Spatial data requirements and infrastructure for geological risk assessment

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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. The economic losses due to natural disasters have shown an increase by a factor of eight over the past four decades, caused by the increased vulnerability of the global society, but also due to an increase in the number of weather-related disasters.

For the management of natural disasters a large amount of multi-temporal spatial data is required. Satellite remote sensing is an ideal tool for disaster management, since it offers information over large areas, and at short time intervals. It can be utilised in the various phases of disaster management, such as prevention, preparedness, relief, and reconstruction. During the last decades remote sensing has become an operational tool in the disaster preparedness and warning phases for different types of disasters, such as 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 an overview of the different processes involved in the use of geoinformation and earth observation for disaster management, and a review of the data requirements, focusing on geological disasters. The paper discusses several important elements related to geospatial data infrastructures for disaster management, pertinent advances of geo-ICT technologies as well as capacity building models.

1. Introduction

1.1 Disasters, a world-wide theme

Natural disasters are extreme events within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differ substantially from the mean, resulting in death or injury to humans, and damage or loss of 'goods', such as buildings, communication systems, agricultural land, forest, and natural environment (Carter, 1991; Alexander, 1993).

The subject of disaster reduction is an important point on the world agenda. Nearly every day disasters appear in the headlines of the news. The number of reported disasters is showing an exponential increase, as is the total damage due to disaster, the insured losses and the number of casualties and people affected. By their powerful impact on the supply of primary commodities, natural disasters disrupt market stability, leading to steep declines in national revenue. In many developing countries, economic growth is seriously limited by the occurrence of natural disasters. For example, estimates of damage caused by Hurricane Mitch in Central America totalled $6 billion in 1998,the equivalent of 16% of that year's GDP, 66 % of exports, 96.5% of gross fixed capital formation and 37.2% of the total external debt of the central American countries (IDB, 2000) .

In 1989 Member States of the United Nations declared the 1990's as the International Decade for Natural Disaster Reduction (IDNDR) with the objective to "reduce the loss of life, property damage, and social and economic disruption caused by natural disasters through concerted international action, especially in developing countries". The IDNDR fulfilled its objective in assisting nations to focus attention on the threat posed by natural hazards and means to reduce their impacts. In 1994, the UN states indicated in the so-called Yokohama statement " Appropriate technology and data, with the corresponding training, should be made available to all freely and in a timely manner, particularly to developing countries". In 2000 the United Nations system has been designated as the appropriate platform to implement an International Strategy for Disaster Reduction (ISDR) as a follow-up for IDNDR, to engage governments, international agencies, civil society, and the private sector. This is motivated by the importance of shifting from a culture of reaction to hazards to one of risk management and prevention. One of the objective of the ISDR is the "integrating on-going risk prevention strategies into sustainable development plans by public, private and local community collaboration through partnership activities".

1.2 Impact of disasters

In the period 1950-2000 natural catastrophes have caused over 1.4 million fatalities, mostly as a result of earthquakes (47%), windstorms (45%) and floods (7%). The estimated economic losses of over 960 billion US $ are more or less similar to the percentage of occurrence of the main types of catastrophes: earthquake (35%), windstorms (28%) and floods (30%). Other events (landslides, drought, forest fires etc.) account for 7% of total losses (Munich Re, 2000). The number of events in the last decade as compared with the decade of the 1950's has increased by a factor of 4, and the losses have increased by a factor of 14. 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 severe in developing countries with lower insurance density (Berz, 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 (Earth Alert, 2000). 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 subdivided in factors leading to a larger vulnerability and factors leading to a higher occurrence of hazardous events, such as:

- Rapid increase of the world population, from 3 billion in the 1960s to 6 billion in 2000, and predicted world population between 7 and 10 billion by the year 2050 (UNPD, 1999).
- Occupation of areas that were previously avoided due to their susceptibility to natural hazards.
- Concentration of people and economic activities in large urban centres, most of which are located in vulnerable coastal areas.
- Development of highly sensitive technologies and the growing susceptibility of modern industrial societies to breakdowns in their infrastructure. The frequency of destructive events related to atmospheric extremes (such as floods, drought, cyclones, and landslides) is increasing, which are related to climatic change.

There is 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 less developed countries, where more than 4.200 million people live. 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 mass evacuations. The application of building codes and restrictive zoning also accounts for a lower number of casualties in developed countries.

1.3 Natural disasters and global change

The effects of climate change are clearly visible and scientific proof has been established with regard to many alarming signs. The mean global temperature has risen in the past 100 years by some 0.7 degree, which is also shown by the increase in ocean temperatures. According to the Intergovernmental Panel on Climate Change (IPCC) the mean global temperature will rise by 0.2- 0.3 degrees per decade. These lead to an exponentially higher rate of evaporation and to a correspondingly elevated water vapour in the atmosphere, promoting high precipitation intensities and tropical cyclones. In many regions of the middle and high latitudes there has been a shift in rain distribution patterns both in regional and seasonal terms. Extensive mountain glacier retreat may be observed throughout the world, leading to higher degrees of danger for glacier lake outburst flooding and a decrease of water supply. The melting of the ice caps, combined with the thermal expansion of ocean waters will lead to an increased sea level rise. In global terms the rise in the 20th century was more than 10 cm. Estimates of sea level rise for the next century oscillate between 10 and 90 centimetres, leading to an increased hazard of coastal flooding in many areas. Global change also is expected to increase windstorm activity outside the tropics. In the late 1980s and early 1990s substantial windstorm damage was caused in Europe (Munich Re, 2000). Heat waves are expected to be more frequent. The results of research also suggest that El Nino and La Nina may also be affected by climatic change. Global warming could generate more ENSO phenomena or could intensify or prolong them. Many other changes have occurred and will occur as a result of climate change. These include land degradation, reduction of biodiversity and and increase of tropical diseases outside their original origins of spread.

A number of attempts have been made in recent times to estimate the cost of anthropogenic climate change worldwide. In the long term the cost of preventive strategies is much lower than the losses to be expected as a result of climate change, which could be in the range of US $ 100 billion a year.

Scientific certainty	Effects of global warming
VERY HIGH	Increase in global mean temperatures in the lower atmosphere and in the upper ocean layers
	Decrease in global mean temperatures in the stratosphere
	Temporarily severe ozone destruction in the polar stratosphere (ozone hole)
	Decrease in global ozone concentration in the stratosphere
	Melting and retreat of inland glaciers
HIGH	Accelerated sea level rise
	Increase in atmospheric turbidity (aerosols) with regional cooling effects of the atmosphere
	Increasing frequency of mild winters with poor snow cover in midle and high latitudes
	Increasing winter rainfall in Central Europe (decrease in Southern Europe)
	Increasing winterstorm activity over the Northern Atlantic
LOW	Increasing winterstorm activity in Western and Central Europe
	Increasing tropical windstorm activity (frequency, intensity, source area, duration od storm seasons)
	Increasing activity of thunderstorms, torrential rainfalls and hailstorms in moderate climates
	Changes in fauna and flora
	Expansion of drought and desert zones in subtropical climates
	Spread of tropical diseases

Table 1: Effects of global warming (Source: Munich Re, 2000)

2. Disaster management

One way of dealing with natural hazards is to ignore them. In many parts of the world, neither the population nor the authorities choose to take the danger of natural hazards seriously, for various reasons (socio-economic, political, cultural, religious). To effectively mitigate disasters a complete strategy for disaster management is required, which is also referred to as the disaster management cycle (UNDRO, 1991; Carter, 1991; Ingleton, 1999; Alexander, 1993).

Disaster management consists of two phases that take place before a disaster occurs, ***disaster prevention*** and ***disaster preparedness*** (both phases together are also referred to as ***disaster mitigation***), and three phases that happen after the occurrence of a disaster, ***disaster relief***, ***rehabilitation*** and ***reconstruction.***

Pre-disaster phases				**Post-disaster phases**	
Risk Identification	**Mitigation**	**Risk Transfer**	**Preparedness**	**Emergency response**	**Rehabilitation and Reconstruction**
Hazard Assessment	Physical structural mitigation works	Insurance/ reinsurance of public infrastructure and private assets	Early warning systems. Communication systems	Humanitarian assistance / rescue	Rehabilitation/reconstruction of damaged critical infrastructure
Vulnerability assessment	Land-use planning and building codes	Financial market instruments	Monitoring and forecasting	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management
Risk Assessment	Economic incentives	Privatization of public services with safety regulations	Shelter facilities Emergency planning	Damage assessment	Revitalization of affected sectors
GIS mapping and scenario building	Education, training and awareness	Calamity funds (national or local level)	Contingency planning (utility companies / public services)	Mobilization of recovery resources	Incorporation of disaster mitigation components in reconstruction

Table 2: Key elements of disaster management (source: IDB, 2000)

Unfortunately, the emphasis in most countries has always been on the phase of disaster relief, and most disaster management organisations in developing countries have been established only for this purpose. Recently, the emphasis is being changed to disaster mitigation, and especially to vulnerability reduction.

Investment companies, (international) donor agencies, banks, and governments are increasingly requiring precise data on the risk due to hazards that may hamper the investment or reduce the return on their investment. Insurance and reinsurance companies are similarly demanding more detailed risk evaluations to be able to set the insurance premiums for projects. Standard procedure will also be the development of risk scenarios that minimise the adverse consequences for the project and financial losses. Projects can be: civil engineering works, housing projects, mining, agricultural and forest developments, etc.

2.1 Geo-spatial requirements

Many types of information that are needed in natural disaster management have both an important spatial as well as temporal component.

Remote sensing and GIS provide a historical database from which hazard maps may be generated, indicating which areas are potentially dangerous. Remote sensing data should be linked with other types of data, derived from mapping, measurement networks or sampling points, to derive parameters useful in the study of disasters. GIS may model various hazard and risk scenarios for the future development of an area.

The spatial modelling of hazards is a complex task, in which many factors play a role, and which can only be executed by experts. It also involves a large number of uncertainties, which have to be taken into account. The zonation of hazard and risk must be the basis for any disaster management project and should supply planners and decision-makers with adequate and understandable information.

Remote sensing data derived from satellites are excellent tools in the mapping of the spatial distribution of disaster related data within a short period of time. Many different satellite based systems exist nowadays, with different characteristics related to their spatial-, temporal- and spectral resolution. As many types of disasters, such as floods, drought, cyclones, volcanic eruptions, etc. will have certain precursors, real time and near-real time satellite remote sensing may detect the early stages of these events as anomalies in a time series.

When a disaster occurs, the speed of information collection from air and space borne platforms and the possibility of information dissemination with a corresponding swiftness make it possible to monitor the occurrence of the disaster. Simultaneously, GIS analysis may be used to plan evacuation routes, design centres for emergency operations, and integration satellite data with other relevant data.

In the disaster relief phase, GIS is extremely useful in combination with Global Positioning Systems (GPS) for search and rescue operations. Remote sensing and GIS can assist in damage assessment and aftermath monitoring, providing a quantitative base for relief operations.

In the disaster rehabilitation phase, GIS can organise the damage information and the post-disaster census information, as well as sites for reconstruction. Remote sensing updates databases used for the reconstruction of an area.

Disaster management is a multidisciplinary activity requiring spatial and temporal information and expertise from many different specialisation fields, such as :

- Expertise on techniques for the collection of geoinformation, generation of data bases, and design of disaster management information systems.
- Expertise on the analysis of disastrous phenomena, their location, frequency, magnitude etc.
- Expertise on hazard zonation and mapping the environment in which the disastrous events might take place: topography, geology, geomorphology, soils, hydrology, land use, vegetation etc.
- Expertise on the inventory of elements that might be destroyed if the event takes place: infrastructure, settlements, population, socio-economic data, emergency relief resources, such as hospitals, fire brigades, police stations, warehouses etc.
- Expertise on cost-benefit analysis, spatial decision support systems, conflict management, and the implementation of disaster management in organisations in developing countries.

2.2 Risk assessment as central theme

Much of the effort in disaster management is on the policy and social side. However, the decision-makers must be supplied with reliable, up-to-date, and interpreted information on the nature and geographical distribution of hazard and risk, and the possible risk scenario's. Risk assessment is considered as the central, and most important aspect within disaster management. Risk is defined as "*the expected number of lives lost, people injured, or economic losses due to potentially damaging phenomena within a given period of time*".

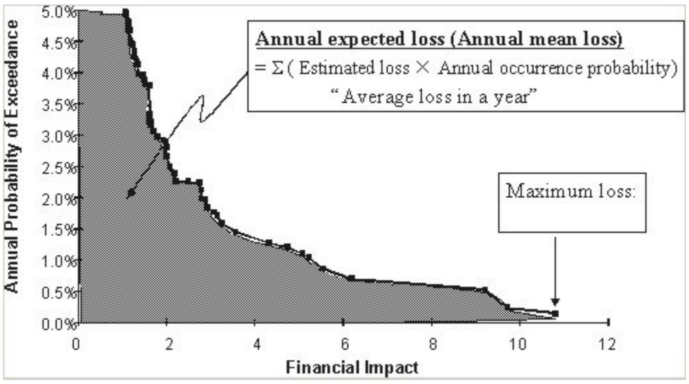


Figure 1: The risk curve

In order to obtain quantitative risk maps the first essential requirement is to carry out a ***quantitative hazard assessment***. Most hazard maps still are of a qualitative nature and do not express the "probability of occurrence of potentially damaging phenomena with a certain magnitude within a given period of time". In many developing countries qualitative hazard maps are the only possibility, due to the scarcity of input data for quantitative analysis. There is an important role for data collection using remote sensing and the design of data bases for hazard assessment, as well as the use of various types of modelling techniques depending on the available data and the scale of analysis. Emphasis should be given to the development of quantitative hazard maps, derived by earth-scientists, based on probabilistic or deterministic modelling.

One other aspect which needs to be worked out in more detail is the ***quantification of vulnerability***, which is achieved by making an inventory of the elements at risk (population, building stock, essential facilities, transportation and lifeline utilities, high potential loss facilities, economic activities) and an assessment of the degree of damage that may result from the occurrence of a potentially damaging phenomena. Emphasis should be given to techniques for rapid inventory of elements at risk in densely populated areas (urban and rural), using high resolution images, and the generation of elements at risk databases, which should be designed for multi-purposes, on the basis of cadastral databases. One other aspect is the modelling of vulnerability, using vulnerability curves in a GIS. Also input from partners is needed in order to include the economic aspects, in order to come to a quantitative loss estimation.

The combined information of hazard and vulnerability is used to derive at ***quantitative risk analysis***, including the total losses due to different hazards with different return periods and magnitudes. Methodologies for data handling and quantification of risks have for a large part still to be developed. For the largest part the expertise is available within specialized organizations (mostly within re-insurance companies which do not publish their methods due to commercial reasons: e.g. MRQuake, MRStorm and MRFlood from Munich Reinsurance (Munich Re., 2000), or RiskLink®from RSM).
On an international non-commercial level, the secretariat of the International Decade for Natural Disaster Reduction (IDNDR 1990-2000), United Nations, Geneva, launched the RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) initiative in 1996, with financial assistance from the Government of Japan. It aimed to promote worldwide activities for reduction of seismic disasters in urban areas, particularly in developing countries, by carrying out studies in 9 case-study cities. Three assigned international institutes, namely, GeoHazards International (GHI, USA), International Center for Disaster-Mitigation Engineering (INCEDE)/OYO Group (Japan), and Bureau de Recherches Géologiques et Minières (BRGM, France), provided the case-study cities with technical guidance through intensive communication. Based on the experiences of the nine case studies, practical tools for earthquake damage estimation and implementation of similar projects were developed so that any earthquake-prone cities might start similar efforts as the first step of seismic risk management. A comparative study to understand urban seismic risk in the world was also conducted. More than 70 cities participated in the study to exchange information. As associate cities, more than 30 cities participated in RADIUS to provide other cities with their valuable experience (Radius, 2001).
Whereas the RADIUS methodology is still rather general, a much more elaborated methodology has been developed in the United States, called HAZUS. HAZUS is a nationally applicable standardized methodology implemented through PC-based Geographic Information Systems for estimating potential losses from earthquakes, floods, and wind. HAZUS is being developed by the Federal Emergency Management Agency (FEMA) under a Cooperative Agreement with the National Institute of Building Sciences (NIBS). HAZUS now has the capability to estimate earthquake losses, and flood and wind

models are under development (HAZUS, 2001). HAZUS is a very advanced methodology, which requires large amounts of data, and is not very feasible to implement in most cities in developing countries within a reasonable time frame.

In Australia, the Cities Project, or the National Geohazards Vulnerability of Urban Communities Project to use its original formal title, is a program of applied research and technique development designed to to analyse and assess the risks posed by a range of geohazards to urban communities (AGSO, 2001).

One of the large challenges is the implementation of these risk maps into risk scenarios, and the development of ***spatial decision support systems for disaster management***, to be used in:

- Anticipating the possible nature and scope of the emergency response needed to cope with disaster,
- Developing plans for recovery and reconstruction following a disaster, and
- Mitigating the possible consequences of disasters.

The methods are focussed on the application at a regional and municipal level, and the result should serve as a basic tool in planning and decision making. Therefore Disaster Management Information Systems (DMIS) will be required, combining GIS with Spatial Decision Support Systems, and which are offered via user interfaces for low-cost GIS systems.

3. Process specifications

3.1 Needs assessment

In defining the themes for research and training in the field of geoinformation for disaster management, the end-users should have the decisive vote. According to our experience with our client group from developing countries, there is a need for a transparent methodology for the estimation of risk due to natural disasters in densely populated areas, applied at regional and municipal level, and guidelines for the implementation of risk scenarios in the disaster management and decision making process. In many countries there is no basic information available on the factors for hazard assessment, nor is there a sufficient structure for the collection of data on elements at risk. The 'adoption and dissemination' of geo-information and information and communication technologies within a government organisation are of critical importance, as well as the 'geo-information information infrastructure and data sharing'.

3.2 Data acquisition

For disaster management the use of multi-temporal spatial data is essential. The type of data that is required is different for each hazard type. In the data acquisition for disaster management the use of remote sensing is be essential for the different aspects: obtaining input data for hazard modelling, the use of near real-time imagery in the prediction and monitoring, and the use of high resolution imagery for damage assessment, combined with other data (video imagery, airphotos). Table 3 gives an indication of the requirements for the application of satellite remote sensing in the various phases of disaster management.

For flooding, satellite data can be used in the phase of disaster prevention, by mapping sequential inundation phases, including duration, depth of inundation, and direction of current. This can be done with classification from radar, SPOT, LANDSAT, WiFS, SPOT4 vegetation instrument, MODIS or NOAA images. Furthermore SPOT and LANDSAT TM can be used in the geomorphological mapping of the potential flood area. However, the most crucial data is derived from the calculation of peak discharges and return periods, using data from gauging stations. RS and GIS are used for rainfall prediction and runoff estimation.

In the phase of earthquake disaster prevention satellite remote sensing can play an important role in the mapping of active faults, using neotectonic studies, with the use of LANDSAT TM/SPOT or radar, and in the measurement of fault displacements, using satellite Laser Ranging (SLR), Global Positioning System (GPS), or radar interferometry. The most important data for seismic hazard zonation is derived from seismic networks. In seismic microzonation, the use of satellite remote sensing is very limited, as the data is derived from accelerometers, geotechnical mapping, groundwater modelling, and topographic modelling, at large scales. Earthquakes cannot be predicted with the current state of knowledge, and therefore also satellite remote sensing cannot play a role in the phase of earthquake disaster preparedness.

Vulnerability assessment starts with an inventory of elements at risk. This can be carried out at various levels of detail, in which high resolution imagery can play an important role. In many areas such inventories have not been made. In urban and rural areas the detail of inventory will also differ. The inventory is not only made for disaster management, but can be related to cadastral information systems. The following groups of elements at risk are essential:

- *Population distribution:* The spatial distribution of the population as well as the distribution according to age classes. In the absence of census information this might also be obtained from occupationcy classes of buildings.
- *General building stock:* The majority of commercial, industrial and residential buildings in a region are not considered individually when calculating losses. They are grouped together into model building types and occupancy classes, and classified according to number of stories.
- *Essential facilities:* Essential facilities, including medical care facilities, emergency response facilities and schools, are those vital to emergency response and recovery following a disaster.
- *Transportation lifeline systems:* Transportation lifelines, including highways, railways, light rail, bus systems, ports, ferry systems and airports, are broken into components such as bridges, stretches of roadway or track, terminals, and port warehouses.

- *Utility lifeline systems:* Utility lifelines, including potable water, electric power, waste water, communications, and liquid fuels (oil and gas), are treated in a manner similar to transportation lifelines.
- *High potential loss facilities:* In any region or community there will be certain types of structures or facilities for which damage and losses will not be evaluated unless supplemental studies specific to these facilities are carried out. Such facilities include dams, nuclear power plants, liquefied natural gas facilities, military installations, and large one-of-a-kind residential or commercial structures.
- *Agricultural land-use and vegetation: for rural vulnerability studies the type of crops, crop calenders are important aspects.*

	Phase	**Data type**	**Spat (m)**	**Temp**	**Other tools**	**Sensors**				
						VIS/IR	**TH**	**SAR**	**INSAR**	**Other sensors**
Flood	Prevention	Land use / landcover	10 - 1000	Months	API + fieldsurvey	X		X		
		Historical events	10 - 1000	Days	Historical records, media	X		X		
		Geomorphology	10 - 30	Years	API + fieldsurvey	Stereo				
		Topography	1 - 10 *	Years	Topomaps	Stereo			X	Laser altimetry
	Preparedness	Rainfall	1000	Hours	Rainfall stations	X	X			Weather satellites/ Passive Microwave/ ground radar
		Detailed topography	0.1 - 1 *	Months	GPS, Field measurements				X	Laser altimetry
	Relief	Flood mapping	10 -1000	Days	Airborne + fieldsurveys	X		X		
		Damage mapping	1 - 10	Days	Airborne + fieldsurveys	X				
Earthquake	Prevention	Land use / landcover	1 - 10	Years	API + fieldsurvey	X				
		Geomorphology	1 - 10	Decade	API + fieldsurvey	Stereo				
		Lithology	30 -100	Decade	API + fieldsurvey	X				Hyperspectral
		Faults	5 - 10	Decade	API + fieldsurvey	Stereo				
		Soil mapping	10 - 30	Decade	API + drilling + lab. Testing	X				
	Preparedness	Strain accumulation	0.01 *	Month	GPS, SLR, VLBI				X	
	Relief	Damage assessment	1	Days	Airborne + fieldsurveys	X				
		Associated features	10 - 30	Days	Airborne + fieldsurveys	X		X		
Volcano	Prevention	Topography	10 *	Years	Topomaps	Stereo			X	Laser altimetry
		Lithology	10 - 30	Decade	API + fieldsurvey	X		X		Hyperspectral
		Geomorphology	5 - 10	Years	API + fieldsurvey	Stereo				
		Landcover/snow	10 - 30	Months	API + fieldsurvey	X				
	Preparedness	Thermal anomalies	10 - 120	Weeks	Field measurements		X			
		Topography	0.01 *	Weeks	GPS, Tilt meters				X	Laser altimetry
		Gas	50 - 100	Weeks	Field spectrometer					Hyperspectral
	Relief	Mapping ash cover	10 - 30	Days	Airborne + fieldsurveys	X				
		Mapping flows	10 - 30	Days	Airborne + fieldsurveys	X	X	X		
		Ash cloud monitoring	1000	Hours	-	X				Hyperspectral / weather satellites
Landslide	Prevention	Landslide distribution	1 - 5	Year	Multi temporal API, fieldsurvey, historic records	Stereo				
		Geomorphology	1- 10	Decade	API + fieldsurvey	Stereo				
		Geology	10 - 30	Decade	API + fieldsurvey	X				Hyperspectral
		Faults	5 - 10	Decade	API + fieldsurvey	Stereo				
		Topography	10 *	Decade	Topomaps	Stereo			X	Laser altimetry
		Landuse	10 - 30	Year	API + fieldsurvey	X				
	Preparedness	Slope movement	0.01 *	Days	GPS, field instrumentation				X	Laser altimetry
		Rainfall	100-1000	Hours	Rainfall stations	X	X			Weather satellites/ Passive Microwave/ ground radar
	Relief	Damage Mapping	1-10	Days	Airborne + fieldsurveys	X				

*Requirements for the application of satellite remote sensing in the various phases of disaster management. For each data type an indication is given of the optimal spatial resolution (spat), the minimum time for which successive data should be available (temp), and the sensor types that could be used (VIS =.visible, IR = Infrared, TH = Thermal, SAR = Synthetic Aperture Radar, INSAR = Interferometric SAR,) * = In this case the minimum resolution of the resulting DEM values are given.*

3.3 Processing, analysis and modelling

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 different levels going from national level up to site-investigation level (Van Westen and Soeters, 2000).

One of the most important levels is the municipal level. Risk mitigation (i.e. moderating the severity of a hazard impact) is the principal objective of risk management at this level. In this context, risk mitigation might be seen as: "the process by which the uncertainties that exist in potentially hazardous situations can be minimised and public (and environmental) safety maximised. The objective is to limit the human, material, economic and environmental costs of an emergency or disaster, and is achieved through a range of strategies ranging from hazard monitoring to the speedy restoration of the affected community after a disaster event" (Granger and Hayne, 2001).

An important tool in the risk management at municipal level is the development of GIS based risk assessment and decision support systems for disaster management by local authorities that will involve the use of multi-source geoinformation data and the participation of various expertise in the field.

The decision support systems must be able to answer and serve societal needs during the planning and emergency response period, and should be transparent and easily used by local authorities in the evaluation of the hazard involved (seismic or flood), vulnerability and risk assessment.

The sustainable implementation of a GIS-based decision support tool for disaster management is only possible if such a tool is geared towards the needs of local authorities. Therefore it should be able to serve as a multi-task tool, which may also be used in other activities such as development planning and control, cadastral applications, tax collection purposes, health, education, roads, energy and water supply, flood control and drainage and waste management. Besides, the methodology developed in one municipality should also be easily duplicated by personnel in other municipalities without the need for extensive knowledge on hazard and risk assessment.

Although the selection of the scale of analysis is usually determined by the intended application of the mapping results, the choice of 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.

GIS is very useful in modelling for the following aspects of risk assessment:

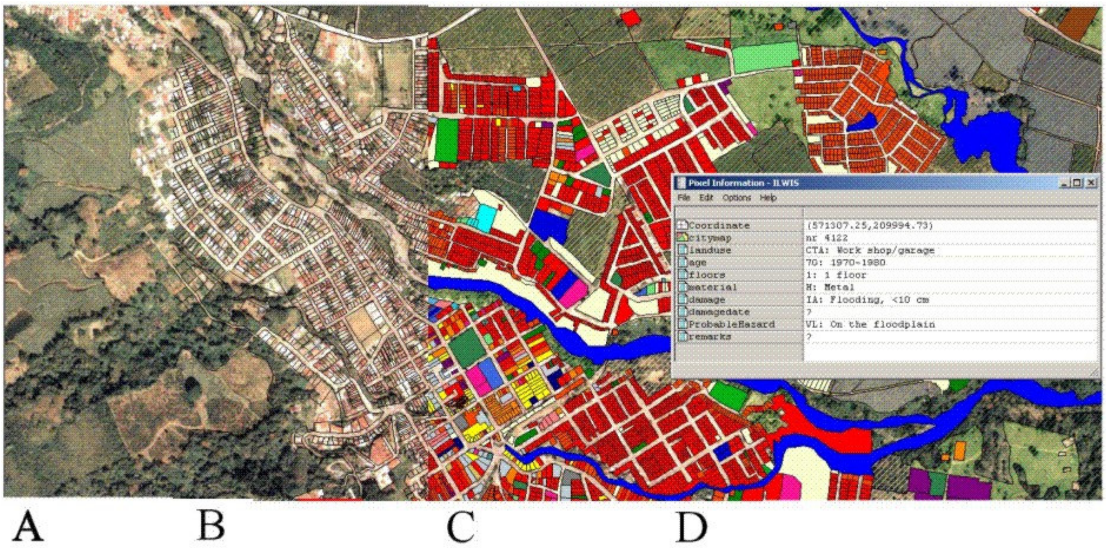
- Quantitative estimates of losses : in terms of direct costs for repair and replacement of damaged buildings and lifeline system components; direct costs associated with loss of function (e.g., loss of business revenue, relocation costs); casualties; people displaced from residences; quantity of debris; and regional economic impacts.
- Functionality losses : in terms of loss-of-function and restoration times for critical facilities such as hospitals, and components of transportation and utility lifeline systems and simplified analyses of loss-of-system-function for electrical distribution and potable water systems.
- Transportation and utility lifelines : for components of the lifeline systems: damage probabilities, cost of repair or replacement and expected functionality for various times following the disaster,
- Essential facilities : damage probabilities, probability of functionality, loss of beds in hospitals.
- Social losses: Number of displaced households, Number of people requiring temporary shelter, Casualties in four categories of severity based on three different times of day)
- Losses associated with general building stock : Structural and non structural cost of repair or replacement, loss of contents, business inventory loss, relocation costs, business income loss, employee wage loss, loss of rental income)
- Indirect economic impact : long-term economic effects on the region based .

3.4 Presentation & Visualisation

A decision-maker works in an environment of forces (i.e. stakeholders) and often within a team, with conflicting interests. Decision-making on executive levels in an organisation use condensed low volume, yet often unstructured data. Thematic specialists (in research and management as well as operational levels) prepare decisions, processing high volumes of relatively structured data, leading for instance to hazard or risk maps. These data need to be condensed to be of use in executive information systems containing information in terms of key decision criteria evaluating alternative courses of action. If a bottleneck exists in the flow of data from thematic specialists to decision-makers, communication between both is impaired. Thus more informed decisions are ignored.

An important tool to improve this communication is a Disaster Management Information System (DMIS) having a digital database under GIS environment is oriented towards providing information for decision makers and encompasses information on natural resources. The integration of these data sets would aid in decision making process for systematic planning and management of resources as well as disaster situations.

Experience has shown that the presentation of hazard, vulnerability and risk data in the form of high detailed ortho-photomaps has a much higher impact than written information. Digital cartography is therefore an important component, either resulting in hardcopy output, or presented in an interactive manner on Internet.



Coordinate	(571307.25,209994.73)
citymap	nr 4122
landuse	CTA: Work shop/garage
age	70: 1970-1980
floors	1: 1 floor
material	H: Metal
damage	IA: Flooding, <10 cm
damagedate	?
ProbableHazard	VL: On the floodplain
remarks	?

Figure 2: Different views of the large-scale database for the city of Turrialba, Costa Rica used for risk managment. A: orthophoto, B: vector overlay of parcels, C: polygons displaying landuse type, D: reading information from the attribute database.

3.5 Dissemination & Use

Some important aspects are (ISDR, 2001):

- **National systems for Disaster Prevention and Response**: building national legal and regulatory frameworks and programs that bring together the planning agencies, local governments and civil society organisations; developing national strategies for risk reduction.
- **Public private partnership for construction safety**. to use public private partnership to encourage safe construction methods and standards with the incentive of receiving economic benefits for adhering to said standards.
- **Transfer of knowledge among local authorities for vulnerability reduction.** In many cases, local players in charge of disaster reduction change depending on national legislation and local regulations. Experience has shown that the interface between different actors involved in managing risk at different levels of responsibility is a powerful tool to increase the level of effectiveness of their work, while improving co-operation and co-ordination initiatives.
- **Obtain commitment by public authorities to reduce risks to people, their livelihoods, social and economic infrastructure, and environmental resources**. Increase opportunities for organizations and multi-disciplinary relationships to foster more scientific and technical contributions to the public-decision-making process in matters of hazard, risk and disaster prevention by identifying and engaging designated authorities, professionals drawn from the widest possible range of expertise, and community leaders to develop partnership activities
- **Risk information for** Decision-Making: evaluating existing risk assessment methodologies; developing indicators of vulnerability, and stimulating the production and wide disseminationof risk information (IDB, 2000)

4. Spatial data infrastructure for disaster management

4.1 Primary actors in disaster management

The primary actors in disaster management are international financial institutions, civil society organisations, academia, private sector and government at all levels.

International financial institutions
Financial institutions such as the Worldbank, ADB, or IDB are investing in risk and hazard departments that evaluate and quantify the risks involved in projects and/or investments. They demand inceasingly complex studies on risk management, in order to safeguard investments made after a disaster has occurred.

Academia
Universities and other high level training institutes recognise the need for the development of training programmes in disaster management, directed to government officials in different positions, ranging from purely technical personnel to decision makers. In many countries initiatives are taken to either include the topic of disaster management as a separate study, or within the curriculum of exisiting academic disciplines.

Private sector
The insurance industry needs to have an accurate overview of hazard sources and risk locations for the purpose of underwriting, rating, accumulation, control and marketing. Insurance and reinsurance companies are becoming more and more interested in developing countries, due to their increasing portfolio and an increase in losses. Reinsurance companies have established close links with several Universities and research institutes in Europa, US and Japan. Reinsurance companies have the main expertise on risk quantification. They have developed their own commercial software tools for loss estimation, which are normally not available for users in developing countries.

Governmental organisations
Government organisations at a national, provincial and local level are perhaps the most important actors in disaster management in terms of their capability – at least theoretically- to supply timely and accurate spatial information for risk management and development planning. Although governments are now increasingly taking a more holistic approach to disaster management, they are still saddled with a host of problems including insufficient use of Geo-ICT technologies, organisational weaknesses and institutional problems.

Such problems are pertinent to government organisations dedicated to disaster management as well as to government (fundamental) geoinformation providers at national, provincial or municipal level. Although it is accepted in general that governments have an obligation to facilitate access to fundamental geoinformation including a description of the data to enable users to make a judgment about fitness for use, progress is slow on the ground. New mechanisms, such as Geospatial Data Infrastructures (GDI) are required to provide accessibility to data and metadata. New organisational structures to deal with the product and service delivery tasks for disaster management will be necessary. The content and structure of data assets and metadata standards, the design and implementation of clearinghouse functionalities have to be negotiated between major actors in disaster management interventions. Technological and organisational issues must be addressed concurrently with institutional issues (e.g. access to restricted, military-controlled data) to support the acceptance of technological solutions.

Civil society organisations
When disaster management at a governmental level is not effective, due to technological inadequacies, and organisational & institutional bottlenecks, civil society organisations are filling up this gap, by working on solutions at a municipal or community level, where the need for spatial information for non-technical users in municipalities is high.

4.2 Geospatial Data Infrastructures (GDI)

In general terms, a Geospatial Data Infrastructure encompasses the networked geospatial databases and data handling facilities, the complex of institutional, organizational, technological, human, and economic resources which interact with one another and underpin the design, implementation and maintenance of mechanisms facilitating the sharing, access to, and responsible use of geospatial data at an affordable cost for a variety of application domains, including disaster management.

On the right hand side of the figure (see figure 3) are the individual application domains with their GIS systems, needing routine supply of directly applicable data. This stream of requirements is being met through a Geospatial Data Service Centre (GDSC). The GSDC harmonises / standardises all data for the application domain. Standardization is an important issue considering the different scales, formats, and content of data collected by different agencies involved in disaster management. The GSDC ensures they are described in a meta data standard to facilitate the sharing of these resources in the domain. It also guarantees the data quality, an issue with major legal and financial implications in risk assessment.

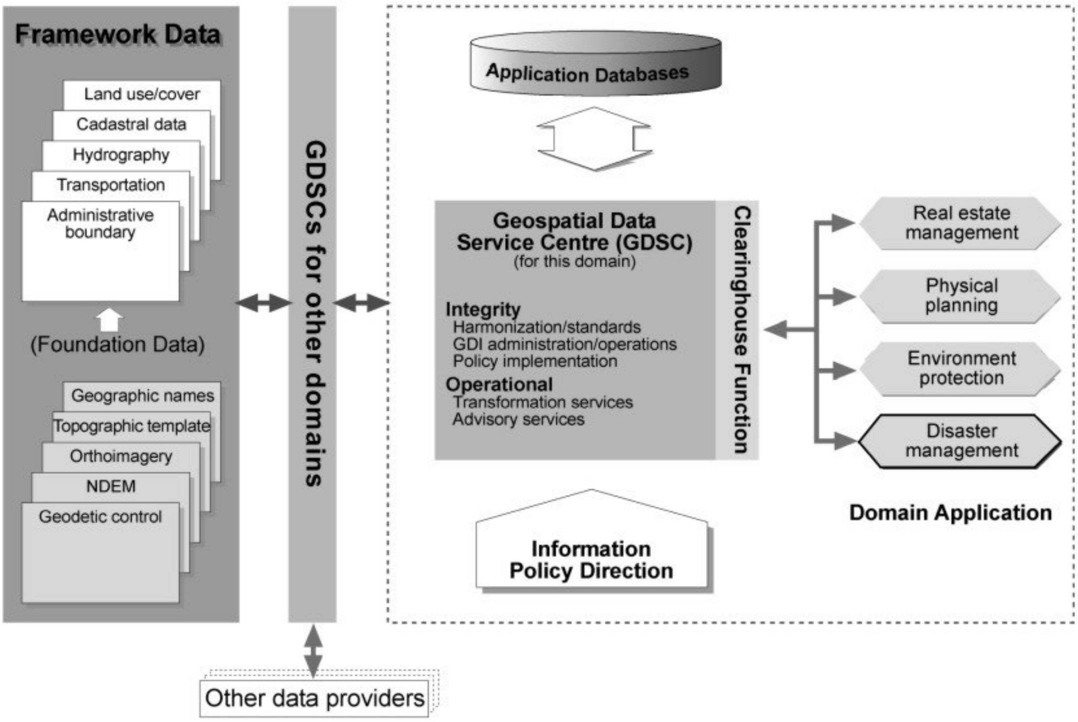


Figure 3: A GDI in relation to the Geospatial Data Service Centre and specific application domains, adapted from Groot & McLaughlin, 2000

The GDSC also enforces the information policies that control access, use and pricing, in keeping with legislation and overall government policy. It is fully accountable for the total integrity of the infrastructure. It is staffed by a cross section of technical, administrative, legal professionals as well as specialists in geoinformatics who understand the language and content of the application domain of disaster management. The latter are essential for the data model and standards development in a manner, which promotes the broadest possible use, and thus sharing, of data resources within the domain.

4.3 Advances in Geo-ICT technologies

Two major advances in geo-ICT technologies are especially pertinent to disaster management: (i) the exploitation of synergies among satellite communication, satellite navigation and Earth Observation and (ii) the increasing availability of global fundamental data sets. For example, a recent ESRIN/ESA/EU project demonstrates how a communication satellite based connection to the internet makes the download times of large images acceptable and therefore enables online access to EO catalogues. Also global fundamental data sets such as the global spatial reference frame and the global digital terrain models from the SRTM mission often have a high level of local usability and superior accuracies/resolutions compared to national fundamental data sets.

We are now witnessing a number of encouraging developments in terms of timely data availability. The "International charter on Space and Major Disasters", CNES, ESA and the Canadian Space Agency have made an agreement to provide remote sensing images to Civil Protection Agencies on their request for free within a very short time after the occurrence of a disaster. A number of other space agencies have also shown interest in joining the charter. The charter is operational since November 2000, and has been activated at least 8 times to date.

4.4 Capacity Building

In a broad sense, capacity building refers to improvements in the ability of organisations to perform agreed tasks, either singly or in co-operation with other organisations. Capacity building has received increasing attention in the international development community during the past decade. It is considered a prerequisite for good governance. It has become the rallying cry of donor agencies and international development think tanks, in an era of declining foreign aid. For the purposes of this paper, the goal of capacity building is to strengthen organisations so that they can assume responsibility for disaster management in a geo-ICT environment.

This includes negotiating new mandates with central government and a new organisational structure, deciding on the content and structure of data assets and metadata standards, designing and implementing clearinghouse functionalities as well as a facilitating environment for decentralising GIS applications in the disaster management application domain. Technological and organisational issues must be addressed at least concurrently with institutional issues to support the acceptance of technological solutions. The purposes and foci of capacity building are illustrated in below.

	PURPOSE	**FOCUS**
CAPACITY BUILDING FOR DISASTER MANAGEMENT	Human resources development	Supply of technical and professional personnel
	Organisational strengthening	Strengthen the management capacity of organisations; institutionalise geo-ICT solutions (systems and processes) as well as strategic management principles
	Institutional strengthening	Strengthen the capacity of organisations to develop & negotiate appropriate mandates and modus operandi as well as appropriate (new) legal and regulatory frameworks

An effort towards this direction in India is the collaboration project between the Indian Institute of Remote Sensing (IIRS), National Remote Sensing Agency, Department of Space, Government of India, Dehra Dun (India) and three partners from the Netherlands: the International Institute for Aerospace Survey and Earth Sciences (ITC), the International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE), and Wageningen University. The project is called GEONEDIS: Geoinformatics for Environmental Assessment and Disaster Management, Institutional Strengthening of the Indian Institute of Remote Sensing

The project aims at institutional development and capacity building for environmental assessment and disaster management in India and the South-Asian region. For this purpose two courses are developed jointly by the project partners:

- A Post-Graduate Course in Environmental Assessment and Disaster Management (first course starting July 2001, duration 10 months)
- A Master of Science course in Geoinformatics for Environmental Assessment and Disaster Management (first course starting July 2002, duration 18 months).

The courses will be part of the regular training programme of the Indian Institute of Remote Sensing (IIRS), Dehra Dun. The aim is to facilitate interdisciplinary problem solving in environmental and disaster issues through the use of geographical information systems and remote sensing.

5. Conclusions

Spatial information technology and its applications are developing fast, allowing a greater accessibility and availability of information obtained through remote sensing and other techniques. Within the user community, there is a clear need for:

- The collection of information on hazard, vulnerability and risk
- The exchange of information between different data providers
- Guidelines, models, and case studies for the use of Geoinformatics for disaster and risk assessment
- Geospatial Data Infrastructures for disaster management
- Capacity building programs for the use of Geoinformatics for Disaster Management

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