disasters (for example floods).

Disaster relief

Disaster relief involves the provision of emergency relief and assistance when it is needed and the maintenance of public order and safety. It involves activities, such as:

- ***Search and rescue operations:*** expert personnel, such as (para)medics, engineers, police and firemen move in the affected area to search and rescue victims;
- ***Implementation of disaster response plan***: starting the disaster co-ordination and command centre; contact and meet with all emergency organisations;
- ***Rapid damage assessment***: assessment of the severity shortly after the occurrence of a disaster, in order to get a general idea of the scale of the disaster; identify continuing threats to survivors. Later on this is followed by a detailed damage census, during which all damaged buildings will be surveyed;
- ***Establish communication and infrastructure***: making sure the basic communication lines for disaster relief co-ordination are working, and re-opening main infrastructure (roads, electricity);
- ***Evacuation, setting up shelters***: perform evacuation, on the basis of the evacuation plan, and the current disaster situation; operationalisation of shelters; storage of salvaged properties.
- ***Food- and medical supply, disease prevention***: providing food rations, assuring water supply and sanitation in shelters;
- ***Maintaining public order***: prevention of looting, making sure no fake-victims arrive from other parts of the country;
- ***Mass media coverage***: arranging logistics for visiting reporters; organisation of press conferences; avoiding biased news coverage;
- ***Co-ordination of international aid***: making sure that the international aid is providing the right materials on the right moment; co-ordination of humanitarian and scientific aid missions.

Disaster rehabilitation and reconstruction

Rehabilitation and reconstruction refer to the provision of support during the aftermath of a disaster, so that community functions can quickly be made to work again. They can be subdivided in the short term rehabilitation activities and the longer term reconstruction activities.

- ***Repair / Demolition of buildings***: based on a detailed damage census, structural engineers decide which of the buildings can still be repaired, and which ones will have to be demolished;
- ***Defining areas of reconstruction***: the areas that have been severely affected by the disaster should be evaluated in detail, to establish the reasons for destruction (due to natural factors, or due to construction type); recommendations should be given whether or not to rebuild in the same area;
- ***Reconstruction planning***: obtaining necessary funds for the reconstruction of the area; return of survivors to the area; planning and construction of imp roved buildings and infrastructure;
- ***Improve disaster management plan***: re-definition of hazard and risk maps; re -definition of building standards:

The reconstruction phase also involves an important aspect of evaluation. The disaster mitigation, prepared ness, and relief activities should be critically reviewed. An explanation should be given as to why despite all disaster mitigation efforts, houses that were constructed according to the official building codes, still were collapsed. Or why there were areas affected, that were not indicated in the hazard and risk maps. This will lead to a new phase of adjustment of the disaster mitigation and preparedness plans.

For more information about disaster management the reader is referred to the following websites :

- The US Federal Emergency Management Agency (FEMA):. The Global Emergency Management System is an online, searchable database containing links to Websites in a variety of categories that are related in some way to emergency management. http://www.fema.gov/
- The Office of Foreign Disaster Assistance of the United States Agency for International Development (OFDA/USAID). OFDA also sponsors development of early warning system technology and in-country and international tra ining programs designed to strengthen the ability of foreign governments to rely on their own resources. http://www.info.usaid.gov/ofda/
- The Disaster Preparedness and Emergency Response Association, Internatio nal (DERA) was founded in 1962 to assist communities world-wide in disaster preparedness, response and recovery, and to serve as a professional association linking professionals, volunteers, and organisations active in all phases of emergency preparedness and management. http://www.disasters.org/deralink.html
- Relief Web: a project of the United Nations Office for the Co-ordination of Humanitarian Affairs (OCHA) http://www.reliefweb.int/w/rwb.nsf

3. RS and GIS: tools in disaster management

3.1 Introduction

Mitigation of natural disasters can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of hazardous events in an area. Many types of information that are needed in natural disaster management have an important spatial component. Spatial data are data with a geographic component, such as maps, aerial photography, satellite imagery, GPS data, rainfall data, borehole data etc. Many of these data will have a different projection and co-ordinate system, and need to be brought to a common map-basis, in order to superimpose them.

We now have access to information gathering and organising technologies like remote sensing and geographic information systems (GIS), which have proven their usefulness in disaster management.

- First of all, remote sensing and GIS provides a data base from which the evidence left behind by disasters that have occurred before can be interpreted, and combined with other information to arrive at hazard maps, indicating which areas are potentially dangerous. The zonation of hazard must be the basis for any disaster management project and should supply planners and decision-makers with adequate and understandable information. Remote sensing data, such as satellite images and aerial photos allow us to map the variabilities of terrain properties, such as vegetation, water, and geology, both in space and time. Satellite images give a synoptic overview and provide very useful environmental information, for a wide range of scales, from entire continents to details of a few metres. Secondly, many types of disasters, such as floods, drought, cyclones, volcanic eruptions, etc. will have certain precursors. The satellites can detect the early stages of these events as anomalies in a time series. Images are available at regular short time intervals, and can be used for the prediction of both rapid and slow disasters.
- Then, when a disaster occurs, the speed of information collection from air and space borne platforms and the possibility of information dissemination with a matching swiftness make it possible to monitor the occurrence of the disaster. Many disasters may affect large areas and no other tool than remote sensing would provide a matching spatial coverage. Remote sensing also allows monitoring the event during the time of occurrence while the forces are in full swing. The vantage position of satellites makes it ideal for us to think of, plan for and operationally monitor the event. GIS is used as a tool for the planning of evacuation routes, for the design of centres for emergency operations, and for integration of satellite data with other relevant data in the design of disaster warning systems
- In the disaster relief phase, GIS is extremely useful in combination with Global Positioning Systems (GPS) in search and rescue operations in areas that have been devastated and where it is difficult to orientate. The impact and departure of the disaster event leaves behind an area of immense devastation. Remote sensing can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations.
- In the disaster rehabilitation phase GIS is used to organise the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction. Remote sensing is used to map the new situation and update the databases used for the reconstruction of an area, and can help to prevent that such a disaster occurs again.

The volume of data needed for disaster management, particularly in the context of integrated development planning, clearly is too much to be handled by manual methods in a timely and effective way. For example, the post disaster damage reports on buildings in an earthquake stricken city, may be thousands. Each one will need to be evaluated separately in order to decide if the building has suffered irreparable damage or not. After that all reports should be combined to derive at a reconstruction zoning within a relatively small period of time.

One of the main advantages of the use of the powerful combination techniques of a GIS, is the evaluation of several hazard and risk scenarios that can be used in the decision-making about the future development of an area, and the optimum way to protect it from natural disasters.

Remote sensing data derived from satellites are excellent tools in the mapping of the spatial distribution of disaster related data within a relatively short period of time. Many different satellite based systems exist nowadays, with different characteristics related to their *spatial-, temporal- and spectral resolution.* An overview of the various remote sensing platforms and sensors is given in Van Meer et al (this volume).

Remote sensing data should generally be linked or calibrated with other types of data, derived from mapping, measurement networks or sampling points, to derive at parameters, which are useful in the study of disasters. The linkage is done in two ways, either via visual interpretation of the image or via classification.

The data required for disaster management is coming from different scientific disciplines, and should be integrated. Data integration is one of the strongest points of GIS. In general the following types of data are required:

- Data on the disastrous phenomena (e.g. landslides, floods, earthquakes), their location, frequency, magnitude etc.
- Data on the environment in which the disastrous events might take place: top ography, geology, geomorphology, soils, hydrology, land use, vegetation etc.
- Data on the elements that might be destroyed if the event takes place: infrastructure, settlements, population, socio-economic data etc.
- Data on the emergency relief resources, such as hospitals, fire brigades, police stations, warehouses etc.

The use of remote sensing and GIS has become an integrated, well-developed and successful tool in disaster management in various countries and regions, such as in North America, Europe, Jap an, and India.

3.2 Application levels

The amount and type of data that has to be stored in a GIS for disaster management depends very much on the level of application or the scale of the management project. Natural hazards information should be included routinely in development planning and investment project preparation. Development and investment projects should include a cost/benefit analysis of investing in hazard mitigation measures, and weigh them against the losses that are likely to occur if these measures are not taken (OAS/DRDE, 1990). Geoinformation can play a role at the following levels:

- **National level**
  At a national level, GIS and remote sensing can provide useful information, and create disaster awareness with politicians and the public, so that on a national level decisions are taken on the establishment of (a) disaster management organisation(s). At such a general level, the objective is to give an inventory of disasters and the areas affected or threatened for an entire country. The deta il will be low, as the assessment is mostly done on the basis of general applicable rules. Mapping scales will be in the order of 1:1,000,000 or smaller. The following types of information should be indicated:
  - Hazard-free regions suitable for development;
  - Regions with severe hazards where most development should be avoided;
  - Hazardous regions where development already has taken place and where measures are needed to reduce the vulnerability;
  - Regions where more hazard investigations are required;
  - National scale information is also required for those disasters that affect an entire country (drought, major hurricanes, floods etc.)

  An example of this application level for the area affected by Hurricane Mitch in 1998 can be found at: http://cindi.usgs.gov/events/mitch/atlas/index.html

- **Regional level**
  At regional levels the use of GIS for disaster management is intended for planners in the early phases of regional development projects or large engineering projects. It is used to investigate where hazards can be a constraint on the development of rural, urban or infrastructural projects. The areas to be investigated are large, generally several thousands of square kilometres, and the required detail of the input data is still rather low. Typical mapping scales for this level are between 1:100,000 and 1:1,000,000.
  Synoptic earth observation is the main source of information at this level, forming the basis for hazard assessment. Apart from the actual h azard information, also environmental and population and infrastructural information can be collected at a larger detail than the national level. Therefore, the GIS can be utilised more for analysis at this scale, although the type of analysis will mostly be qualitative, due to the lack of detailed information.
  Some examples of GIS applications at the regional level are:
  - Identification of investment projects and preparation of project profiles showing where hazard mitigation measures (flood protection, earthquake resistant structures) must be taken into account in the design.
  - Preparation of hazard mitigation projects to reduce risk on currently occupied land.
  - Guidance on land use and intensity (OAS/DRDE, 1990)

- **Medium level**
  At this level GIS can be used for the prefeasibility study of development projects, at an inter-municipal or district level. For example for the determination of hazard zones in areas with large engineering structures, roads and urbanisation plans. The areas to be investigated will have an area of a few hundreds of square kilometres and a considerable higher detail is required at this scale. Typical mapping scales are in the order

of 1:25,000-1:100,000. Slope information at this scale is sufficiently detailed to generate Digital Elevation Models, and derivative products such as slope maps. GIS analysis capabilities for hazard zonation can be utilised extensively. For example, landslide inventories can be combined with other data (geology, slope, land use) using statistical methods to provide hazard susceptibility maps (van Westen, 1993).

- **Local level (1:5,000 - 1:15,000)**
  The level of application is typically that of a municipality. The use of GIS at this level is intended for planners to formulate projects at feasibility levels. But it is also used to generate hazard and risk map for existing settlements and cities, and in the planning of disaster preparedness and disaster relief activities. Typical mapping scales are 1:5,000 – 1:25,000. The detail of information will be high, including for example cadastral information. The hazard data is more quantitative, derived from laboratory testing of materials and in-field measurements. Also the hazard assessment techniques will be more quantitative and based on deterministic/probabilistic models (Terlien et al, 1995).

- **Site-investigation scale (> 1:2,000)**
  At site-investigation scale GIS is used in the planning and design of engineering structures (buildings bridges, roads etc), and in detailed engineering measures to mitigate natural hazards (retaining walls, checkdams etc). Typical mapping scale are 1:2,000 or larger. Nearly all of the data is of a quantitative nature. GIS is basically used for the data management, and not for data analysis, since mostly external deterministic models are used for that. Also 3-D GIS can be of great use at this level (Terlien, 1996).

Although the selection of the scale of analysis is usually determined by the intended application of the mapping results, the choice of a analysis technique remains open. This choice depends on the type of problem, the availability of data, the availability of financial resources, the time available for the investigation, as well as the professional experience of the experts involved in the survey. See also Cova (1999) for an overview of the use of GIS in emergency management.

3.3 Characteristics of natural disaster types and the role of geoinformation

When we want to describe to usefulness of remote sensing and GIS for disaster management, we have to answer a number of questions for each type of disaster. These questions can be subdivided into two blocks: how to characterise the disaster (disaster characterisation), and how to observe the features associated with the disaster (disaster observation) (ISU, 1993).

Disaster characterisation
For each disaster type the following questions need to be answered:
- What is known about their speed of evolution?
- What is their return period?
- What is the area affected?
- What is the nature and extent of damage?
- What is the toll in loss of human life?
- Which forms of preparedness are practical?
- Which forms of mitigation/relief are practised?

Disaster Observation
For each disaster type the following questions need to be answered:
- Which observable features precede the disaster?
- Which observable features accompany the disaster?
- Which observable features can be used to assess the damage?
- In what sense are space observation techniques used in the various phases?
  - Are they main tools or complementary?
  - Are the current techniques adequate?
  - Can these technique be automated?
  - What are the lacks in techniques?
- What are the requirements of satellite imagery:
  - Spatial resolution, Temporal resolution, Spectral resolution
- What type of data should be collected to analyse the hazard and risk?
- What type of modelling is carried out to analyse hazard and risk?
- How can GIS be used for the particular type of disaster?

In the following paragraphs an attempt to answer some of these questions will be given for a number of different disaster types.
The use of satellite data for disaster management includes both polar orbital Earth Resource Satellites and operational meteorological satellites. The polar orbital Earth Resource Satellites are of two types:

- *optical sensors* that cannot see through clouds operating at low (AVHRR), medium (LANDSAT, SPOT, IRS) and high resolutions (IKONOS), and
- *microwave sensors* which can see through clouds, which include high resolution active sensors such as Synthetic Aperture Radar (SAR) (RADARSAT, ERS, JERS) and low resolution passive sensors (SSMI) .

Meteorological satellites are of two types: geostationary and polar orbital.

- *geostationary satellite* (GOES: METEOSAT, GMS, INSAT, GOMS) providing images in visible (VIS) and infrared (IR) wavelength every half-hour.
- *polar orbital satellites* (POES: NOAA and SSM/I) circle the earth twice a day and provide VIS and IR imagery and microwave data.

4. Examples of the use of GIS and Remote Sensing

4.1 Flooding

Different types of flooding (e.g. river floods, flash floods, dam-break floods or coastal floods) have different characteristics with respect to the time of occurrence, the magnitude, frequency, duration, flow velocity and the areal extension. Many factors play a role in the occurrence of flooding, such as the intensity and duration of rainfall, snowmelt, deforestation, land use practices, sedimentation in riverbeds, and natural or man made obstructions. In the evaluation of flood hazard, the following parameters should be taken into account: depth of water during flood, the duration of flood, the flow velocity, the rate of rise and decline, and the frequency of occurrence.

Satellite data has been successfully and operationally used in most phases of flood disaster management (CEOS, 1999). Multi channel and multi sensor data sources from GOES and POES satellites are used for meteorological evaluation, interpretation, validation, and assimilation into numerical weather prediction models to assess hydrological and hydro geological risks (Barrett, 1996). Quantitative precipitation estimates (QPE) and fo recasts (QPF) use satellite data as one source of information to facilitate flood forecasts in order to provide early warnings of flood hazard to communities.

Earth observation satellites can be used in the phase of disaster prevention, by mapping geomor phologic elements, historical events and sequential inundation phases, including duration, depth of inundation, and direction of current.

The geomorphological approach consists of the geomorphological analysis of the landforms and the fluvial system, to be supported wherever possible by information on (past) floods and detailed topographic information. The procedures to be followed can be summarised as follows:

a) detailed geomorphological terrain mapping, emphasising fluvial landforms, such as floodplains, te rraces, natural levees, backswamps, etc.;
b) mapping of historical floods by remote sensing image interpretation and field verification to define flooded zone outlines and characteristics;
c) overlaying of the geomorphological map and the flood map to obtain ind ications for the susceptibility to flooding for each geomorphological unit;
d) improving the predicting capacities of the method by combination of geomorphological, hydrological, landuse, and other data.

The example given in figure 4 shows a flood hazard zona tion of an area in Bangladesh on reconnaissance (small) scale based on a geomorphological approach to flood hazard mapping using a series of NOAA AVHRR images and a geographical information system (Assaduzaman et al., 1995).

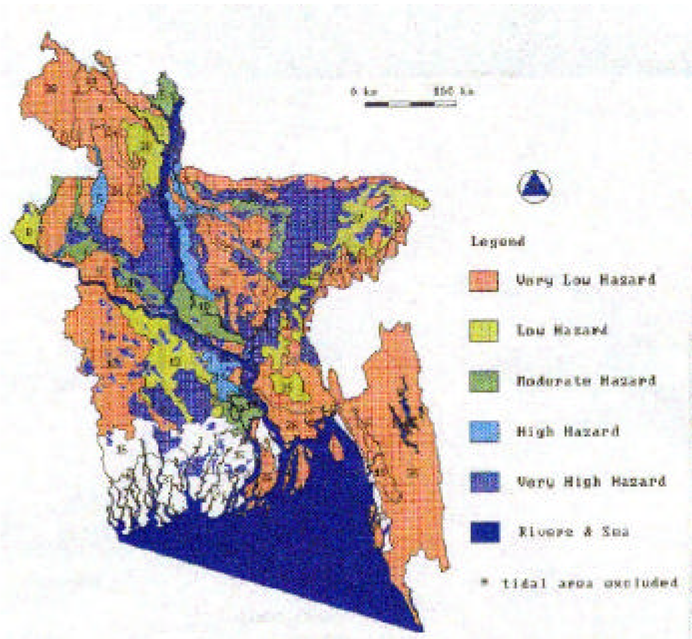

Figure 4::flood hazard zonation map of an area in Bangladesh: results of a reclassification operation using flood frequencies assigned to geomorphological terrain units. Asaduzzaman et al. (1995)

For the prediction of floods, NOAA images, combined with meteorological satellites and radar data, are used to estimate precipitation intensity, amount, and coverage, measure moisture and winds, and to determine ground effects such as the surface soil wetness (Scofield and Achutuni, 1996).

Earth observation satellites are also used extensively in the phases of preparedness/warning and response/monitoring. The use of optical sensors for flood mapping is seriously limited by the extensive cloud cover that is mostly present during a flood event. Synthetic Aperture Radar (SAR) from ERS and RADARSAT have been proven very useful for mapping flood inundation areas, due to their bad weather capability. In India, ERS -SAR has been used successfully in flood monitoring since 1993, and Radarsat since 1998 (Chakraborti, 1999). A standard procedure is used in which speckle is removed with medium filtering techniques, and a piece-wise linear stretching. Colour composites are generated using SAR data during floods and pre -flood SAR images.
For the disaster relief operations, the application of current satellite systems is still limited, due to their poor spatial resolution and the problems with cloud covers. Hopefully, the series of high resolution satellites will improve this. Remote sensing data for flood management should always be integrated with other data in a GIS. Especially on the local scale a large number of hydrological and hydraulic factors need to be integrated. One of the most important aspects in which GIS can contribute is the generation of detailed topographic information using high precision Digital Elevation Models, derived from geodetic surveys, aerial photography, SPOT, LiDAR (Light detection And Ranging) or SAR (Corr, 1983). These data are used in two and three dimensional finite element models for the prediction of floods in river channels and floodplains (Gee et al., 1990).
When satellite imagery is combined with other GIS data such as land use, population data, cadastral data, transportation and infrastructure networks, an analysis may be done of the high risk areas that may be subject to damage from disasters. Examples of the integrated use of GIS and remote sensing dealing with the flood of 1993 in the Midwest of the US are shown by Speed (1994).

4.2 Earthquakes

The areas affected by earthquakes are generally large, but they are restricted to well known regions (plate contacts). Typical recurrence periods vary from decades to centuries. Observable associated features include fault rupture, damage due to ground shaking, liquefaction, landslides, fires and floods. The following aspects play an important role: distance from active faults, geological structure, soiltypes, depth of the watertable, topography, and construction types of buildings.
In earthquake hazard mapping two different approaches are to be distinguished, each with a characteristic order of magnitude of map scale (Hays, 1980).

- Small scale (regional) *seismic macro zonation* at scales 1:5,000,000 to 1:50,000, which show the likely hood of occurrence and magnitude and the expected recurrence interval of earthquake events in (re gions of) countries or in (sub)continents.
- Large scale (local) *seismic micro zonation* at scales of 1:50-25,000 to 1:10,000 which indicates the magnitude and probabilities of the various effects of seismic waves at the terrain surface: ground shaking, surface faulting, tsunamis, landslides and soil liquefaction.

The most important data for seismic hazard zonation is derived from seismic networks. In seismic microzonation, the data is derived from accelerometers, geotechnical mapping, groundwater modelling, and topographic modelling, at large scales.
Satellite remote sensing does not play a major operational role in earthquake disaster management. In the phase of disaster prevention satellite remote sensing can play a role in the mapping of lineaments and faults, the study of the tectonic setting of an area, and neotectonic studies (Drury, 1987). Visible and infra -red imagery with spatial resolutions of 5-20 meters is generally used.
Satellite Laser Ranging (SLR) and Very Long Base Baseline Interferometry (VLBI) have been used for the monitoring of crustal movement near active faults. In the measurement of fault displacements Global Positioning System (GPS) have become very important. An increasingly popular remote sensing application is the mapping of earthquake deformation fields using SAR interferometry (InSAR) (Massonet et al., 1994, 1996). It allows for a better understanding of fault mechanisms and strain. However, although some spectacular results have been reported, the technique still has a number of problems which does not make it possible to apply it on a routine basis.
There are no generally accepted operational methods for predicting earthquakes. Although there is some mentioning of observable precursors for earthquakes in literature, such as variations in the electric field or thermal anomalies, they are heavily disputed.
In the phase of disaster relief, satellite remote sensing can at the moment only play a role in the identification of large associated features (such as landslides), which can be mapped by medium detailed imagery (SPOT, IRS etc.). Structural damage to buildings cannot be observed with the poor resolution of the current systems. The Near Real Time capability for the assessment of damage and the location of possible victims has now become more possible with the availability of the first civilian optical Very High Resolution (VHR) mission, IKONOS-2, though this will only make a difference if adequate temporal resolution, swath-coverage and ready access to the data can be achieved (CEOS, 1999).
Unlike Remote Sensing, the use of Geographic Information Systems in earthquake disaster management is much more prominent. GIS is used in all phases of disaster management. In the prevention phase the large amount of

geological, geophysical and geotechnical data are integrated using models in order to derive at earthquake response characteristics of soil and the buildings on it.
The use of GIS for earthquake response is even more important. Emergency managers should have adequate knowledge about the extent of the damage shortly after the earthquake. This both requires detailed digital information about the situation before the disaster occurs, on population, buildings infrastructure, utilities etc. as well as damage assessment models (Emmi and Horton, 1995). Also on a longer time frame, damage databases are important for the insurance industry and for the recovery and rehabilitation phase (see figure 5).

Tsunamis are sea waves due to large-scale sudden movement of the ocean floor during earthquakes. They travel at very high speeds in deep ocean waters, as much as 900 km/hour, with very long distance (as much as 500 km) between wave crest, and very low heights (around one meter) until the waves approach shallow water. There speed decreases and the wave height increases very rapidly, reaching 25 m or even more. The time interval between waves remains unchanged, usually between 15 minutes and one hour. When tsunamis reach the coastline, the ocean recedes to levels around or lower than the low tide and then rises as a giant destructive wave.
In the Pacific there is an operational Tsunami Warning System (TWS), in the Pacific Warning Center in Honolulu, Hawaii. It consists of 62 tide stations, and 77 seismic stations in 24 countries surrounding the Pacif ic ocean. The tsunami warnings are effective on a 1-hour basis over the Pacific, and 10 minutes on a regional scale. For local tsunamis systems with a shorter response time are being tested.
The tsunami hazard zonation is effectively helped by a geomorphological interpretation of the coastal lowlands, whereby a zonation in terrain units on the base of their height above mean sealevel is the primary objective. Such an interpretation can be executed successfully on satellite imagery. Stereo SPOT images and the landuse pattern as obtained from the interpretation of Landsat TM are the main information sources. The terrain “roughness” is the parameter that influences the depth of inland penetration of a tsunami. Vegetation (e.g. mangrove forest) is one of the most important factors influencing the terrain roughness. Also this observation is obtained from the interpretation of Landsat TM imagery.

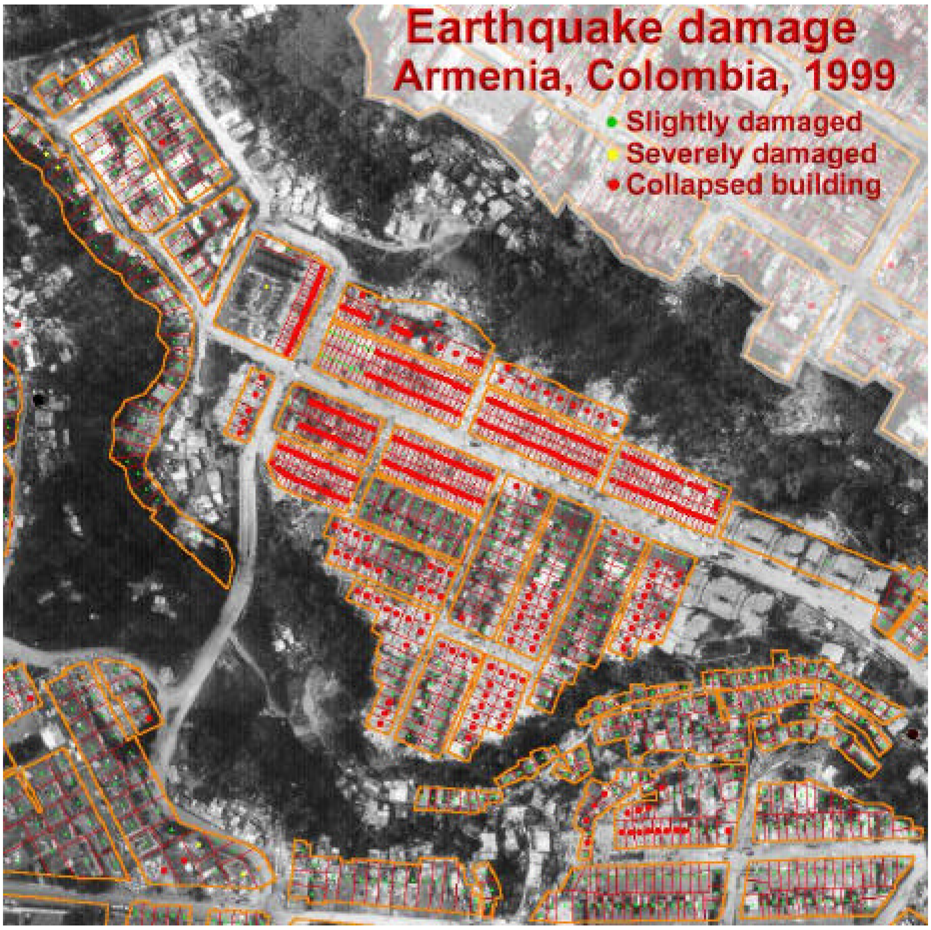

Figure 5: Damage assessment of the earthquake in Armenia, Colombia, 1999.

4.3 Volcanic eruptions

The areas affected by volcanic eruptions are generally small, and restricted to well known regions. The distribution of volcanoes is well known, however, due to missing or very limited historical records, the distribution of active volcanoes is not (especially in developing countries). Many volcanic areas are densely populated. Volcanic eruptions can lead to a large diversity of processes, such as explosion (Krakatau, Mount St. Helens), pyroclastic flow (Mt. Pelee, Pinatubo), lahars (Nevado del Ruiz, Pinatubo), lava flows (Hawaï, Etna), and ashfall (Pinatubo, El Chincon). Volcanic ash clouds can be distributed over large areas, and may have considerable implications for air-traffic and weather conditions.

Satellite remote sensing has become operational in some of the phases of volcanic disaster management, specifically in the monitoring of ash clouds. The major applications of remote sensing in volcanic hazard assessment are: 1) monitoring volcanic activity & detecting volcanic eruptions , 2) identification of potentially dangerous volcanoes, especially in remote areas and 3) mapping volcanic landforms and deposits (Mouginis-Mark and Francis, 1992).

Earth observation satellites can be used in the phase of disaster prevention in the mapping of the distribution and type of volcanic deposits. For the determination of the eruptive history other types of data are required, such as morphological analysis, tephra chronology, and lithological composition. Volcanic eruptions occur within minutes to hours, but are mostly preceded by clear precursors, such as fumarolic activity, seismic tremors, and surface deformation (bulging).

For the (detailed to semi-detailed) mapping of volcanic landforms and deposits, the conventional interpretation of stereo aerial photographs is still the most used technique. The stereo image does not only give a good view of the different lithologies and the geomorphological characteristics of the volcanic terrain, but it can also be used for delineating possible paths of different kinds of flows.

One of the most useful aspects of remote sensing is the ability of the visible and infrared radiation to discriminate between fresh rock and vegetated surfaces. This is useful because vegetation quickly develops on all areas except those disturbed by the volcano or other causes (urban development, etc).

Topographic measurements, and especially the change in topography are very important for the prediction of volcanic eruptions. Synthetic Aperture Radar (SAR) sensors can provide valuable data which describes the topography. Measurement of ground deformation may eventually be achieved using SAR interferometry.

For the monitoring of volcanic activity a high temporal resolution is an advantage. For the identification of different volcanic deposits a high spatial resolution and, to a lesser extent, also a high spectral resolution are more important.

Hot areas, e.g., lavas, fumaroles and hot pyroclastic flows can be mapped and enhanced using Thematic Mapper data. Landsat Band 6 can be used to demonstrate differences in activity which affect larger anomalies such as active block lava flows. For smaller and hotter (>100 C) anomalies the thermal infrared band can be saturated but other infrared bands can be used (Rothery et al., 1988; Frances and Rothery, 1987; Oppenheimer, 1991). Uehara et al. (1992), used airborne MSS (1.5m resolution) to study the thermal distribution of Unzendake volcano in Japan to monitor the lava domes causing pyroclastic flows when collapsed.

Volcanic clouds may be detected by sensors that measure absorption by gases in the cloud such as TOMS (Krueger et al, 1994), by infrared sensors such as AVHRR (Wen and Rose, 1994), by comprehensive sensors on meteorological satellites, and by microwave or radar sensors. Remote sensing has become an indispensable part of the global system of detection and tracking of the airborne products of explosive volcanic eruptions via a network of Volcanic Ash Advisory Centers (VAACs) and Meteorological Watch Offices (MWOs). Satellite data provide critical information on current ash cloud coverage, height, movement, and mass as input to aviation SIGnificant METerological (SIGMET) advisories and forecast trajectory dispersion models (CEOS, 1999).

The assessment of volcanic hazards using GIS is a relatively new approach. Wadge and Isaacs (1988) used GIS techniques to simulate the effects of a wide variety of eruptions of the Soufriere hills volcano, on Montserrat. The energy line concept (Malin and Sheridan, 1983) was applied by Kesseler (1995) to model pyroclastic flows, using an energy cone in 3-D. The cone is modelled and compared with a Digital Elevation Model in order to find the potentially affected area. For evaluating the hazard to pyroclastic falls, Kesseler (1995) applied a ballistic model in GIS. Carey and Sparks (1986) presented quantitative models of the fallout and dispersal of tephra from volcanic eruption columns. Macedonio et al. (1988), and Armeti and others (1988) made computer simulations for the 79AD Plinian Fall of Mt. Vesuvius, and the 1980 tephra transport from Mt. St. Helens, respectively. The rapidly changing geomorphology of the watersheds before, during and 3 consecutive years after the eruption of Mount Pinatubo was investigated by Daag and Van Westen (1996). To quantify the volumes of pyroclastic flow material and the yearly erosion, five digital elevation models (DEM) were made, and analysed using a GIS.

Examples of lava flow modelling can be found in Wadge et al (1994). A complex and accurate method is known as the *Cellular Automata method* (Barca et al., 1994). A Cellular Automata can be considered as a large group of cells with equal dimensions. Each of these cells receives input from its neighbouring cells, and gives output to its neighbours at discrete time intervals. For lava flow modelling, each cell is characterised by specific values (the state) of the following physical parameters: altitude, lava thickness, lava temperature and lava outflow towards neighbouring cells. With this method the interaction of several lava flows in the same cell can be modelled. Promising results were obtained for the Etna lava flows from 1991-1993.

However, although the physical modelling of volcanic processes seems to be a promising powerful tool, the methods are still in an investigation phase. The results of thes e models need to be further integrated in a real hazard mitigation project.

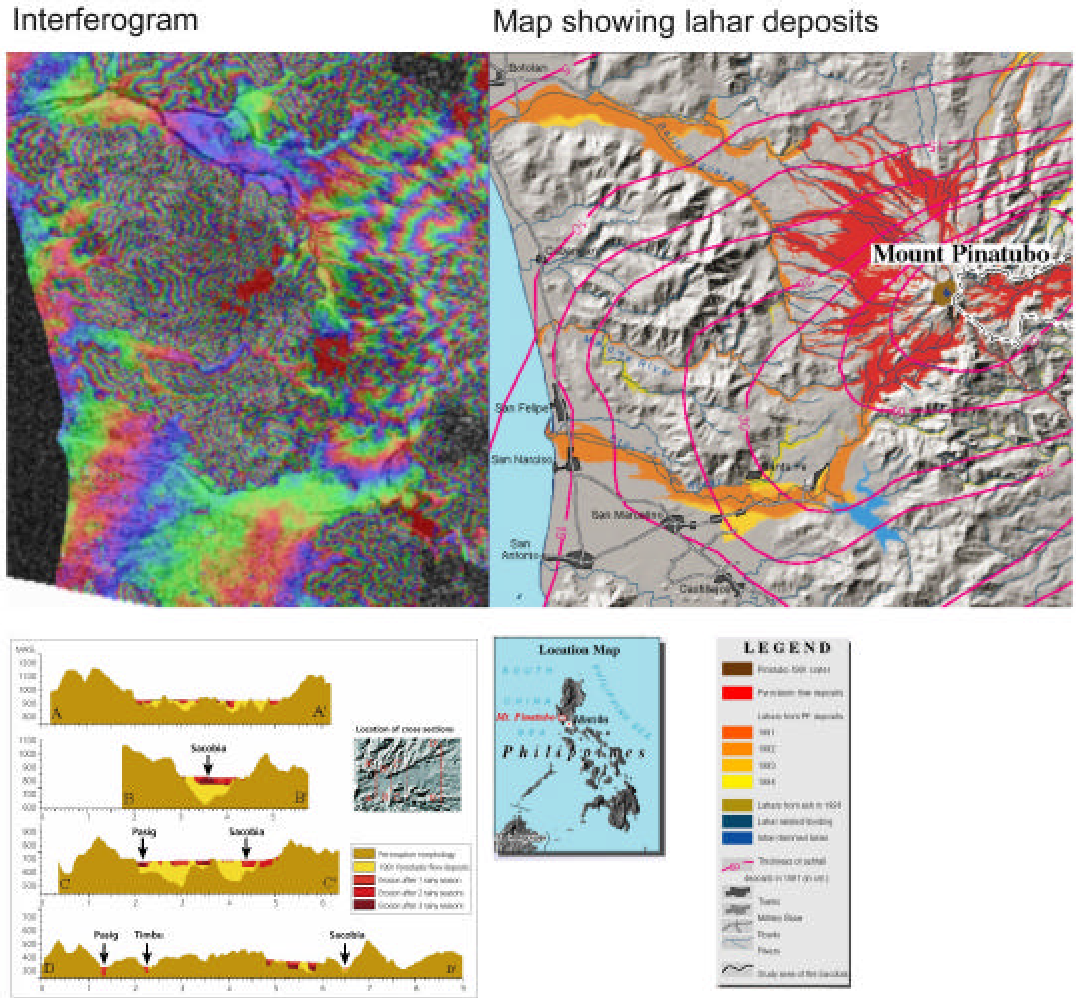

Figure 6 : Left: Interferogram of Mount Pinatubo generated using a tandem pair of ERS images, Right: map showing main deposits related to the 1991 eruption (ash fall, pyroclastic flows) as well as the extension of lahar deposits in subsequent years (partly after:Daag and van Westen, 1996).

4.4 Landslides

Individual landslides are generally small but they are very frequent in certain mountain regions. Landslides occur in a large variety, depending on the type of movement (slide, topple, flow, fall, spread), the speed of movement (mm/year - m/sec), the material involved (rock, debris, soil), and the triggering mechanism (earthquake, rainfall, human interaction).

In the phase of disaster prevention satellite imagery can be used for two purposes: landslide inventory and the mapping of factors related to the occurrence of landslides, such as lithology, geomorphological setting, faults, land use, vegetation and slope.

For landslide inventory mapping the size of the landslide features in relation to the ground resolution of the remote sensing data is very important. A typical landslide of 40000 m^2, for example, corresponds with 20 x 20 pixels on a SPOT Pan image and 10 x 10 pixels on SPOT multispectral images. This would be sufficient to identify a landslide that has a high contrast, with respect to its surroundings (e.g. bare scarps within vegetated terrain), but it is insufficient for a proper analysis of the elements pertaining to the failure to establish characteristics and type of landslide. Imagery with sufficient spatial resolution and stereo capability (SPOT, IRS) can be used to make a general inventory of the past landslides. However, they are mostly not sufficiently detailed to map out all landslides. Aerial photo-interpretation still remains essential.

It is believed that the best airphoto-scale for the interpretation of landslides is between 1:15.000 and 1:25.000 (Rengers et al., 1992). If smaller scales are used, a landsl ide may only be recognised, if size and contrast are sufficiently large. It is expected that in future the Very High Resolution (VHR) imagery, such as from IKONOS-2, might be used successfully for landslide inventory.

Satellite imagery can also be used to collect data on the relevant parameters involved (soils, geology, slope, geomorphology, landuse, hydrology, rainfall, faults etc.). Multispectral images are used for the classification of lithology, vegetation, and land use. Stereo SPOT imagery is used in geomorphological mapping, or terrain classification (Soeters et al. 1991). Digital elevation models can be derived from SPOT or IRS images, or using airborne or spaceborne inSAR techniques.

In the phase of disaster preparedness use could be made of the following techniques for the monitoring of landslide movements: ground measurements, photogrammetry, GPS, Radar interferometry. Warning systems for landslides are only operational in a few places in the world, with a very high density of information (landsli de dates as well as daily rainfall should be known in order to establish rainfall thresholds) (Keefer et al, 1987). The use of Meteosat & NOAA, combined with raingauge data for predicting these threshold is being investigated.

The assessment of landslide damage using satellites is only possible if the spatial distribution is very high, or if the individual landslides are large.

Various methodological approaches of landslide hazard using GIS can be differentiated (Van Westen,1993):

The most straightforward approach to landslide hazard zonation is a *landslide inventory*, based on aerial photo interpretation, ground survey, and/or a data base of historical occurrences of landslides in an area. The final product gives the spatial distribution of mass movements, represented either at scale, as points or as isopleths (Wright et al.,1974).

In *heuristic methods* the expert opinion of the geomorphologist, making the survey, is used to classify the hazard. The mapping of mass movements and their geomorphological setting is the main input factor for hazard determination (Kienholz, 1977; Rupke et al., 1988, Hansen, 1984).

In statistical landslide hazard analysis, the combinations of factors that have led to landslides in the past, are determined statistically and quantita tive predictions are made for landslide free areas with similar conditions.

In the bivariate statistical method, each factor map (slope, geology, land use etc.) is combined with the landslide distribution map, and weight values, based on landslide densiti es, are calculated for each parameter class (slope class, lithological unit, land use type, etc). Several statistical methods can be applied to calculate weight values, such as *landslide susceptibility* (Brabb, 1984; Van Westen, 1993), the *information value method* (Yin and Yan, 1988), *weights of evidence modelling , Bayesian combination rules, certainty factors, Dempster-Shafer method* and *fuzzy logic* (Chung and Fabbri, 1993).

The use of *multivariate statistical* models for landslide hazard zonation has mainl y been developed in Italy by Carrara and colleagues (Carrara et al, 1990, 1991, 1992). In their applications, all relevant factors are sampled either on a large grid basis, or in morphometric units. For each of the sampling units also the presence or absen ce of landslides is determined. The resulting matrix is then analysed using multiple regression or discriminant analysis.

Despite problems related to collection of sufficient and reliable input data, *deterministic models* are increasingly used in hazard an alysis at large scales, especially with the aid of geographic information systems, which can handle the large amount of calculations involved when calculating safety factors. This method is usually applied for translational landslides using the infinite sl ope model. The methods generally require the use of groundwater simulation models (Okimura and Kawatani, 1986). Stochastic methods are sometimes used for selection of input parameters (Mulder, 1991; Hammond et al., 1992).

4.5 Fires

Due to large-scale human deforestation activities, grassland fires, and naturally occurring wild fires around the world, biomass burning is a major source of greenhouse gases and aerosols. These emission products significantly impact atmospheric chemistry, clouds, and the Eart h's radiant energy budget (heat and sunlight) in ways that influence climate on regional and global scales. Also coal fires contribute significantly to the annual CO_2 production.
Wildland fires are caused by human activities or by natural phenomena such a s lightning,volcanic eruptions and underground coalfires. The development of a wildland fire depends on three main factors: the fuel (biomass type, condition, moisture etc.), the weather (windspeed, direction, relative humidity, precipitation, temperature) and topography (slope angle, direction, length etc.)
Earth observation satellites are used in several phases of fire management such as fuels mapping, risk assessment, detection, monitoring, mapping, burned area recovery, and smoke management.
In the pha se of fuel mapping remote sensing is extensively used to map the vegetation type and vegetation stress. The most frequently used data source for this information is NOAA/AVHRR data. Other alternative data sources are ATSR-2; the VEGETATION onboard SPOT 4 as well as the GLI (Global Imager) that will be launched onboard ADEOS-II (CEOS, 1999).
Existing satellite sensors with wildland fire detection capabilities are under -utilised. They include NOAA-GOES, NOAA-AVHRR, and DMSP-OLS. (Robinson, 1991) AVHRR measures radiation in five spectral channels. The mid-infrared channel at 3.7 um is especially suited to detect fires due to the increased radiant energy from fires as opposed to the background.
The TOMS UV aerosol index is used to map the spatial distribution of the UV absorbing aerosols. With the launch of the Tropical Rainfall Measuring Mission (TRMM) program, new remote sensing capabilities now exist to monitor fires, smoke and their impact on the earth -atmosphere system. On the TRMM platform a broadband sensor that measures reflected short-wave radiance in the spectrum between 0.2-4.5 um called the CERES scanner is used. From the UV part of the electro-magnetic spectrum, all the way to the thermal infrared, a combination of sensors can be used to highlight the different features of the smoke and fire events. Each sensor has its own unique capability. From the spatial, spectral and temporal resolution to the number of overpasses during the day, they can provide useful information on the damage to the ecosystems and the impact of fires on the earth-atmosphere system.
For the mapping of burned areas on a national and international scale NOAA/AVHRR data are most commonly used. The VEGETATION instrument onboard SPOT4 is a new alternative source of data.
For detailed fire assessment Earth observation satellites such as SPOT and Landsat are currently applied to detect and map burned areas by means of images of a vegetation index (NDVI) based on a specific combination of red and near infrared bands, which specially refle cts the amount of green vegetation (Kennedy et al., 1994). Remote sensing images have been widely used to detect fire scars, fire regimes and the regeneration of plant communities. Time series of images are currently used to monitor -through NDVI values- the regeneration process followed by plant communities after forest fires. Regeneration ratios of different plant communities are compared and the effect of other environmental factors on such a process is also studied. (Viedma et al. 1997)
Urban encroachment into natural areas, in conjunction with forest and rangeland fire suppression policies, have increased the frequency and intensity of large-area fires in many portions of the world. Similar to flood events, high spatial resolution imagery can be used b efore, during, and after a fire to measure fuel potential, access, progress, extent, as well as damage and financial loss.
Hamilton et al. (1989) discuss the usefulness of GIS for wildfire modelling. They integrate data on topography, weather, and vegetati on types, to calculate rate of spread and fireline intensity. Vasconcelos and Guertin (1992) developed the FIREMAP model, which uses GIS spread functions for the calculation of the rate of spread, fireline intensity and direction of maximum spread. The mai n problems in this model relate to the lack of flexibility of GIS spatial operators and the discrete time nature of the simulations. In order to allow for the modelling of temporal changes in weather and fire conditions, Vasconcels et al. (1994) propose th e use of distributed discrete event simulation (DEVS) for the spatial dynamic modelling of wildfires.

Coal fires
Apart from forest and bush fires, coal fires are one of the largest contributors to CO_2 emissions. In 1992 the CO_2 emission was estimated to be 2-3% of the world's total. Both large underground coal fires occur under natural conditions, as well as in coal mining regions, caused by spontaneous combustion of coal seams.
Remote Sensing has proven to be a reliable technology to detect both surface and underground coal fires. A combination of satellite based sensors and airborne sensors are required to unambiguously detect and locate coal fires. By doing such remote sensing based detection on a regular basis, new fires can be detected at an early stage, when they are easier/cheaper to put out. Also, such routine monitoring is very efficient for evaluating the effectiveness of the fire fighting techniques being employed, and which can be remedied/changed as a result.

Thermal infrared data from satellite s, especially from the Landsat-5 channel have been proven to be very useful. The detection of underground coal fires is limited by the non-uniform solar heating of the terrain. To remove these effects, a DEM can be used for modelling the solar incidence angle. Night-time TM data are more useful for detection, but are not routinely available. On the other hand, due to the low spatial resolution of the TM thermal data (120x120 m) the best night-time TM thermal data can not detect a coal fire less than 50 m ev en if they have high temperature anomalies. Thus airborne data for detailed detection are still needed.
For the detection and monitoring of coal fires airborne thermal and Landsat TM data have been successfully applied as well as NOAA-AVHRR, ERS1-ATSR and RESURS-01 thermal data (Van Genderen and Haiyan, 1997)

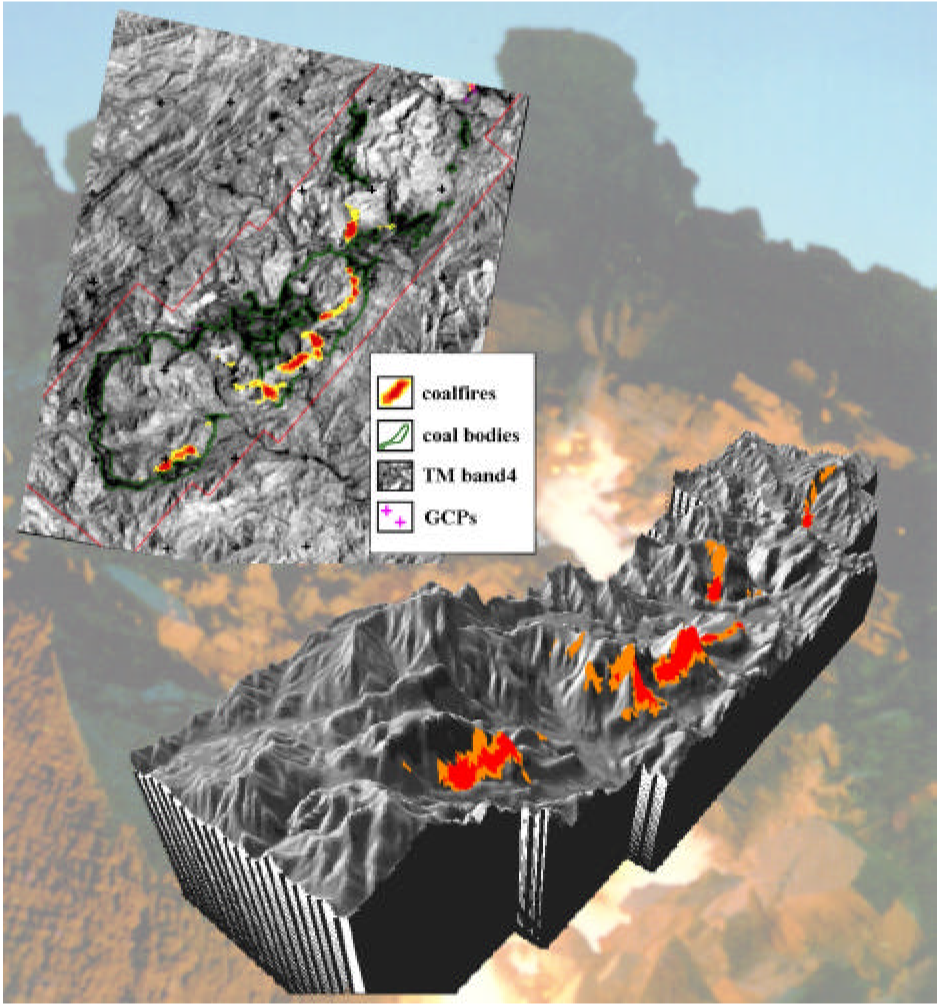

Figure 9: Thermal infrared image of a coal fire area in northern China, shown in 3-D. High surface temperatures are made visible by coding pixels with a certain range of values into a striking colour.
http://www.itc.nl/ags/data/pdf/posters/graig.pdf)

4.6 Drought and degradation

Globally, an estimated 1,965 million ha of land are subject to some kind of degradation. Of this, 1,094 mill ion ha are subject to soil erosion by water, and 549 million ha by soil erosion by wind. An estimated 954 million ha of land are affected by salinity or sodicity or both. (UNEP/ISRIC, 1991). Drought is one of the most severe natural disasters, since it effects very large areas over a long period of time, and therefore has very serious economic and social consequences. In order to reduce these consequences droughts must be predicted, once they occur they should be monitored, their impact should be assessed, and rapid response should be given. Meteorological satellites, such as are used for prediction in combination with other observation data and complex models.

For the measurement of meteorological parameters such as precipitation intensity, amount, and co verage, atmospheric moisture and winds, and surface (soil) wetness combined data is used from multi-channel and multi-sensor data sources from geostationary platforms such as GOES, METEOSAT, INSAT and GMS etc. and polar orbiting satellites such as NOAA, DMSP SSMI and IRS-P4 MSMR (CEOS, 1999).

Drought warning and monitoring is normally done by measuring the healthiness of vegetation over large areas, using Vegetation Index (VI), which helps in monitoring the photosynthetically active vegetation. A number o f vegetation parameters, such as Leaf Area Index (LAI) or biomass, are related with the Vegetation Index. Vegetation needs to be monitored throughout the growing season, and results should be compared with field data, in order to make predictions about the crop yield.

The NOAA AVHRR, is the workhorse for drought monitoring and prediction. It is used to generate a time series of Normalised Difference Vegetation Index (NDVI) maps, which is a function of green leaf area and biomass. IRS WiFS sensors on IRS-1C and IRS-1D, with ground resolution of 188 metres, swath of 800 km and revisit time of 5 days is extensively used in India for drought prediction and monitoring (Charkraborti, 1999). Recently SPOT4/Vegetation is used extensively for drought monitoring and early warning.

In the drought monitoring and warning, remote sensing data is fully integrated in a GIS with other types of data, such as data from rainfall stations, elevation data, agroclimatic data (rainfall pattern and length of growing season) and administrative subdivision of the country under study (Henricksen and Durkin, 1986; Hellden and Eklundh, 1988) .

High-resolution satellite sensors from LANDSAT, SPOT, IRS, etc. are being used for the assessment of impacts in a few areas, but in most cases this is not a country-wide activity.

Multi-temporal Landsat TM, SPOT and IRS imagery has been successfully used for the mapping of eroded lands, salt-affected soils, waterlogged soils, and shifting cultivation areas.

Several programs and centres are operational worldwide for drought monitoring and early warning, such as the Africa real-time Environmental Monitoring using Imaging Satellites (ARTEMIS) , the Indian National Agricultural Drought Assessment and Monitoring System (NADAMS), the USDA/NOAA Joint Agricultural Weather Facility (JAWF), and the European Commission's Joint Research Centre (JRC) with the MARS-STAT programme (Application of Remote sensing to Agricultural statistics).

4.7 Cyclones

Tropical cyclones are intense cyclonic storms which form over warm tropical oceans and threaten lives and property primarily in coastal locations of the tropics, subtropics, and eastern continents in mid -latitudes (WMO, 1995). The term "tropical cyclones" is often used as a general term for all intensities and locat ions, including hurricanes, typhoons, tropical storms, tropical depressions, and tropical cyclones. Approximately 80 -100 tropical cyclones occur globally in an average year, with a well documented climatology according to their location, season, intensity, and tracks (WMO, 1993).

The following hazards are normally associated with tropical cyclones: strong winds, high ocean waves, flash floods and landslides due to extreme rainfall amounts, and storm surges (are coastal flooding at the landfall point of the cyclone). In flat areas the storm surge may reach kilometres far inland and cause considerable loss of life and property damage. The World Meteorological Organisation has organised and co -ordinated tropical cyclone warning centres around the world, in whi ch geostationary satellite imagery is the primary tool for tracking tropical cyclones and estimating intensities. Additional conventional observations, aircraft reconnaissance and numerical model analysis and forecasting, are required for reliable warnings .

Information on the location of the tropical cyclone centres and the way they move can be obtained from weather satellites. The cyclone intensity is estimated using pattern analysis techniques and cloud top temperature information (Drove, 1984). High quality animated satellite imagery is used on computer workstations, and objective IR techniques have been developed (CEOS, 1999). Radar images can also provide tracking and intensity information. Doppler radars have been used in locations where tropical cyc lones occur.

The tropical cyclone warning produces a forecast for at least a 48 hours period of the tropical cyclone's centre track and the intensity, which is given by the maximum associated surface winds, along with a forecast of the radial extent of gale force (> 17 m/s), and hurricane force winds in various directions. The most important warning information consists of the time and severity of expected hazardous conditions with regard to damaging winds, ocean wave heights, storm surge, and rainfall.

GIS based emergency systems for cyclone emergency management are used extensively in the SE United States.

These systems also are used to provide useful information, for example, on the expected storm surges, which are based on the track and intensity forecast along with a knowledge of the local ocean floor and coastline topography, which are stored digitally in the GIS. Also for the evacuation planning, actual evacuation, search and rescue operations and damage assessment the detailed information stored in the GIS, such as cadastral and population data, is indispensable.

4.8 Environmental hazards

Satellite remote sensing is increasingly being used for the mitigation of all sorts of environmental hazards. Accurately locating, identifying, and monitoring the condition of coral reefs, seagrass beds, mangroves, salt marshes, chlorophyll, sedimentation, and development activities is greatly facilitated through the use of satellite imagery. Coastal areas can be evaluated for environmental sensitivity and suitability for developing ports, tourist facilities, aquaculture, fisheries etc. Large resolution multispectral imagery can be used for small-scale mapping of wetlands, beaches, submerged vegetation, urbanisation, storm damage, and general coastal morphology. Surface contamination and effects on the surrounding environment can be detected and monitored with high spatial resolution satellite imagery. Routine monitoring of facilities world-wide that handle or store hazardous chemicals and/or waste will be possible, within the coming years. Frequent satellite revisits will allow for early detection of contamination events, such as holding tank failures. The satellite imagery can then be used to assess damage and monitor cleanup and recovery.

Remote sensing can also be used to detect legal and illegal discharges from industrial and municipal facilities into waterways. The surface dimensions of a discharge plume, as well as the source, can be identified and measured if it contains suspended material, such as hydrocarbons, sediments, bubbles, or dye. The effectiveness of containment methods can also be assessed using satellite imagery.

Remote sensing has been used very successfully to detect illegal oilspills by ships on the open sea. In order to be able to proof these illegal acts, it should be possible to trace the ships leaving behind an oilplume, within a short time period. For this purpose airborn radar systems have been used, but with the disadvantage that only a very limited level of coverage (both spatial and temporal) could be obtained.

Using satellite based SAR however, it is possible to detect oil slicks in a wide range of environmental conditions, day and night, at a considerable reduction in cost compared to conventional techniques. At present, satellite SAR data are used within limited areas due to mission constraints on the attainable revisit and spatial coverage. Results from the current exploitation of the data indicate however, that a greater reliance on satellite data will develop with the new generation of SAR instruments such as the ENVISAT ASAR and Radarsat-2.

Accidental airborne releases of toxic chemicals can be detected and monitored with satellite imagery. For example, if the plume from an oil tank fire is visible to the naked eye, satellite imagery can measure the extent and dissipation of the airborne release, as well as pinpoint the source and identify potential areas of impact downwind.

As one of the purely human-made disasters, landmines may be the most widespread, lethal, and long-lasting form of pollution we have yet encountered. Up till now about 10 million anti-personnel mines per year have been produced. The production costs of an anti-personnel mine are between three to 30 dollars. To remove a mine about 300 to 1000 dollars have to be spend. In order to accelerate the mine clearance process new demining methods are urgently necessary. The military has developed remote sensing techniques to detect minefields. Since the need for humanitarian demining has increased, many of these sensors and techniques are now also available to detect minefield from commercially available platforms and sensors.

Recently it is tried to detect minefields by combining the results of several airborne remote sensing sensors which are used on test fields. The sensors used cover the optical, infra red (thermal) or microwave (radar) region of the electro-magnetic spectrum (http://www.itc.nl/ags/research/posters/minefields_general.htm)

5. Conclusions

The decade of the 1990's, designated as the International Decade for Disaster Reduction, has not resulted in a reduction of the losses due to natural disasters. On the contrary, the statistics show a rapid increase, both related to an increasing vulnerability of large part of the earth's population, as well as to an increase in the number of weather related events.

The decade of the 1990's also showed a rapid increase in the technological capabilities and tools that can be used in disaster management. Some of these tools deal with the collection and management of spatial data, such as remote sensing and Geographic Information Systems. Although none of the new satellites was specifically designed to be used in disaster mitigation, most of them also have demonstrated their usefulness in disaster prevention, preparedness and relief.

For several types of disasters the use of earth observation techniques has become operational in the warning and monitoring phases, within a relatively short period of time. Remote sensing is used operationally in the warning and monitoring of cyclones, drought, and to a lesser extend floods.

The operational applications mainly use imagery with low spatial resolution, coming from meteorological satellites or NOAA-type satellite.

The Turn-Around-Time (TAT) is the time required between the image is obtained until the answer should be given for the warning or monitoring of a specific hazard. This differs strongly one type of disaster to another. For example for wildfire the TAT is very short (0.5 hour), for cyclone's and floods it is 24 hours, and for drought it is weeks. The TAT depends on many factors, such as the location of the event, the satellite constellation, the weather conditions (cloud free images or radar), the data receiving aspects, data analysis aspects (e.g. visual interpretation or automated analysis) and commercial and legal aspects.

A summary of the application of satellite remote sensing for detection/warning, monitoring and assessment is shown in table 4.

		Detection / Warning	Monitoring	Assessment	
				Structural damage	Area affected
Drought	Spatial	1km	1 km	N/A	30 m / 1km
	Temporal	1 week	1 week	N/A	1 week
	Sensor	VIS, NIR	VIS, NIR	N/A	VIS, NIR
Flood	Spatial	1 km	20 m - 1 km	1- 10 m	10 - 50 m
	Temporal	12 hours	< 1 day	1 image	< 1 day
	Sensor	VIS, NIR	SAR, VIS	VIS or SAR	SAR, VIS
Cyclone	Spatial	2 - 50 km	2 - 50 km	1- 10 m	5 - 20 m.
	Temporal	1 - 6 hr	1 - 6 hr	1 image	< 1 day
	Sensor	IR,Microwave, Scatterometer, Doppler radar	IR,Microwave, Scatterometer, Doppler radar	VIS or SAR	SAR, VIS
Earthquake	Spatial	10 - 30 m	N/A	1- 10 m	5 - 20 m
	Temporal	Days	N/A	1 image	< 1 day
	Sensor	SAR (interferometry)	N/A	VIS or SAR	SAR, VIS
Volcanic eruption	Spatial	10 - 50 m	1 km (Ash cloud)	1 - 10 m	5 - 20 m
	Temporal	1 day - months	2 - 4 hours	1 image	< 1 day
	Sensor	MIR, TIR	AVHRR	VIS or SAR	SAR, VIS
Landslide	Spatial	N/A	10 - 30 m	1 - 10 m	5 - 20 m
	Temporal	N/A	Days - months	1 image	< 1 day
	Sensor	N/A	SAR (interferometry)	VIS or SAR	SAR, VIS
Fire	Spatial	0.5 - 1 km	20 - 30 m	1 - 10 m	20 m - 1 km
	Temporal	Continuous - 1/day	Daily	1 image	< 1 day
	Sensor	TIR	TIR	VIS or SAR	NIR
Oil Spill	Spatial	10 - 30 m	10 - 100 m	N/A	20 - 100 m
	Temporal	Hours	hours	N/A	1 - 3 days
	Sensor	SAR	SAR	N/A	SAR

Table 4: Summary of the use of satellite remote senisng for disaster management.
Pan = Panchromatic, VIS = Visible, NIR = Near Infrared, MIR = Mid Infrared, TIR = Thermal infrared, SAR = Synthetic Aperture Radar, NDVI = Normalized Difference Vegetation Index, N/A = Not applicable.

In many of the weather related disasters, obtaining cloudfree images for damage assessment is often a severe problem. For some types of disasters, such as floods, debris flows or oil spills, SAR is the solution in that case. For other types of disasters (e.g. landslides, earthquakes) detailed optical images should be used.

In the phase of disaster relief, satellite remote sensing can only play a role in the identification of the affected areas, if sufficiently large. Structural damage to buildings cannot be observed with the poor resolution of the current systems. Near Real Time damage and the location of possible victims has now become theoretically possible with the availability of the first civilian optical Very High Resolution (VHR) mission, IKONOS-2, though this will only make a difference if adequate temporal resolution, swath-coverage and ready access to the data can be achieved. The temporal resolution provided by individual satellites, especially considering cloud cover, will not be sufficient, and VHR will not become operational in damage mapping unless multiple satellites are used. This capability is of prime concern to relief agencies who require NRT imagery to locate possible victims and structures at risk, and also to map any changes to access that may have occurred. With the anticipated availability of VHR data, co-ordination of effort and motivation to acquire imagery will become paramount. Ideally, there needs to be a single co-ordinating body for the ordering, receiving, preparation and dissemination of data.

In most cases, the availability of GIS databases, containing information about elements at risk, if combined with less detailed images containing the extend of the area affected, will allow for a rapid assessment of the number of persons and buildings affected.

In view of the limitations inherent to the data collection and analysis techniques and the restrictions imposed by the scale of mapping, especially the phase of hazard assessment within the disaster management cycle will always retain a certain degree of subjectivity. This does not necessarily imply an inaccuracy. The objectivity and certainly the reproducibility of the assessment can considerably be improved by the interpretation of sequential imagery, the use of clear, if possible, quantitative description of the factors considered, as well as well defined analytical procedures and decision rules, which are applied to come to the hazard assessment. The most important aspect however remains the experience of the analyst, both with regard to various factors involved in hazard surveys, as well as in the specific conditions of the study area. Due to the difficulty of formalising expert rules, the use of expert systems in hazard assessment is still not very advanced (Pearson et al., 1991)

Although warning systems have become more advanced, recent disasters such as the earthquake disasters in Turkey and Taiwan, the cyclone disaster in the state of Orissa, India, and the huge landslide disaster in Venezuela, have shown that the technological capabilities often have no major advantage for the persons that are really affected by the disaster. Future applications of GIS and Remote Sensing for disaster management should make an attempt to include more social science perspectives from the risk and hazards fields than has been the case thus far, and bring the hazard management back to the local level.

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