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Disaster mapping in developing countries

1. Introduction

A disaster is defined as "a calamitous event bringing great damage, loss or destruction" (Burrough, 1986). Such events can be earthquakes, landslides, floods, hurricanes, volcanic eruptions etc.
An event such as a volcanic eruption by itself is not considered a disaster when it occurs in uninhabited areas. The debris flows resulting from an eruption of the Nevado del Ruiz volcano in 1985, for example, are not considered to be disaster in the uninhabited surroundings of the volcano. However, when such a debris flow moves down the inhabited valleys downslope it becomes a hazard. And it may result in a disaster when it hits upon a city, as did the debris flows in this example. The debris flow, triggered by a volcanic eruption of the Nevado del Ruiz, wiped out the entire city of Armero in November 1985, killing 30.000 people.

Some disasters strike within a short period with devastating outcomes (like earthquakes), whilst others have a slow onset period with equally or even more serious repercussions (such as drought). Disasters can be classified in several ways. A possible subdivision is:

- *Natural disasters* are events which are caused by natural phenomena (such as earthquakes, volcanic eruptions, droughts, 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, desertification).

Another subdivision is into *geological disasters* (earthquakes, volcanic eruptions, landslides, floods) and *ecological disasters* (drought, desertification, erosion, deforestation).

Almost all disasters are accompanied by a loss of some kind. This could be in the form of property, infrastructure or human life. The losses experienced vary with the type of disaster, its magnitude and the areas affected.

Globally, it appears that the toll of death and damage in natural disasters is increasing, although there is no international databank of sufficient comprehensiveness to verify this supposition. The cost to the global economy now exceeds US $50.000 million per year, of which a third represents the cost of predicting, preventing and mitigating disasters and the other two thirds represent the direct cost of the damage (Alexander, 1993). Death tolls vary from year to around a global mean of about 250.000, while major disasters kill an average of 140.000 people a year.

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 deaths occur in the Third world, where more than 4.200 million people live. Economic losses attributable to natural hazards in developing countries may represent as much as 10% of gross national product. In *industrialized* countries, where warning-systems and buildings codes are more sophisticated, it is easier to predict the occurrence of natural phenomena, and to warn people in time. The damages, however, are usually less severe in developing countries, with strictly limited resources (Alexander, 1993). An example of this can be given by comparing the great floods in Bangladesh (1988) which caused the death of 1410 people with the Mississippi flood in the USA in 1993, which only caused about 30 fatalities. However, when we compare the economic losses of the two events, the result are reversed: in Bangladesh a total loss of 1.1 Billion US$ was estimated, while 15.8 Billion US$ in the US. Even more striking is a comparison between the hurricane disasters of 1990 in Bangladesh and the 1992 hurricane Andrew in the US.

These statistics illustrate well the importance of hazard mitigation. The International community has become aware of the necessity to increase the work on disaster management. The decade 1990-2000 has been designated the "International Decade for Natural Disaster Reduction" by the general assembly of the United Nations.

To reduce the impacts of natural disasters a complete strategy for disaster management is required (OAS, 1990; 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.
- Infrastructural monitoring, to ensure an undisturbed supply of aid.

2. Tools in hazard mitigation

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. The zonation of hazard must be the basis for any hazard mitigation project and should supply planners and decision makers with adequate and understandable information. This information is given in the form of risk maps. In order to be able to make a risk map one should have information on the probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area, which is called hazard.

Hazard is commonly shown on maps, which display the spatial distribution of hazard classes. Hazard zonation requires a detailed knowledge of the processes that are or have been active in an area, and on the factors leading to the occurrence of the potentially damaging phenomenon. This is considered the task of earth scientists. Vulnerability analysis requires detailed knowledge of the population density, infrastructure, and economic activities, in addition to the hazard. Therefore, this part of the analysis is done mainly by persons from other disciplines, such as urban planning, social geography, and economics.

In each of these aspects the use of remote sensing and Geographic Information Systems can play an important role. Remote sensing data, such as satellite images and aerial photos, allow us to map the variabilities of terrain properties, such as vegetation, water, geology, both in space and time (ISL, 1993). They can provide information on the extent of disaster within a relatively short period of time. And they are of extreme importance in obtaining the necessary data to make an evaluation of the hazard, vulnerability and risk, if combined with other types of data.

Analysis of hazard is a complex task, as many factors can play a role in the occurrence of the disastrous event (e.g. an earthquake, or a landslide). The analysis requires a large number of input parameters, and techniques of analysis may be very costly and time-consuming. The increasing availability of computers during the last decades has created opportunities for a more detailed and rapid analysis of natural hazard.

A very powerful tool in the combination of these different types of data 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). Spatial data is data with a geographic component, such as maps, aerial photography, satellite imagery and rainfall data, borehole data etc. GIS allows for the combination of these different kind of data using models.

3. Scales of analysis

Before starting any data collection, an earth scientist working on a hazard analysis project will have to answer a number of interrelated questions:
- What is the aim of the study?
- What scale and with what degree of precision must the result be presented?
- What are the available resources in the form of money and manpower?

Selecting the working scale for a hazard analysis project is determined by the purpose for which it is executed. The following scales of analysis can generally be distinguished:
- National scale (< 1:1.000.000)
- Synoptic or regional scale (< 1:100,000)
- Medium scale (1:25,000 - 1:50,000)
- Large scale (1:5,000 - 1:10,000)

In the following sections three examples of the application of remote sensing and Geographic Information Systems will be demonstrated: one on determining flood hazard in Bangladesh, and the other one on determining landslide hazard in the Andes.

4. Flooding in Bangladesh

Bangladesh is the country which is probably most affected by natural catastrophes, especially floods. Approximately 40 percent of the country is subjected to regular flooding. It contains more than 250 perennial rivers, of which 56 originate outside of the country, in Tibet, India, Bhutan and Nepal. Ninety percent of the river discharge from the main rivers, the Ganges, the Brahmaputra and the Meghna originates from other countries.

The primary cause of flooding in Bangladesh is directly or indirectly related to rainfall in the catchment areas of the three major river systems. The rainfall, together with snowmelt from the Himalayas generates enormous quantities of runoff to be discharged through Bangladesh into the Bay of Bengal.

Moderately strong semidiurnal tides are prevailing in the Bay of Bengal. Due to the extreme flat topography of the country (half the country lies below the eight meter contour line), the tidal influence reaches very far into the country. During the monsoon, recession of the floodwater is delayed due to the tidal effect. Cyclonic sea flooding occurs when due to the friction of the wind on the surface of the sea a storm surge moves inland.

From 1960-81 Bangladesh has suffered 63 disasters with the loss of 655.000 lives. Of these events, 37 were tropical cyclones, which killed 386.200 people. The last major floods were in 1987 and 1988 and a cyclone in 1990, killing about 140.000 inhabitants on the Bay of Bengal coast (Alexander, 1993).

The evaluation of the flooding hazard is an international effort, as rainfall and river discharge monitoring in the entire catchment of the major rivers is required, as well as monitoring of see levels and warning systems for tropical cyclones.

For flood stage mapping and river dynamics determination, digital image processing and analysis of sequential SPOT images using GIS was performed. The study area covers the confluence of the rivers Meghna and Ganges, south east of the capital of Dhaka.

Three SPOT images were used in this analysis:

- One from January 1987, during the dry season
- One from November 1987, just after a moderately severe flood with a recurrence interval of 50 years.
- One from October 1988, just after a severe flood with a recurrence interval of 100 years.

The SPOT images are used in this study to assess the spatial distribution of the inundations (flood stage mapping) and the river dynamics (changes in channel geometry and channel pattern). The imagery shows different water levels, corresponding to flooding recurrence intervals. The flooded areas can be separated from land, using the spectral characteristics of different satellite image bands used. In this case water and land were separated using spectral band ratio's (see table 1).

09-01-1987	07-11-1987	10-10-1988	percentage van het gebied
Land	Water	Land	0.3
Water	Land	Land	0.5
Water	Water	Land	0.6
Land	Land	Water	7.8
Land	Water	Water	10.4
Water	Land	Water	10.9
Water	Water	Water	17.3
Overstroomd tijdens de piek in 1988			21.4
Land	Land	Land	30.8

Table 1

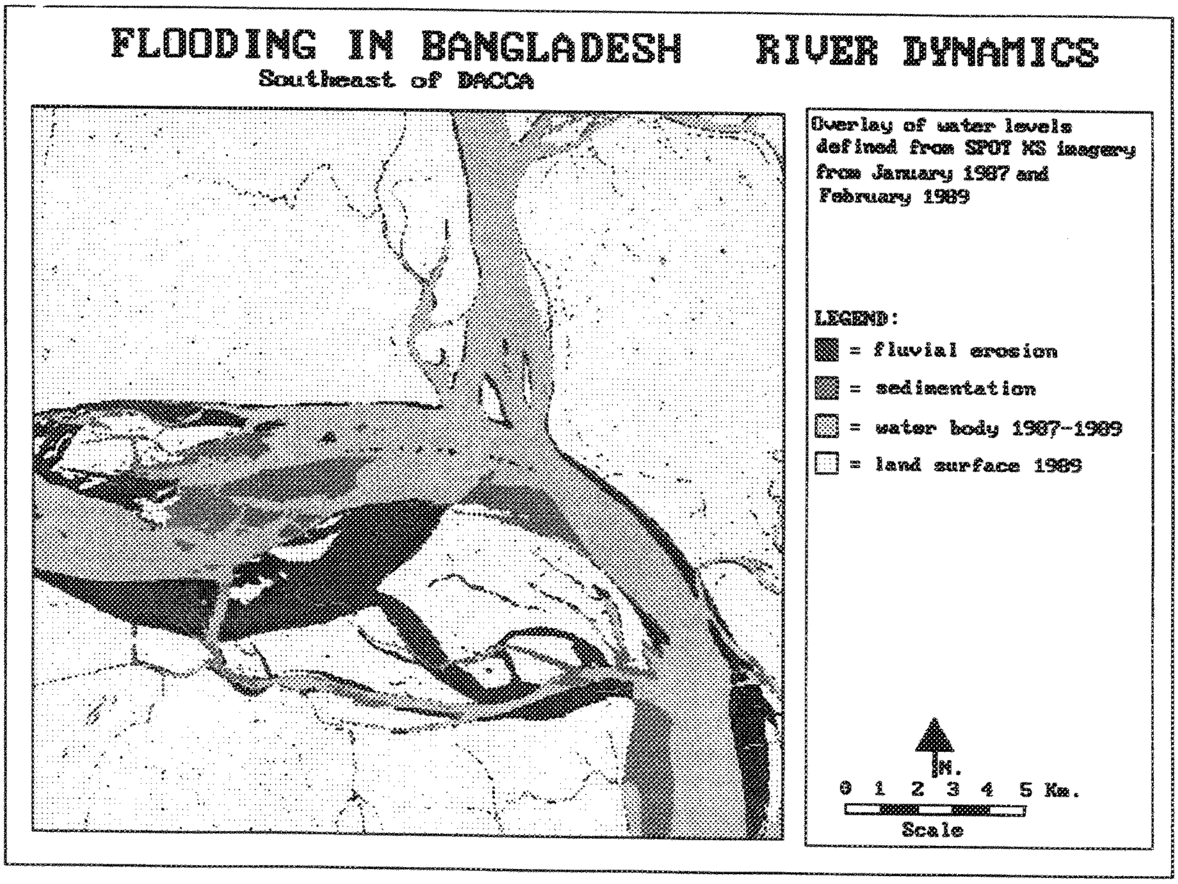

Figure 1: Combination of two classified SPOT images, prior and after the 1988 inundation, showing substantial differences in the river pattern (Assaduzzaman, 1994)

Repetition of this procedure for several flood levels and overlaying the corresponding digital maps resulted in a map showing the areas which are frequently flooded, areas affected by lateral shifting due to river dynamics (see figure 1) and areas which have a low flood probability. The low flooding areas will obviously be more suitable for major investments, whereas the other areas may need more protective measures. It can also be concluded that Relief Centres to mitigate flooding disaster impact should be situated in areas of low flooding risk, but near high risk-areas.

Regarding the use of satellite images and GIS, the study has shown that the use of SPOT images provided good results, although the inundated areas could be somewhat underestimated due to the lag time between the floods and the acquisition date of the images. This problem could partly be overcome by combining SPOT imagery with NOAA (with a high frequency of data acquisition, but at less detail). Combination with radar-satellite data (ERS-1, JERS) could overcome the problem of obtaining cloud-free images during the monsoon.

5. Mass movements in the Andes

The second example of the use of remote sensing and GIS in natural hazard analysis comes from the Andes, and is dealing with the evaluation of landslide hazard. The Andes is an active mountain chain which is still being uplifted due to the collision of the earth mantle plates, leading to hazard such as earthquakes and volcanic eruptions. Many of these hazards are the triggering mechanism for landslides. For example a debris flow, triggered by a volcanic eruption of the Nevado del Ruiz, wiped out the entire city of Armero in November 1985, killing 30.000 people.

The major problem areas in the Andean region with respect to landslides are the boundaries of the major cities, such as Rio de Janeiro, or Medellin. In this last city, some 400 people were killed in 1988 when a large landslide covered a part of the squatter areas in the northern margin of the city. Most of these cities are growing very rapidly, with an urgent demand for planning. In the plans for urban extension an analysis of natural risks has not usually been taken into account, resulting in slope failures within recently constructed parts of the cities.

In the evaluation of landslide hazard the use of remote sensing data and GIS plays a very important role. Landslides are controlled by a large variety of factors, such as slope angle, soil and rock material types, vegetation, landuse, rainfall and earthquakes. Many of these factors can be evaluated from remote sensing data, especially airphotos. To evaluate the combined effect of these factors the use of Geographic Information Systems in the modelling of landslide hazards using many different parameter maps, is indispensable. Many different methods are developed, which are related to the scale of analysis, the availability of input data and the required detail of the hazard map.

Regional-scale hazard analysis (<1:100.000 scale) is used to outline problem areas with potential slope instability. The maps are mainly intended for agencies dealing with regional (agricultural, urban, or infrastructural) planning.

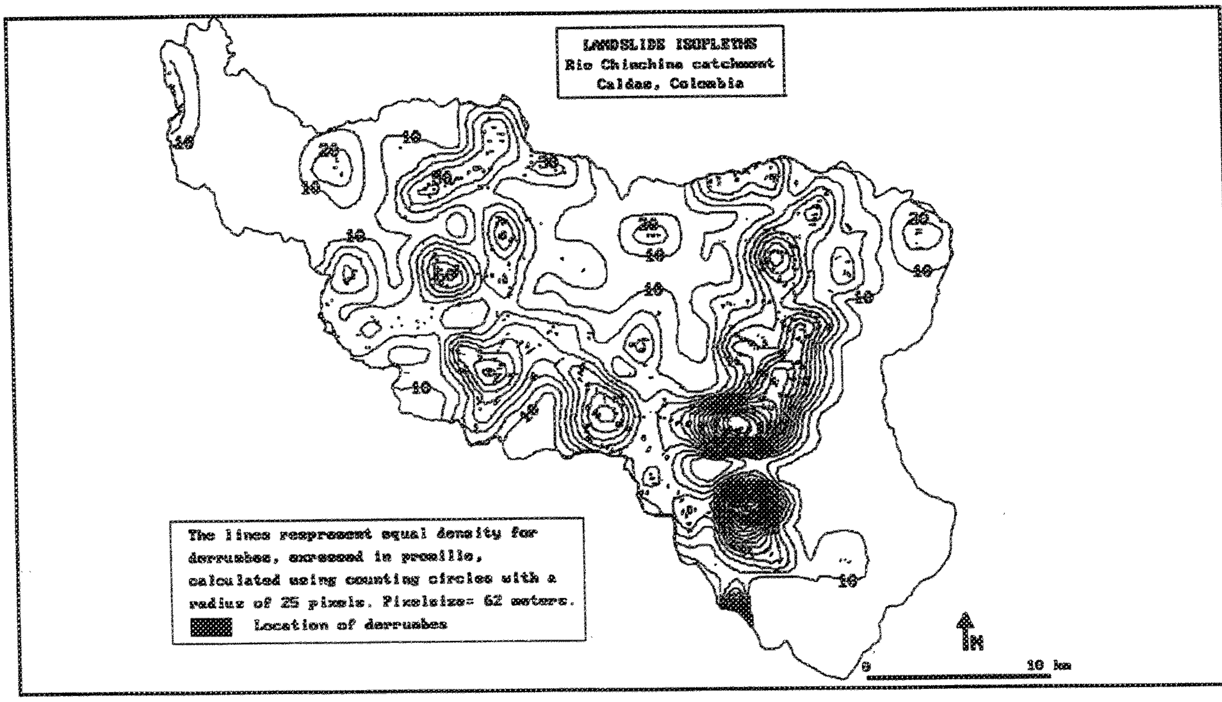

Figure 2 - Delineation of terrain mapping units obtained from interpreting stereo SPOT images of the Manizales region, Colombia.

The areas to be investigated are very large, on the order of 1000 square kilometres or more, and the required detail of the map is low. The maps indicate regions where severe mass movement problems can be expected to threaten rural, urban, or infrastructural projects. Terrain units with areas of at least several tens of hectares are outlined on the basis of satellite imagery. Within these so called Terrain Mapping Units the degree of hazard is assumed to be uniform. General landslide information is obtained from small scale aerial photography (see figure 2). Qualitative analytical methods are used to combine the various parameters within the Terrain Mapping Units and to come to a qualitative rating of the hazardness.

Medium-scale hazard maps (1:25.000 scale) are made mainly for agencies dealing with intermunicipal planning or companies dealing with feasibility studies for large engineering works (such as dams, roads, railroads). The areas to be investigated will have areas of several hundreds of square kilometres. At this scale considerably more detail is required than at the regional scale. The maps may serve, for example, for the choice of corridors for infrastructural construction or zones for urban development. At this scale it is feasible to map out the various factors leading to landsliding. Interpretation of aerial photography is the main source of information for many of the input maps and should be carried out in a well structured manner, with the use of clear criteria and photo checklists. Emphasis is placed on the use of multitemporal aerial photo interpretation to evaluate changes in mass movement activity and landuse patterns. Fieldwork techniques were developed which include the use of checklists for the description of mass movement phenomena, and the collection of soil and rock data, also using simple field tests. The landslide hazard is evaluated statistically (see figure 3), by evaluating those conditions that have lead to landslide occurrences in the past, and to use those critical combinations in the prediction of landslides in the future (figure 3).

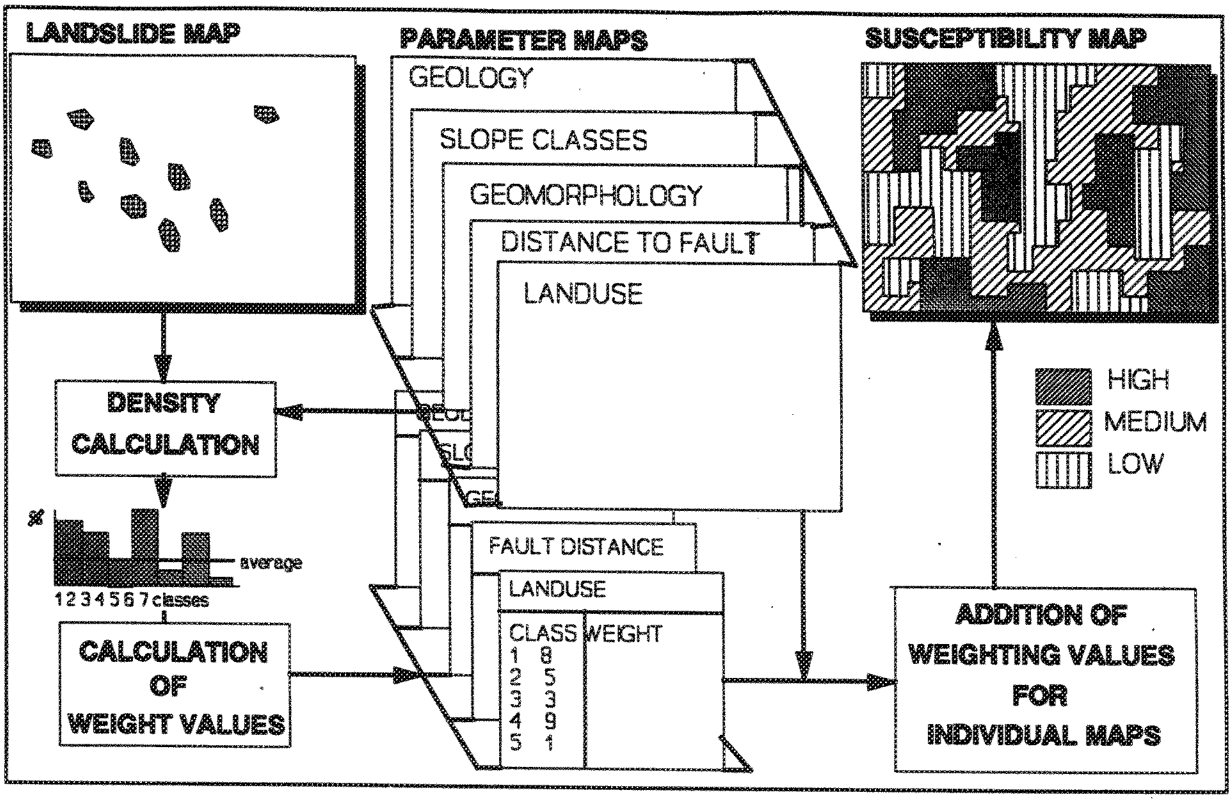

Figure 3 - Statistical derived hazard map of the Chinchina area, Colombia.

Large-scale hazard maps (1:10.000) are produced mainly for authorities dealing with detailed planning of infrastructural, housing, or industrial projects, or with evaluation of risk within a city. The size of an area under study would be on the order of several tens of square kilometres.

The hazard classes on such maps should be absolute, indicating, for example, the probability of failure for each individual units with areas down to less than a hectare. Detailed material mapping, in combination with geotechnical testing and ground water level measurement should provide sufficient information for the application of deterministic slope stability models (see figure 4).

6. Volcanic eruptions in the Philippines

The geographic location and tectonic setting of the Philippines make it prone to volcanic hazards. Out of the two hundred twenty volcanoes spread over the seven volcanic belts in the country, twenty one of them are considered

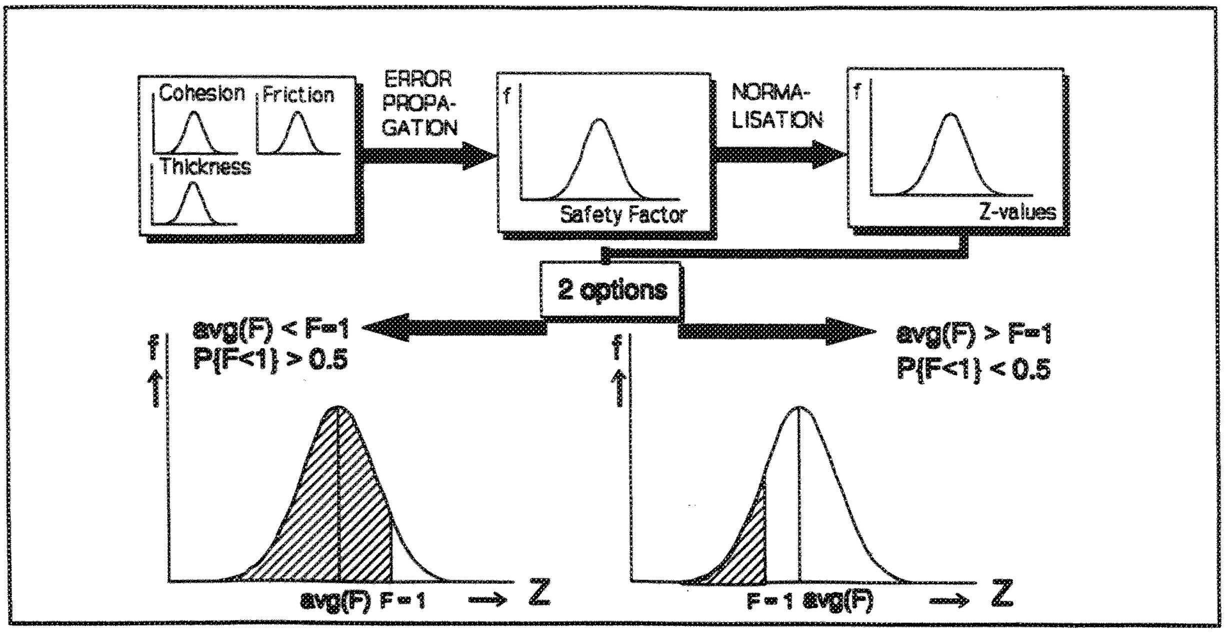

Figure 4: Deterministic slope stability models

active. One of these, Mount Pinatubo, is located on the main island Luzon, 80 km Northwest of Manila. The slopes of Mount Pinatubo are used intensively for agriculture. Within a 30km radius around the crater a large number of population concentrations are situated, amongst which two large American army bases.

The eruption of Pinatubo Volcano on June 15, 1991 had placed approximately 5 to 7 cubic kilometres (km^3) of pyroclastic flows (Daligdig and Besana,1990; Scott and others,1992). The accumulated thickness of pyroclastic flows varies, depending on the proximity to the crater and the pre-eruption morphology, and could reach more than 200 meters along deep pre-eruption valleys.

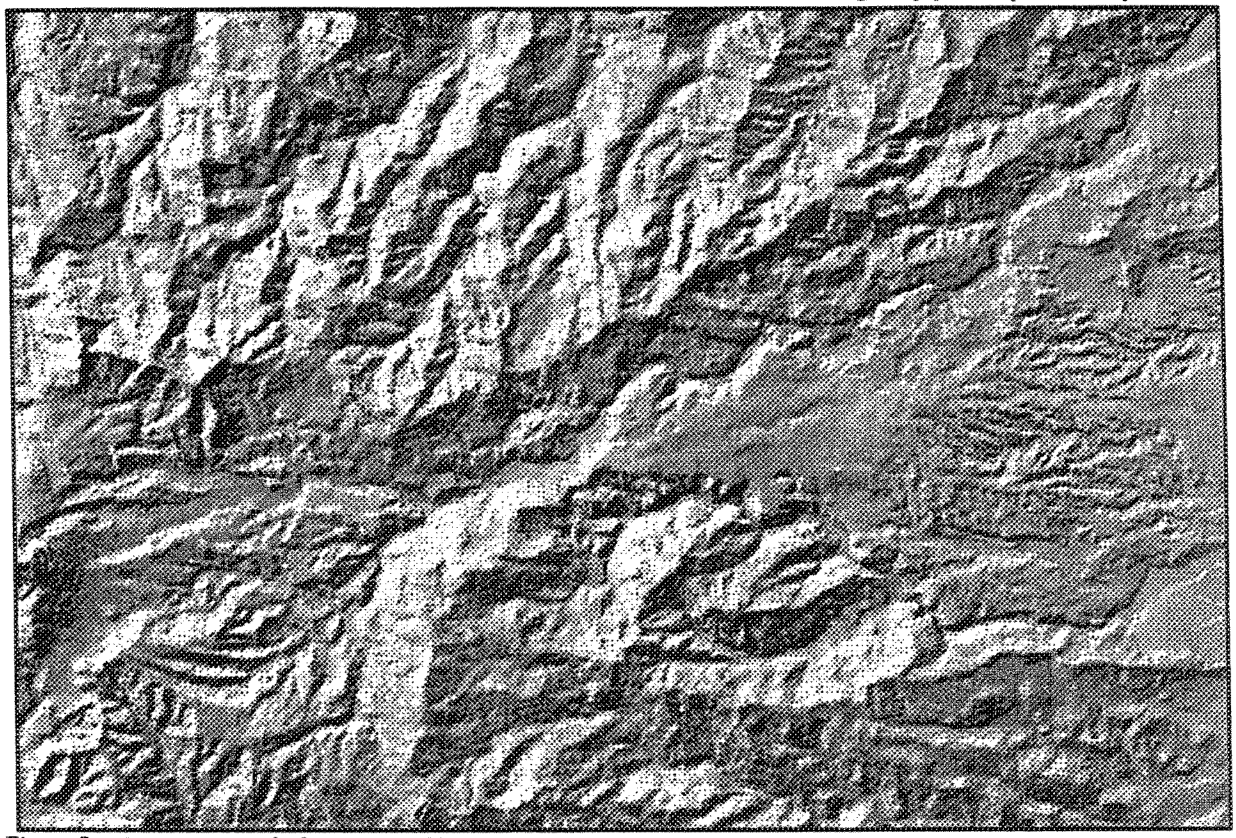

Figure 5a - Sacobia watershed area, pre-1991 eruption situation

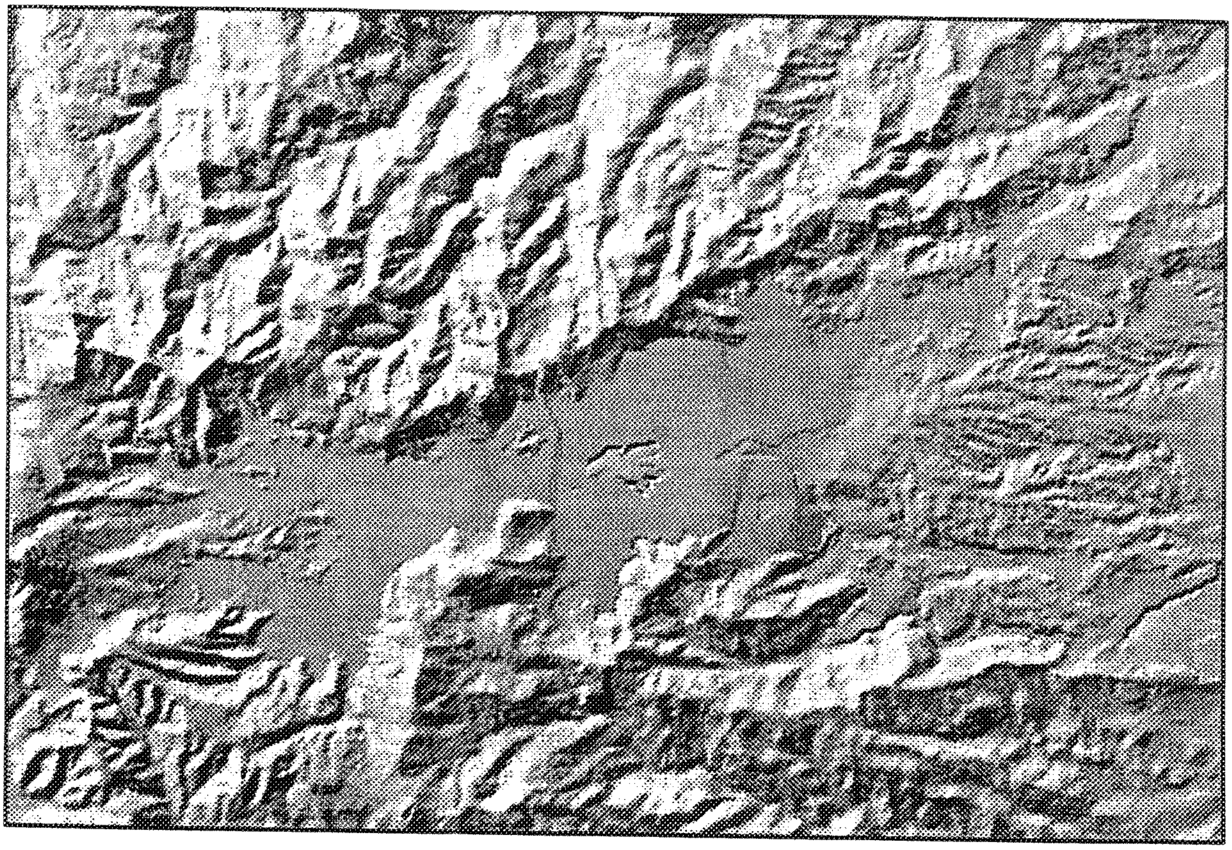

Figure 5b - Sacobia watershed area, original 1991 pyroclastic flow level

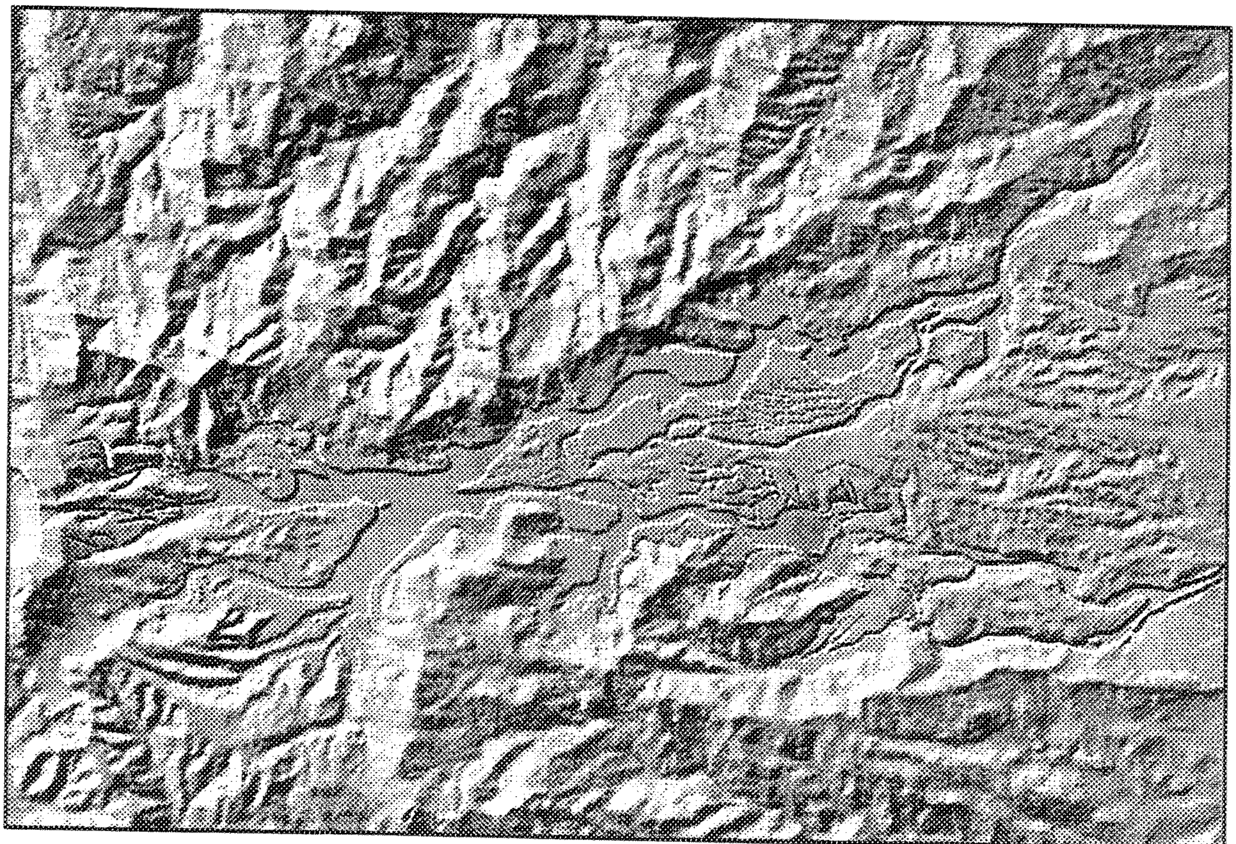

Figure 5c - Sacobia watershed area, third lahar season (1993)

The pyroclastic flow deposits affected eight major watersheds around the slopes of the volcano and radically altered the hydrological regimes, leading to unprecedented amount of erosion and sediment delivery in the footslopes of the volcano. The erosion rates of pyroclastic flows deposits in different watersheds vary considerably depending on the volume and thickness of the emplaced pyroclastic flows; size and configuration of watershed; and the variability of local precipitation as enhanced by the orographic effect. Out of the 8 major drainage systems that were affected by the eruption, one was studied in detail: the Sacobia watershed (see figure 5). The Sacobia watershed is situated on the eastern slope of the volcano and drains 3 major rivers: Sacobia, Abacan and Pasig. It was estimated that about 1.27 km^3 of pyroclastic flows was deposited during the June 1991 eruption with thicknesses reaching to about 200 meters. The deposit covered 24 km^2 of the upper watershed and reached 15 km downstream from the crater.

The rapidly changing geomorphology of Sacobia watershed before, during and 3 consecutive years after the eruption will be the scope of this study. Geomorphologic changes were studied using terrain mapping approach. Yearly erosion rates were calculated using digital terrain model (DTM).

The study of geomorphologic changes was based on the interpretation of both vertical and hand-held oblique aerial photos, video tapes, and on satellite imageries taken at different time periods. The pre-eruption geomorphology of the Sacobia watershed was interpreted from 1:12,000 scale black and white aerial photographs from 1968. The post-eruption depositional surface of pyroclastic flows was analysed using oblique, vertical photos and SPOT satellite image from 1991 and together with information from existing maps. Post-eruptions major gully developments and other geomorphic features on the 1991 pyroclastic flow deposits were analysed using vertical aerial photos taken in 1991 and 1992 and hand-held oblique photos from April 1994, before the start of the rainy season, thus illustrating the situations at the end of the yearly "lahar season". A terrain mapping approach was used to describe the temporal geomorphic changes.

To quantify erosion rates, digital terrain models were made from different years. A pre-eruption digital terrain model (DTM) with a 20 meter pixel size was made by interpolating the digitised contour map with 20 m contour interval. The 1991 pyroclastic flows deposit boundary, interpreted from aerial photos, was overlaid on the pre-eruption DTM and additional contours were digitised to fit the general slopes of the new pyroclastic flows (figure 5b). Based on these contour lines, a DTM was made to infer the original 1991 pyroclastic flow level. Yearly developments of erosional features after three rainy seasons were also interpreted using vertical and oblique photos. Valley and gully widths were plotted on the enlarged pre-eruption contour map and digitised.
The vertical incision depth of valleys and gullies were estimated in the field for a limited number of sites. The depths at other inaccessible sites, were measured with the parallax bar measurement method. Unfortunately, the precise control points were only available for the lowermost, inhabited part of the catchment, which ruled out the option of using digital photogrammetric methods. Due to the inaccessibility of the terrain and the fact that a precise GPS was not available, it was also not possible to collect precise control points. Due to the use of simple parallax measurements, the minimum mappable depth of gullies in this report is about 5-10 meters. The boundaries of gullies in 1991 were plotted over the 1991 pyroclastic flow deposits. The depth measurements made with the parallax reading were subtracted to the heights of the 1991 pyroclastic flow level to have the elevation data along stream lines. The elevations of the remaining gully slopes were interpolated to provide a new DTM. This procedure was repeated for the situations after the 1992 and 1993 rainy seasons, resulting in 5 DTM's of the following situations: pre-eruption, post- plinian eruption, first lahar season (1991), second lahar season (1992), and third lahar season (1993). Three of these DTMs are represented with hillshading in figures 5a to 5c.

The volume of the pyroclastic flow deposit was obtained by overlaying the pre-eruption and post-eruption DTM's. The volume of the eroded pyroclastic flow deposits was calculated by overlaying the post-eruption DTM and the DTM of the 1991 lahar season. Volumes of erosion in 1992 and 1993 were calculated by overlaying the DTM's before and after.

Conclusion

In conclusion, remote sensing and GIS are considered to be useful tools in the assessment of natural hazards. These tools, however, apart from their potential for data manipulation, updating, and analysis, confront the user with the importance of detailed, accurate, and reliable input maps and ample field experience.

The results from this study, which was financed by European Economic Community, UNESCO and the Dutch Ministry of Education and Science, are published in the form of a training package (figure 6). With this training package, earth scientists from developing countries can learn the various aspects of working with GIS in landslide hazard zonation. Also in the assessment of other geological hazards, such as volcanic-, seismic-, and flood hazard, ITC is working on the development of training packages. Based on these training packages a number of expert workshops have been held to disseminate the knowledge of these powerful tools to expert from developing countries.

The establishment of a UNESCO-centre of excellence for the integration of environmental and development aspects in disaster reduction, could also play an important role in the further development of new techniques for natural hazard assessment and to disseminate this knowledge to experts from developing countries.

How mapping changes with GIS.

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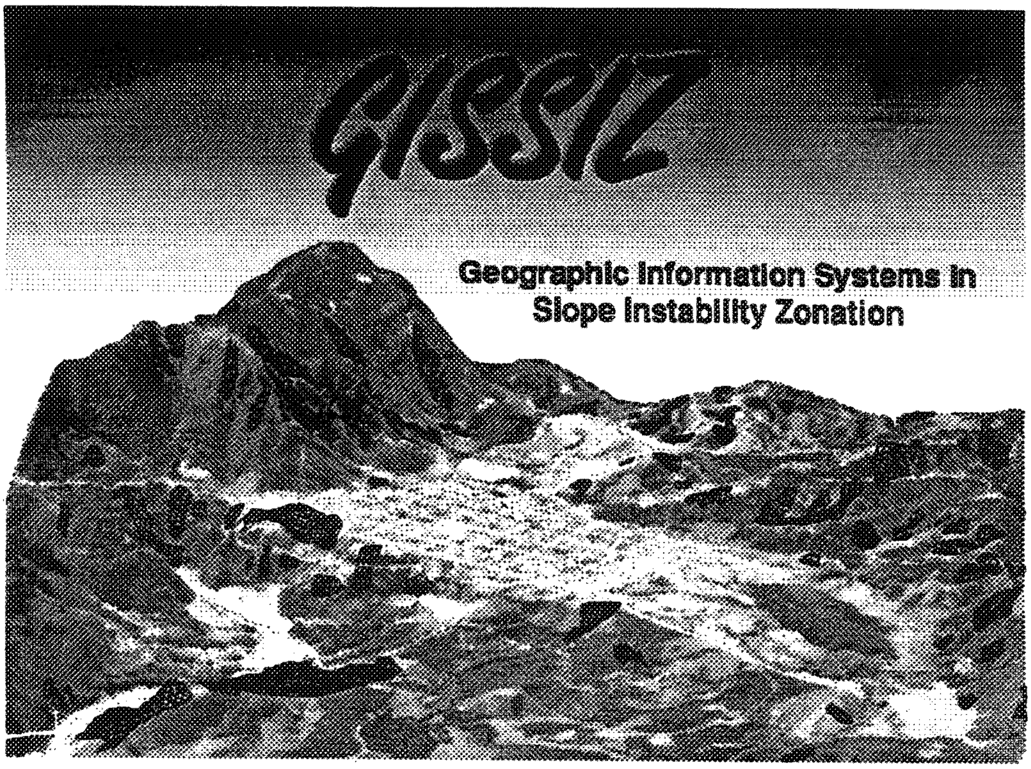

Figure 6: Cover page of the second volume of the GISSIZ training package.