Policies for Natural Disaster Reduction in Modern Societies

Megacities: The Vulnerability of Infrastructure to Natural Disaster

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1. Introduction

Natural hazards, and therefore the mitigation of risk, have always been part of the world scene. This Decade was initiated because of a widespread realisation that it is now time to place the spotlight on a situation in which increasing numbers of people and their property and welfare are at risk, at a time when the knowledge and resources of humanity can be focused to alleviate this situation. The Decade provides an incentive to find the means and the will to do so. Events around us consistently endorse the wisdom of this incentive.

As one contribution to the Decade, the World Federation of Engineering Organisations (WFEO), an international NGO representing the engineering community, was invited by the UN Scientific and Technical Committee to coordinate an international demonstration project for IDNDR, on "*Urban developments and their vulnerability to natural disasters with particular reference to megacities*". The Institution of Civil Engineers in the UK is providing the work centre for study of this theme.

The unprecedented rise in population and growth of urbanisation presents a compelling requirement for study. Indeed the management of these great and growing cities of the world is perhaps the greatest challenge facing the world as the millennium approaches. The additional threat posed by the occurrence of a natural hazard is one which many of these cities are simply not equipped to withstand.

The "megacity" - a term used by the UN to denote an urban development with a population of over 8 million - is the culmination and archetype of this process of increasing population pressure. It is also destined to become a phenomenon concentrated overwhelmingly within the developing world; recent UN projections indicate that, while the population of the world as a whole will increase by 45–75% by 2025, that of the least developed regions will grow by twice to three times that amount. It is predicted that there will be 20 "megacities", and 67 smaller cities with population of between 2.5 million and 8 million, in the developing world by the year 2000.

Many of these megacities are situated in regions which are susceptible to natural hazards such as floods, windstorms, earthquakes and sea surges; the consequent risk to life, property infrastructure and the economy present a major challenge for national, regional and municipal governments throughout the developing world. The megacity of the developing world must therefore be of special interest to all those concerned with disaster mitigation activities.

2. The Disaster Management Cycle

The cycle of disaster management activities — incorporating mitigation, preparedness, relief and response, rehabilitation and reconstruction — will be a familiar concept to all assembled at this

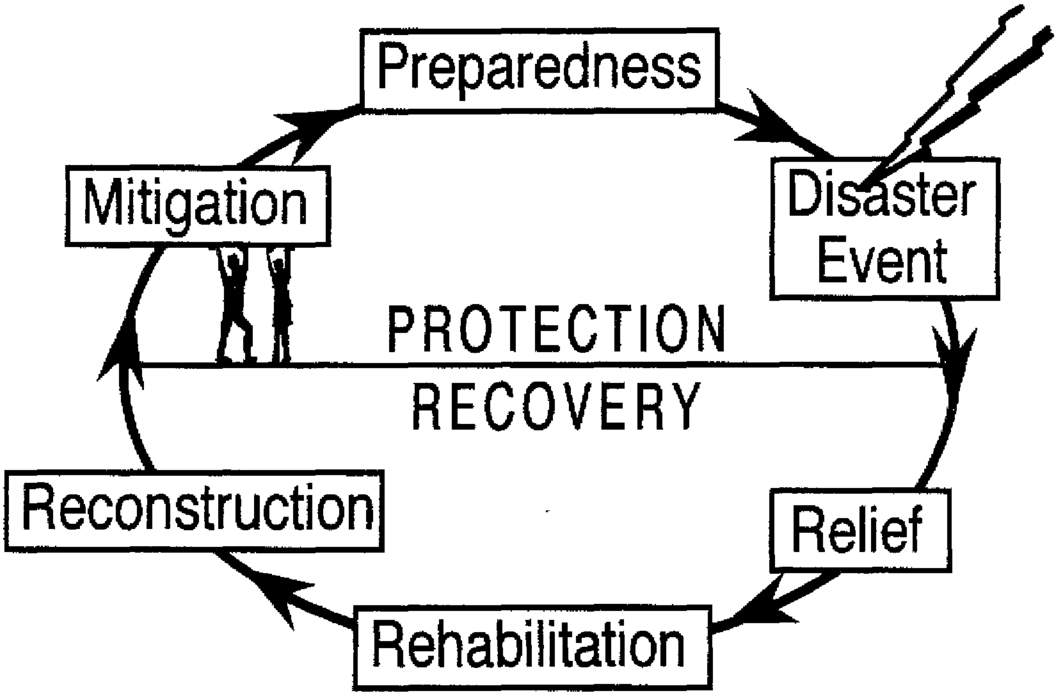

Figure 1

conference (Figure 1). Within this cycle, immediate post-disaster relief efforts often attract the most interest; from the media, for their "newsworthy" appeal, and from national and local administrations in recognition of the great urgency and necessity of such efforts. The following stage, of rehabilitation and reconstruction, is usually far less prominent and, although it may be infused with a consciousness of preparation for future events, momentum can often be lost.

Relief and rehabilitation is vital. However this Institution argues that mitigation is better than cure. Spending time and resources in planning and preparing to minimise the effects of natural hazards is preferable to responding to the often disastrous effects of such hazards. The implication of this emphasis is that the process of disaster management becomes inextricably enmeshed with that of strategic planning and development. Disaster mitigation should become a vital facet in the matrix of co-ordinating and prioritising expertise and resource in city planning. A well-planned city is, by definition, one which is prepared to withstand the impacts of those natural hazards to which it might be susceptible. Referring to the title of this paper, the infrastructure — physical, organisational and social — of the city must be sound and healthy if it is to respond well to such threats.

This principle may seem all too apparent and would no doubt meet with the agreement of many organisations working in the area of disaster mitigation. This does not mean however, that it is put into practice either consistently or effectively. Ultimately, effective implementation of mitigation measures must be the key to reducing the impact of natural disasters worldwide. The next section of this paper will identify some of the barriers to successful implementation.

3. Barriers to Implementation

Within the developing world, disaster mitigation measures are often given a low priority, simply because of the presence of many other urgent needs. This is especially true of the typical megacity, in which rapid and uncontrolled growth overwhelms both the city planning process and the infrastructure. The result is often an inadequate or unreliable supply of basic services such as water, electricity and transport, and little or no public health provisions. It is perhaps understandable that, faced with such harsh realities on a daily basis, the city dweller will be less concerned with the prospect of natural disasters which have yet to happen, and that the administration will have many more immediate and pressing calls upon its funds.

Another typical feature of the megacity, (also a result of rapid growth in population) is the rise of informal settlements or shantytowns. It is of note that up to 35% of the population of the typical megacity fall within this category. These areas generally suffer from the lowest standards of infrastructure, accommodation, public service and facilities. Residents typically have no land rights and have little incentive or opportunity to improve their conditions. Disaster mitigation is far from their minds.

However, these areas will often be particularly vulnerable to natural disaster, due to their location. The scarcity of land in urban areas tend to push informal settlements onto marginal land which is often totally unsuitable, such as flood plains, unstable slopes or poor quality ground, rendering them easily susceptible to hazards such as flooding, landslides or earthquakes.

Conversely it is sometimes argued that the very poorest areas could be relatively insensitive to the occurrence of natural hazards and the residents more resilient and more readily adaptable to their effects. Houses which were built in a day can be rebuilt as easily; in contrast, high-rise structures are often more susceptible to the devastation wrought by, for instance, earthquake.

Due to their very complexity, the effects of natural disasters upon the megacity are not easily understood or quantified; the preparation and implementation of an effective disaster mitigation strategy is a daunting task. The integration of that strategy into the wider political and social objectives of the city's administration, and the prioritisation of resources are equally difficult to achieve, but equally essential.

A weak and ineffective organisational infrastructure can be significant obstacle in the promotion of disaster mitigation. Evidence suggest that, where strong institutional organisations exist providing forecasting capability, evacuation procedures, and sound infrastructure, the escalation of major problems and the loss of life are significantly reduced. In many countries, legislative procedures for reducing risks are generally well established and supported by an extensive foundation of knowledge and experience. However, procedures in themselves will be ineffectual unless their implementation is supported by adequate resources, careful planning and co-ordination, and trained personnel.

There is no doubt that professional and technical expertise, knowledge and information of a high standard is widely available. However, it seems equally clear that the information required for sound decision-making is not reaching those for whom it would be most useful. Without the existence of a strong professional infrastructure, the co-ordination and integration of such knowledge, both

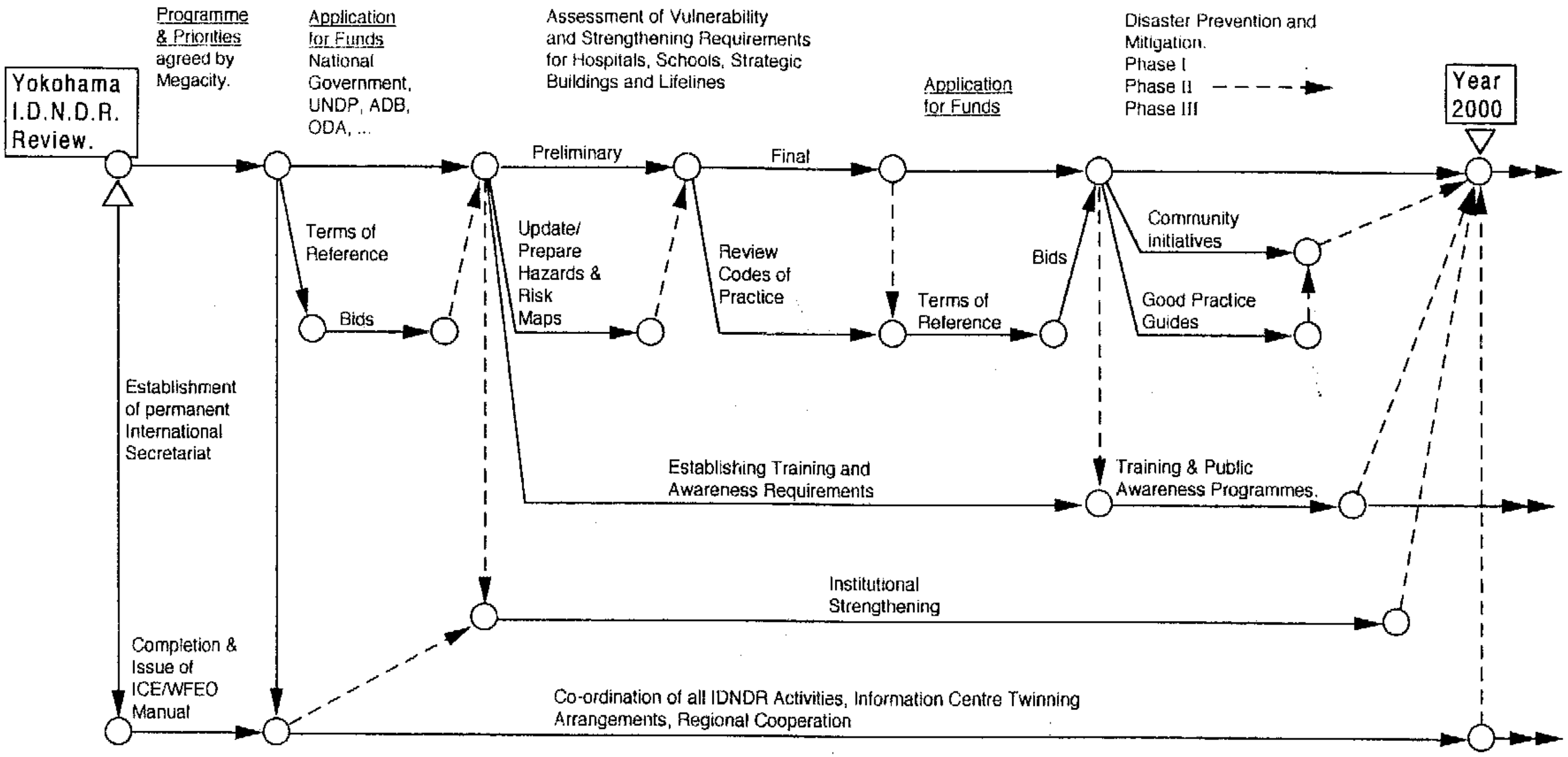

Figure 2. Programme logic diagramme to the year 2000.

geographically and across disciplines, its practical application to specific situations will be lacking.

If we accept that these are the problems, some solutions can, at least in principle, be outlined. The aim of the ICE's work for IDNDR is to develop a comprehensive methodology incorporating activities appropriate to each level of governance and to the private sector. Some principles of this methodology (an example of which is given in figure 2) are suggested in the closing section of this paper.

4. Principles of a Methodology for Disaster Mitigation

We will have failed if we do not persuade governments and authorities of the fact that disaster mitigation is an integral element of all development. Many projects are undertaken throughout the developing world by both national and international development agencies and by local community-based organisations, which aim to improve the provision of infrastructure and basic community facilities and ultimately the quality of life of those affected. However, to be genuinely effective and sustainable in the long term, such projects must incorporate an awareness of the principles of disaster management.

For the megacity at risk, the most fundamental requirement is for a comprehensive risk assessment and cost-benefit analysis, in order to assess the economic and strategic implications of the available options for mitigation and to identify areas in which further action can most usefully be taken. This analysis is likely to highlight the vital need to reduce the vulnerability of major strategic infrastructure. Cost-effectiveness is a vital consideration if disaster mitigation is to embrace the immense task of inner city slum-clearance and shanty town re-development. In these conditions, a comprehensive and perfect solution may not be feasible given the resources available, and careful prioritisation will be essential.

Cost-effective solutions will also emphasize the contribution of inexpensive measures which build upon existing resources, skills and facilities. Raising awareness, encouraging preparedness and disseminating information such as advise notes and good practice guides are areas in which the role of local government and community organisations can be particularly significant.

Adequate building regulations and codes of practice are widely available, but are not consistently applied; a long-term objective should be to ensure the implementation of improved standards for new buildings and structures. This could be achieved through various incentives, such as the subsidy of building materials in the informal sector, the provision of grants or low-interest credit in the private housing sector, and reduced insurance premia and tax incentives in the commercial sector. For all sectors, technical assistance could be made readily available and a continuous education and public awareness campaign adopted.

Fundamentally, however, progress in disaster mitigation depends upon the achievement of a clear and well-defined consensus which agrees upon a strategy and sets an agenda for co-ordinated action. To be truly effective, this consensus must be reflected at every level of government and across every section of the community. To be universally effective, it must derive from a broadly-based international consensus.

The principal conclusion of our thinking to date is therefore that, on the international level, there is a clear necessity for a central co-ordinating body, established within the United Nations, to bring together the work of the various fields of disaster management and to develop a strategic vision and long-term objectives for the mitigation of risks worldwide. The vast body of knowledge and information available, if collated and published in a systematic and accessible format, would be greatly beneficial in terms of both immediate short-term response and (more importantly in our view) for long-term planning and mitigation measures.

5. Conclusion

We believe therefore that the principal task of this Decade is to persuade international, national and municipal authorities to promote disaster *mitigation*, and to agree and progress an international agenda for further action.

With the creation of an effective co-ordinating agency within the United Nations, it will for the first time become possible to disseminate information and good practice widely, to stimulate universal and consistent progress, and to ensure that disaster mitigation is afforded the high priority which it undoubtedly deserves. The alternative is to accept the status quo; however, in view of the forecasts of an escalating world population, this option is no longer acceptable.

Application of Satellite Remote Sensing for Natural Disaster Reduction in Developing Countries

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The paper describes the integrated application of Remote Sensing (RS) and Geo Information Systems (GIS) in the process of monitoring and hazard assessment of natural disasters.

After a short introduction on the methodology of hazard assessment emphasis is given to the unique role which satellite Remote Sensing can play in this context.

An evaluation is made on the applicability of different types of RS-imagery, considering their spatial, spectral and temporal resolution. The capabilities of the use of RS-data in GIS for data integration and analysis of hazard occurrence specifically for conditions in developing countries are highlighted.

1. Introduction

Satellite Remote Sensing techniques can be used for the reduction of natural disasters if these techniques enable us to collect data about atmospherical conditions and/or the characteristics of the earth's surface which may lead to the occurrence of processes which may bring about natural disasters or can help us to take actions which reduce the disastrous effects of these processes.

To reduce the impacts of natural disasters with the help of satellite Remote Sensing, a complete strategy for disaster management is required (OAS, 1990 and UNDRO, 1991), involving the following aspects:

Disaster prevention

- *Hazard analysis*: assessing the probability of occurrence of potentially damaging phenomena.
- *Vulnerability analysis*: assessing the degree of loss expected to population, infrastructure, economic activities, as the consequence of an event of a certain magnitude.
- *Risk assessment*: assessing the numbers of lives likely to be lost, the persons injured, damage to property and disruption of economic activities caused by a particular natural phenomenon.
- *Landuse planning and legislation*: implementation of the risk map in the form of building codes and restrictions.

Disaster preparedness

- *Forecasts/warning/prediction* of disasters (for example, hurricane warning).
- *Monitoring*: Evaluating the development through time of disasters (for example, floods).

Disaster relief

- *Damage assessment* shortly after the occurrence of a disaster.
- *Defining safe areas*, to indicate possible escape areas.
- *Infrastructure monitoring*, to ensure an undisturbed supply of aid.

2. Characteristics of Satellite Remote Sensing and GIS

	LANDSAT MSS	LANDSAT TM	SPOT	
			XS	PAN
Nr. of spectral bands	4	7	3	1
Spectral resolution	0.5 – 1.1 µm	0.45 – 2.35 µm 10.4 – 12.5 µm	0.5 – 0.9 µm	0.5 – 0.7 µm
Spatial resolution	80 m	30 m 120 m in TIR	20 m	10 m
Swath width	185 m	185 m	2 x 60 km	2 x 60 km
Stereo	no	no	yes	yes
Temporal resolution	18 days	18 days	26 days 5 days off nadir	26 days 5 days off nadir

Table 1. Comparison of the specifications of different multi-spectral remote sensing products.

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 distribution*: the size of the area on the terrain that is covered by the instantaneous field of view of a detector.
- — *Temporal resolution*: the revisit time of the satellite for the same part of the earth's surface.
- — *Spectral resolution*: the number and width of the spectral bands recorded.

The most frequently used systems are given in table 1.

Besides the use of conventional aerial photographs, which often remain the most useful tools in many types of disaster studies, the application of satellite data has increased enormously over the last decades. After the initial low spatial resolution images of the LANDSAT MSS (60 x 80 meters), LANDSAT is also offering Thermatic Mapper images with a spatial resolution of 30 meters (except for the thermal infrared band) and an excellent spectral resolution with 6 bands covering the whole visible and the near and middle infrared part of the spectrum and with one band in the thermal infrared. LANDSAT has an overpass every eighteen days, offering a theoretical temporal resolution of eighteen days, although weather conditions are a serious limiting factor in this respect, as clouds are hampering the acquisition of data from the ground surface. The weakest point of the LANDSAT System is the lack of an adequate stereovision. Theoretically a stereomate of a TM image can be produced with the help of a good digital terrain model (DTM), but this remains a poor compensation as long as very detailed DTM's are not currently available.

The French SPOT satellite is equipped with two sensor systems, covering adjacent paths each one with a 60 kilometers swath width. The sensors have an off-nadir looking capability, offering the possibility for images with good stereoscopic vision. The option for sidewards looking results also in a higher temporal resolution. SPOT is sensing the terrain in a wide panchromatic band and in three narrower spectral bands (green, red and infrared). The spatial resolution in the panchromatic mode is 10 meters, while the three spectral bands have a spatial resolution of 20 meters. The system lacks spectral bands in the middle and far (thermal) infrared.

Radar satellite images, available from the European ERS-1 and the Japanese JERS, are offering an all weather capability, as the system is cloud penetrating. Theoretically this type of images can yield detailed information on surface roughness and micromorphology, however, the till now applied wavelengths and looking angle have not been very appropriate for the application in mountainous terrain. The first results of the research with radar interferometry are very promising and indicating that detailed terrain models to an accuracy of around one meter can be created, which creates the possibility to monitor slight movements related to landslides, fault-displacements or bulging of volcanic structures.

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 (Rengers et al., 1992).

A very powerful tool in the combination of the different types of data, required for disaster management, are Geographic Information Systems. A geographic information system (GIS) is defined as a "powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough, 1986). The first experimental GIS's were developed as early as the 1960's, but the real boom came in the 1980's, with the increasing availability of "cheap" (personal) computers. It is estimated that by 1986, more than 4000 different systems have been developed around the world (Burrough, 1986). Many different GIS systems exist today, with different characteristics with regards to the type of data structure (vector versus raster), data compression techniques (Quadtrees, run-length coding), two-dimensional versus three-dimensional data storage, mainframe, mini-, and microcomputer hardware, and user interfaces (pop-up menus, mouse driven, help options, etc.).

Spatial data, used in GIS, is data with a geographic component, such as maps, aerial photography, satellite imagery and rainfall data, borehole data, etc. Many of these data will have a different projection and coordinate system, and need to be brought to a common map-basis, in order to superimpose them. GIS allows for the combination of these different kinds of spatial data, with non spatial, attribute data, and use them as input data in complex models. One of the main advantages of the use of the powerful combination techniques of a GIS, is the evaluation of several scenarios, and the analysis of the sensitivity of the models by varying some of the input data.

3. Characteristics of Geological Natural Disaster types and the Role of Remote Sensing

Widely known are the potentials of applications of data from satellites to predict weather-related disastrous phenomena such as extreme storms and rainfall.

This paper concentrates on geology-related natural disasters. As these disaster types are concerned with natural phenomena with wide variations in characteristics, size, speed of development, etc., the following paragraphs will concentrate separately on the role of satellite remote sensing in the reduction of the following four types of geological hazards: flooding, earthquakes, volcanic eruptions, and landslides.

Flooding

The areas affected by flooding are generally large in size (in the order of 10^3–10^5 km^2). Many different types of flooding exist, with different requirements as to the satellite imagery. In general the following subdivisions can be used:

- *river floods*, which can be seasonal floods related to big rivers, or flash floods in smaller catchments.
- *coastal floods*, which can be related to tropical cyclones, or to high tides.

Many factors play a role in the occurrence of flooding, such as the intensity and duration of rainfall, snowmelt, deforestation, poor farming techniques, sedimentation in riverbed, 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 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 automated classification from SPOT, LANDSAT 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 the peak discharges and return periods, using data from gauging stations.

For the prediction of floods, promising results have been reported recently, on the use of NOAA images, combined with meteorological satellites and radar data, in the calculation of rainfall over large areas. For the monitoring of floods in large catchments, such as in Bangladesh, NOAA images are successfully applied.

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. However, SPOT data, if available, can be applied successfully in the determination of safe areas, and the planning of relief operations.

Earthquakes

The area affected by earthquakes are generally large (on the order of $10^2 - 10^4$ km^2), 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, soil types, depth of the water table, topography, and construction types of buildings.

In the phase of 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 the measurement of fault displacements, using satellite Laser Ranging (SLR), Global Positioning System (GPS), or radar inferometry. 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.

In the phase of disaster relief, satellite RS can only play a role in the identification of large associated features (such as landslides). Structural damage to buildings cannot be observed with the poor resolution of the current systems.

Volcanic eruptions

The areas affected by volcanic eruptions are generally small (< 100 km^2), 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 well known (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 (Hawaii, Etna), and ashfall (Pinatubo, El

Disaster type	Disaster prevention	Disaster preparedness	Disaster relief
Volcanism	++	++	++
Earthquakes	+	-	o
Landsliding	o	+	+
Flooding	++	++	++

Table 2. Usefulness of Satellite Remote Sensing for Disaster Management:
++ = very useful, + = useful, o = of limited use, – = not useful

Chincon). Volcanic ash clouds can be distributed over large areas, and may have considerable implications for air-traffic and weather conditions.

Satellite remote sensing can be used in the phase of disaster preparedness in the mapping of the distribution and type of volcanic deposits, using LANDSAT TM, SPOT, or Radar. For the determination of the eruptive history, other 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). The thermal band of LANDSAT TM can be used to monitor the thermal characteristics of a volcano, and radar inferometry in the measurement of surface deformation. NOAA-AVHRR data can be used to monitor lava flows or ash plumes. Meteosat, GOES or TOMS (Nimbus-7) can be used to monitor the extent of volcanic ash clouds and the SO_2 content.

Landslides

Individual landslides are generally small (0.001 – 1 km^2), but they are very frequent in many mountain regions. Landslides occur in a large variety, depending on the type of movement (Slide, Flow, Fall), the speed of movement (mm/year – m/sec), the material involved (rock ⇔ soil), and the triggering mechanism (earthquake/rainfall/human interaction).

In the phase of disaster prevention, satellite imagery with sufficient spatial resolution and stereo capability (SPOT) can be used to make an inventory of the past landslides, and to collect data on the relevant parameters involved (soil, geology, slope, geomorphology, landuse, hydrology, rainfall, faults, etc.).

In the phase of disaster preparedness, use could be made of the same systems used in the prediction of floods (see Flooding). Monitoring of displacements of large landslides could be done with radar inferometry.

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

4. Conclusions

In table 2, a summary is given of the usefulness of satellite remote sensing in the different phases of disaster management for flooding, earthquakes, volcanic eruptions and landslides. From this table it can be concluded that most promising results can be expected in the fields of volcanic eruptions and flooding, as both types of disasters result in features that are clearly recognizable with the use of satellite imagery. Earthquakes and landslides generally result in damages to objects that are too small to recognize on the current imagery.

Table 3 lists the current satellite remote sensing imagery that could be used in disaster

Disaster type	Disaster prediction	Disaster preparedness	Disaster relief
Volcanism	TM/SPOT (radar)	TM/NOAA	TM/SPOT/GOES TOMS
Earthquakes	TM/SPOT (radar)	—	TM/SPOT
Landsliding	SPOT	radar NOAA	TM/SPOT
Flooding	TM/SPOT NOAA	NOAA Meteosat	TM/SPOT

Table 3. Current satellite remote sensing data which can be used in disaster management.

management.

Finally the following conclusions can be stated:

— The existing tools can generally be considered adequate. Current SPOT and LANDSAT TM are the most used systems.

— Temporal resolutions (& spatial resolution) should be improved. There is however, a clear need for certain types of disasters (earthquakes, landslides) to have stereoscopic data with a larger spatial resolution.

— In many applications, weather conditions are the most important drawback. In the near future, however, it is expected that many applications will be possible from the use of multispectral satellite data is seriously limited by the nearly continuous cloud coverage.

— New tools should be analyzed:
- Satellite radar: ERS-1, ERS-2
- EOS programme

— The application of the satellite data is seriously limited by the lack of funding. Funding of research in applications is in no relation to funding for space technology research.

— Accessibility of data is a problem. Applications in real time are usually only possible on paper, as the time needed for ordering and acquiring satellite images is usually excessively large.

— Satellite remote sensing can only give part of the answer to Geological Disaster Management. It will always have to be combined with other types of data.

— Policy decisions are required to make operational use of satellite remote sensing in the following fields:
- Investments in hardware and software.
- Compatibility and continuity of systems.
- More training.
- Improved awareness among decision makers.

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