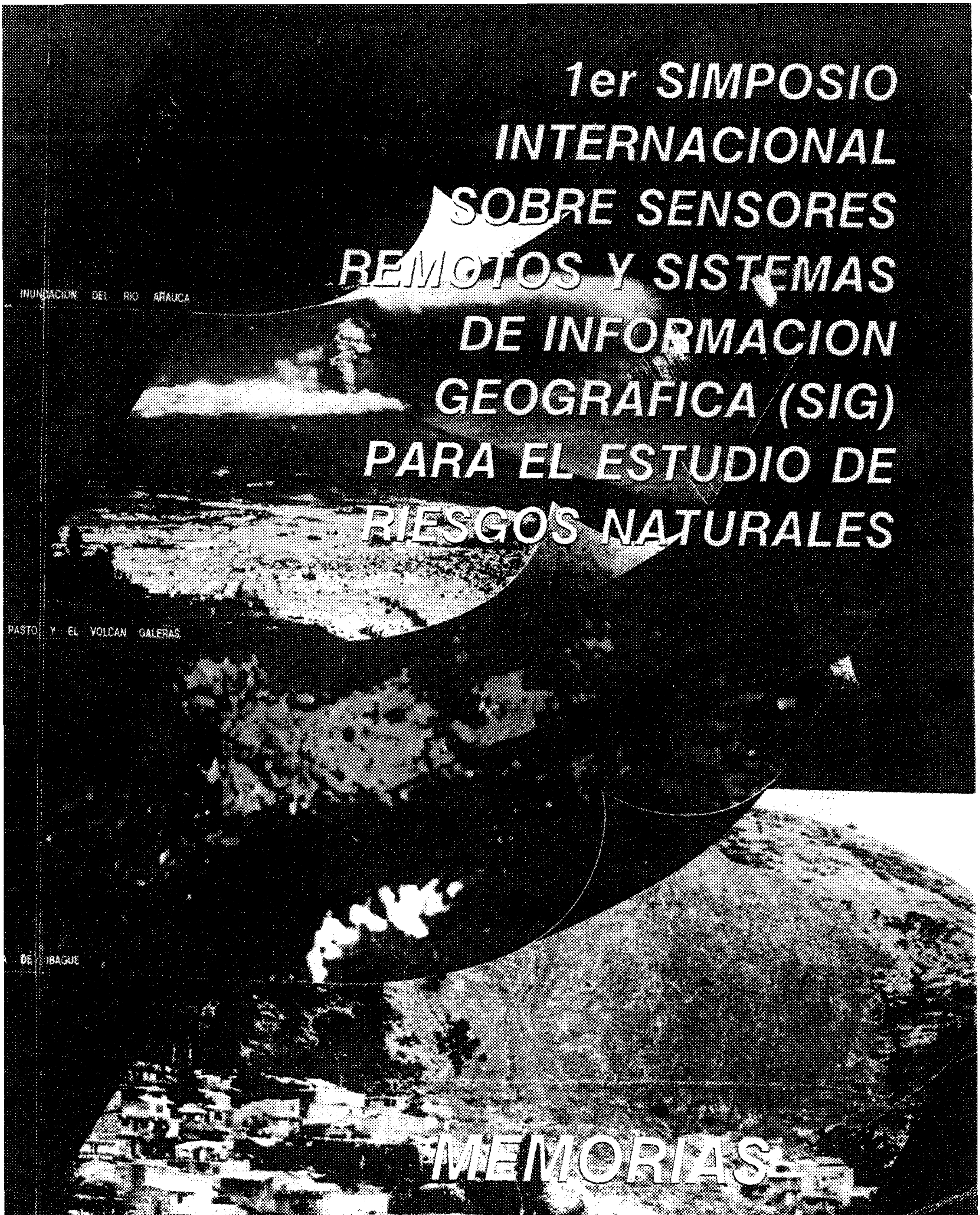
1er SIMPOSIO INTERNACIONAL SOBRE SENSORES REMOTOS Y SISTEMAS DE INFORMACION GEOGRAFICA (SIG) PARA EL ESTUDIO DE RIESGOS NATURALES



MEMORIAS

SCALE RELATED GIS TECHNIQUES IN THE ANALYSIS OF LANDSLIDE HAZARD

By
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Abstract
This paper describes in a general way the importance of the scale of landslide hazard analysis and its consequences for the necessary input data, and the possible analysis techniques that can be performed using a PC-based GIS system. The choice of the type of hazard analysis that will be performed using the GIS depends on a large number of factors among which the desired degree of precision, the objective for the investigation and the available resources are the most important. Three different scales of investigation are differentiated: a regional scale (<100.000) on which qualitative hazard analysis techniques are most appropriate, a medium scale (1:25.000 - 1:50.000) on which statistical techniques are most powerful and a large scale (>1:10.000) on which enough quantitative data can be obtained to use simple deterministic models in connection with a GIS.

Resumen
Este articulo describe en una manera general la importancia de la escala de analisis de amenazas por deslizamientos en relacion con los datos de entrada y los possibles metodos de analisis que se pueden aplicar utilizando un SIG basado en un computador personal. La eleccion del tipo de analisis depende de un numero de factores, como el detalle de precision deseado, el objetivo de la investigacion y los recursos disponibles. Se pueden distinguir tres escalas de investigacion: una escala regional (< 100.000) en la cual se peuden aplicar metodos qualitativos, una escala media (25.000-50.000), en donde los metodos estadisticos son los mas poderosos, y una escala grande (> 10.000) en la cual se puede obtener un suficiente volumen de datos para utilizar modelos deterministicos simples en conexion con un SIG.

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Introduction

A large amount of research on hazard analysis has been done over the last thirty years considering the urgent demand for slope instability hazard mapping. Initially the investigations were mainly oriented to the problem solving on the site investigation scale and the development of deterministic models. The large variability in geotechnical data such as cohesion, angle of internal friction, thickness of layers or the depth of groundwater at a more regional scale in comparison to the homogeneity required in deterministic models and the costly and time consuming site investigations, made the engineering approach unsuitable to be applied with an acceptable cost/benefit ratio over larger areas in the phases of planning and decision making for engineering projects.

In order to solve this problem the earth scientists became involved in the modelling of the spatial variability of the causative factors in slope instability and thus geomorphological approaches to landslide assessment were developed. The first attempts were based on the analysis of the relationships of slope failures and landforms obtained by a landslide oriented applied geomorphological/geological survey, followed by the extrapolation over a wider area with similar terrain conditions (Brunsden et al 1975; Carrara and Merenda, 1974; Malgot and Mahr, 1979: Rupke et al, 1987).

Aiming at a higher degree of objectivity and a better reproducibility of the hazard zonation, which is also important for legal reasons, some authors assigned weight factors to the controlling parameters, while others defined the hazard level on the multivariate analysis of large data sets obtained during the survey.

The applicability of the techniques for hazard assessment has profited strongly from the development of Geographical Information Systems: computerized systems for collecting, storing, retrieving, transforming and displaying geographically referenced data (Aronoff 1989, Burrough, 1987).

Although the possibilities for application of computers for modelling and statistical analysis of landslides are well developed, as shown for example by the Proceedings of the 5th ISL in Lausanne (Bonnard, 1988), GIS are seldomly used in this field. The first coarse raster based GIS systems were used in the late seventies. Newman et al (1978) presented a method for the creation of a hazard susceptibility map, by combining a landslide occurrence map with a rocktype map and a slope map.

A much more elaborate method, using field checklists and multivariate analysis was presented by Carrara et al (1978, 1982). A large number of the morphometrical parameters for the hazard analysis can be sampled automatically from a Digital Elevation Model (Carrara, 1988,1990).

The importance of geomorphological input data is stressed in the methods used by Kienholz et al (1988) who use a commercial GIS package in a qualitative mountain hazard analysis. Detailed airphoto-interpretation is used as a basis. The authors state that due to the lack of good models and geotechnical input data, the use of a relatively simple model based on geomorphology seems to be the most honest method. Other GIS applications for landslide hazard were presented amongst others in Stakenborg (1986), Wadge (1988) and Wagner et al (1988).

Scales in hazard analysis

Before starting any kind of data collection an earth scientist working in a hazard mapping project will have to decide upon a number of interrelated matters; what is the aim of the study, at which precision the result is needed, what are the available resources and what is the scale of working.
In this relation a primary objective of the research has to be the development of a methodology with a clear hierarchical approach, as such a methodology assures a possibility to optimize the cost/benefit ratio which is a necessary condition for a practical applicability.
As a result a reconnaissance level, a medium scale and a detailed hazard survey should be defined parallel and comparable to similar hierarchical steps in the development of engineering projects (project conception, site investigation and design phase). At the same moment such an approach offers the opportunity to define standards in relation to minimum requirements and procedures at the different levels, which are of course also function of the availability of financial resources and time restrictions, as well as the level of knowledge and experience in the survey department.
When on the basis of the above mentioned factors, a choice is made with respect to the scale of analysis, a working method or methodology using certain types of techniques has to be elected. In this choice a number of limitations related to the use of GIS in hazard analysis should be considered:
- *Image interpretation*
In principle all the input maps needed for a hazard analysis that are made via air photo interpretation could be made for all three scales, if photos are available. A number of these input maps could also be made by interpretation of satellite images (SPOT stereo preferably) or small scale airphotos.
However, for interpreting the detailed geomorphological units, or landslide phenomenon the imagery should be of a scale larger than 1:25000 (Rengers et al, 1991). As can be seen from table 1 on a small scale the amount of photos and hence the time needed for interpreting will be too large in relation with the required degree of precision on this reconnaissance scale.

Size of the area	Photo-scale	Active area per photo km^2	Number of photos
1000 km^2	50.000	35% of 126 = 44.3	around 23
1000 km^2	25.000	35% of 31.6= 11.1	around 90
1000 km^2	10.000	35% of 5.06= 1.7	around 565

Table 1: Required number of airphotos for studying an area at different photo scales.

Scale related input data

The use of a GIS requires a different methodology of data capture than the conventional mapping methods as used in geomorphology. Demek and Embleton (1978) give an overview of geomorphological mapping systems for medium scale work.
For the use in GIS the maps should be areal type maps, with different information stored in different layers. A large amount of detail that used to be presented in the conventional map with all kinds of symbols, should now be gathered as quantitative attribute data and stored in a data-base.
The mapping units in GIS based maps can be either points, lines, polygons (units) or matrices (with an individual value per pixel). Therefore the various maps should be modified into these basic forms. Different point data should be stored as points with different codes, combined with attribute data in an attribute data-base. The same is true for lines or polygons.
In table 3 a list is given of the various input maps needed for mountain hazard analysis on the regional, medium and large scale. The list is an extensive one, and only in an ideal case all types of information will be available. However, as will be explained in the section on analysis, the amount of input maps that can be collected determines the type of hazard analysis that can be used, from a qualitative one with little information to complex statistical methods, which may involve up to 100 variables.
In table 3 it is indicated for each type of input data whether the possibility for obtaining is good (+), moderately (0) or poor (-) on each of the three scales under consideration.

Data base layers	Data type	Tables	Made by use of	S	M	L
GEOMORPHOLOGY						
1 Terrain Mapping units	Units	Legend	SPOT + walk over	+	0	-
2 Geomorphological units	Units	Legend	API + fieldcheck	0	+	+
3 Geomorphological subunits	Units	Legend	API + fieldcheck	-	+	+
4 Landslides (recent)	Units/ points	Legend Checklist	API + fieldwork Field descriptions	-	+	+
5 Landslides (older period)	Units/ points	AP-checklist Lands. dates	API Newspaper or fire brigade	-	+	+
TOPOGRAPHY						
6 Digital Terrain Model	Pixel	-	Contour interpolation	0	+	+
7 Slope map (degrees or %)	Pixel	Legend&Classify	Filtering from DTM	0	+	+
8 Slope direction map	Pixel	Legend&Classify	Filtering from DTM	0	+	+
9 Breaks of slope	Lines	Legend	API	-	0	+
10 Concavities/convexities	Units	Legend	Calculating from DTM	-	-	+
ENGINEERING GEOLOGY						
11 Lithologies	Units	Legend Rockstrength Discontinuity	API + mapping Lab. & field tests Laboratory tests	0	+	+
12 Material sequences	Units	Profiles Depths USCS-class. Grainsize par Hydrology par C and phi	Map made by combination of geomorphological map and slope Field descriptions Field & lab tests Laboratory test	-	0	+
13 Sampling points	Points	Location	Field descriptions	0	+	+
14 Faults & lineaments	Lines	Legend	SPOT and API	+	+	+
15 Seismic events	Points	Dates/depths magnitudes	Seismic observatory	+	+	+
16 Isolines seismic intens.	Lines	Legend	From questionnaires on observed damage	-	0	+
LANDUSE						
17 Infrastructure (recent)	Lines	Legend	API + topomap + fieldcheck	+	+	+
18 Infrastructure (older)	Lines	Legend	API + topomap	+	+	+
19 Landuse map (recent)	Units	Legend, Tree density, Rooting	API + SPOT/LANDSAT Fieldwork Fieldwork	0	+	+
20 Landuse map (older)	Units	Legend	API	0	+	+
21 Cadastral blocks	Units	Cadastral data base	Cadastre	-	-	+
HYDROLOGY						
22 Drainage	Line	Legend/order	API + topomaps	+	+	+
23 Catchment areas	Units	Legend/order	API + topomaps	0	+	+
24 Meteorological stations	Points	Rainfall,Temperature,Evapotrans	Meteorological survey	+	+	+
25 Watertable	Pixel	Legend Ksat values	Field measurements of Ksat + model	-	-	0

Table 3: Overview of input maps for landslide hazard analysis. Possibility for obtaining data :+ = good, 0= moderate and -=poor

Scale related GIS techniques

Good state of the art overviews of existing techniques for landslide hazard assessment are given by Varnes (1984) and Hansen (1988), although the GIS related techniques are briefly mentioned. Brabb (1984,1987) also encorporates GIS in his overview. For landslide hazard analysis using GIS most of the conven-tional techniques can be used. They are adapted with respect to the various GIS procedures that should be performed, such as map crossing, joining of tables, renumbering of maps from tables etc. Examples of these basic procedures within the use of a GIS can be found in Aronoff (1989) or Burrough (1987).
In the next section some GIS techniques for landslide hazard analysis will be presented, together with a list of input data (the numbers are derived from table 3), the most appropriate scale of analysis, the advantages and disadvantages and relevant literature.
The methods were tested with a GIS system called ILWIS, developed at ITC, which is a good example of a raster based GIS working on a low budget configuration (PC), which combines some vector modules (mainly for entering data), extensive raster modules (including image processing, mapcalculation, crossing, georeferencing, DTM analysis etc) and a relational attribute database with good exchange capacity to other software (Valenzuela, 1988). The main distinction between the methods is given in table 4.

Type of analysis	Main characteristic
A. Landslide distribution	Direct mapping of landslide features resulting in a map that only gives information on those sites where landslides have occured in the past
B. Qualitative hazard mapping	Direct, or semi direct method in which the geomorphological map is renumbered to a hazard map, or in which several maps are combined in one using subjective decision rules, based on the experience of the geomorphologist.
C. Statistical techniques	Indirect method in which the GIS is used to sample a large number of parameters in landslide locations and where the results are projected over the rest of the terrain.
D. Deterministic models combined with GIS	Indirect method in which the GIS is used to generate parameter maps and to select information from them which is used in slope stability programs. The results are again merged with the map data in the GIS.
E. Landslide frequency	Indirect method in which earthquake and/or rainfall records or hydrological models are used to correlate them with known landslide dates, to obtain threshold values with a certain frequency

Table 4: General overview of hazard analysis techniques with GIS

In the following pages examples from each of these types of analysis will be given.

A1: *LANDSLIDE INVENTORY*

Introduction:
The most straightforward approach to landslide hazard analysis is a landslide inventory map, based on aerial photointerpretation, ground survey or a data base of historical occurrences of landslides in a certain area.
The final product gives the spatial distribution of landslides, represented either at scale or as points.
Although a landslide inventory map is not the result of GIS analysis itself, as it merely displays the mapped phenomena, in most of the following methodologies the landslide occurrence map plays a crucial part in the hazard analysis.
The GIS can perform an important task in transferring the digitized photo-interpretation to the map projection using a series of control points and camera information.

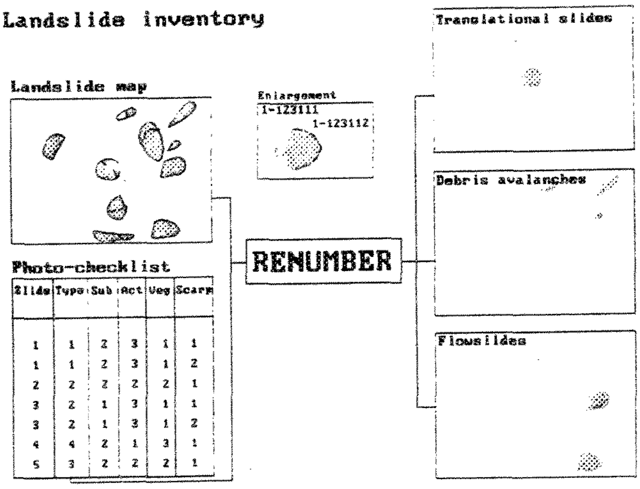
Input data:
Photo-interpretation of landslides visible on recent, relatively large scale, airphotos (4).

GIS techniques:
- Digitizing landslides with unique identifiers and a six-digits code containing information on type, subtype, activity, depth, vegetation and whether it is scarp or body.
- Renumbering the landslide map with the parameters for type or subtype into maps displaying only one type of process.

Appropriate scale: Medium or large
On small scale the construction of a landslide distribution map is very time consuming and too detailed for general hazard zoning. Although when it is possible it is advised to make it also on the regional scale, be it with less detail.

Evaluation: Very useful
- The landslide occurrence map is the most important input map in the hazard analysis, as it gives the distribution of the phenomena that one wants to predict.
- The interpretation of landslides and the use of photo-checklists depend on the skill of the interpreter and is subjective. Field checking is very important.
- The GIS is only used to store the information and to display the map in different forms (f.e. only the scarps, only slides, only active ones etc).

Relevant literature:
- Wieczorek 1984



A2: *LANDSLIDE DENSITY*

Introduction:
Instead of displaying landslides individually they can also be presented as a percentage cover within mapping units. These mapping units may be TMU's, geomorphological units, geological units etc.
The method is also used to test the importance of each parameter individually in relation to landslides. A special form of landslide density mapping is the landslide isopleth mapping, by using a large, moving counting filter. The result will be a contour map of landslide density. The scale of the pixels and the size of the filter used define the order of accuracy of the result map.

Input data:
Landslide occurrence map with adjoining table.
Basic parameter maps to display landslide density: 1,2 or 3.
For testing the importance of the parameters the following data can be used to cross with the landslide distribution map on the three different scales:
Regional: 6,11,19,23,24 distance to: 14,15,17
Medium: 6,7,8,11,12,19,23, distance to: 14,17,22
Large: 6,7,8,10,11,12,16,19,21,23,25, distance to: 9,14,17,22

GIS techniques:
- calculating a bit map for each landslide type
- crossing of the parameter map with the bit maps
- calculating the percentage per parameter class occupied by landslides.

With a small alteration also the number of landslides can be calculated instead of the area.

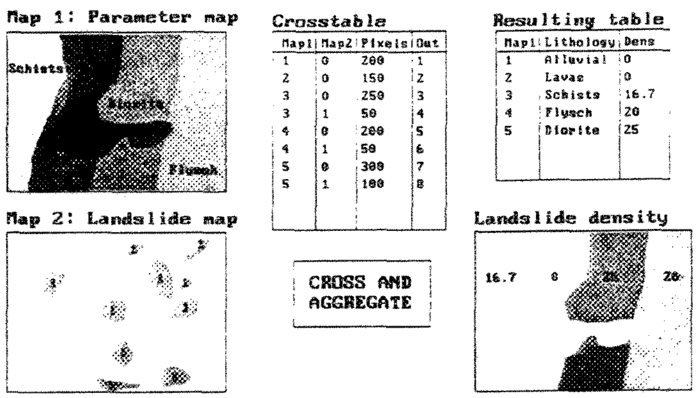
Appropriate scale: Medium and large
- Applicability on regional scale depends on the availability of a landslide occurrence map. See above for input maps.

Evaluation: Very useful
- Basic technique to investigate importance of individual parameters.
- The map crossing facilities of GIS are extremely helpful in this.

Relevant literature:
- Wright and Nilsen (1974), Wright et al (1974), DeGraff, J.V. and Canuti (1988)

Schematic representation of the technique:

Landslide density



A3: *LANDSLIDE ACTIVITY MAPS*

Introduction

Landslide occurrence maps only provide the situation at the time when the airphotos were taken. They do not provide insight in the temporal changes in landslide density. Many landslides that have occurred a decade before may have become undetectable on the later photographs. Also for studying the effects of changing parameters, such as landuse changes, multi temporal airphoto interpretation is indispensable.
For each landslide a small checklist is filled out with the following parameters: type, subtype, activity, deep/surficial, vegetation, scarp/body. Depending on the time and photos available, and on the type of terrain that is being studied time intervals of 5 to 20 years can be selected.

Input data:

- Multitemporal photointerpretations with photo-checklists (4 & 5).

GIS techniques:

- Conversion of all the photointerpretations to the same base map.
- Calculating increases in activity between two different times by comparing the data from the checklist combined with the map data.
- Calculating all landslides that have initiated or that were reactivated during the time of the photo-coverage.

Appropriate scale: Medium or large

The applicability on the regional scale depends on the availability of landslide occurrence maps. This is difficult on the regional scale, since various interpretations from different times are needed, which will double, or triple the amount of work.

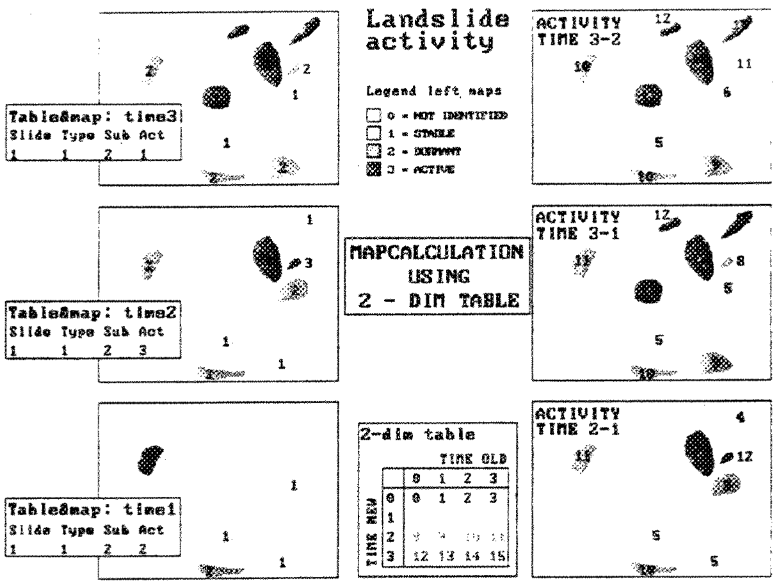
Evaluation: Very useful

- Offers quantitative values of the number or percentage of reactivated or new landslides
- The photointerpretation procedure is very time consuming, and it is difficult to prevent inconsistencies between the various times.

Relevant literature:

- Crozier (1984)

Schematic representation of the technique:



B1: *QUALITATIVE HAZARDS MAP*

__Introduction__
The basis for this type of hazard mapping is the geomorphological map. The actual hazard map is made by the geomorphologist, using his site specific knowledge, either directly in the field, or renumbered from the geomorphological map.
One step less subjective as the above mentioned method is the method in which weight values are assigned to each class of a parameter map, and where different parameter maps are weighted among each other. However the amount of weighting comes from the experience of the geomorphologist, and is not based upon quantitative data.

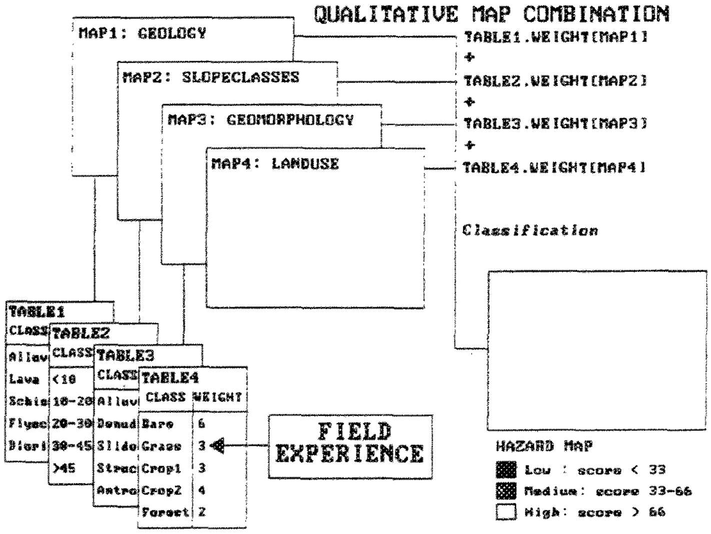
__Input data:__
Depending on the extent of the study several input maps can be used, among which are the most important: geomorphology (1,2,3), landslides (4), slopes (7), geology (11), and landuse (19), and distance to faults (14), roads (17) and drainage (22).

__GIS techniques:__
- Classifying each parameter into a small number of meaningful classes.
- Assigning weight values to each of the parameter classes (f.e. on the scale 1 to 10)
- Assigning weight values to each of the parameter maps themselves.
- Calculation of weights for each pixel and classifying the result in a small number of hazard classes.

__Appropriate scale:__ Regional, medium and large
The method is applicable on all three scales. Each scale has its own requirements as to the detail of the geomorphological input data.

__Evaluation:__ Moderate
- The method as such may result in a very reliable hazard map, but the reliability completely depends on the experience of the geomorphologist.
- Weighting values are subjective, but they are reproducible and can be discussed and changed.
- The mapper can put quite a lot of his knowledge on local circumstances in this approach.
- The method doesn't employ the full possibilities of GIS, as it is also possible to base the decision rules on quantitative map crossing results.

__Relevant literature:__
Humbert (1977), Dow, Kienholz and Plam (1979), Malgot and Mahr (1979), Kienholz et al (1983), Seijmonsbergen et al (1989), Brunsden et al (1975)



C1: *SIMPLE SUSCEPTIBILITY MAPS BASED ON MAP CROSSING*

Introduction:
In this method map crossing of parameter maps and calculating landslide densities form the core of the analysis. The importance of each individual parameter can be analyzed separately, and specific combinations of parameters can also be tested. Using normalized values (landslide density of parameter/landslide density over whole area) a total hazard map can be made by summing up the weights.
The weighting values can also be used to design decision rules which are also based on the experience of the earth scientist.
Or various parameter maps can be crossed into a map of homogenous units, which is then crossed with the landslide map, giving a density per unique combination of input parameters.

Input data:
Landslide occurrence map with adjoining table.
For testing parameters the following data can be used on the three different scale:
Regional: - 1,6,11,19,23, distance to: 14,15,17
Medium: - 2,3,6,7,8,11,12,19,23, distance to: 14,17,22
Large: - 2,3,6,7,8,10,11,12,16,19,21,23,25, distance to: 9,14,17,22

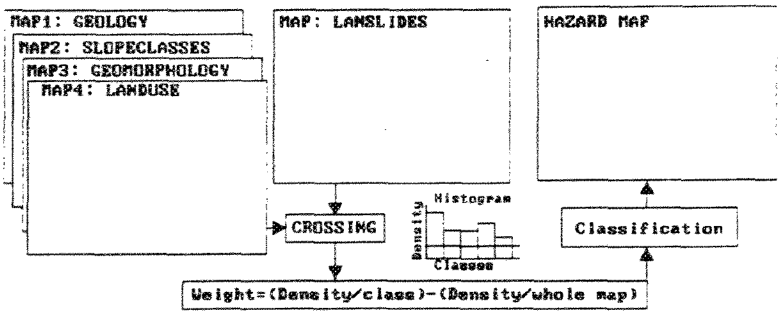
GIS techniques:
- Adapting, classifying or combining parameter maps until the classes are made of which the susceptibility for landslide will be tested.
- Crossing each map with the landslide distribution map.
- Calculating the parameters on the basis of the cross table data.
- Summing up weight values for different parameters,or designing decision rules which are applied to the maps, and classifying the resulting scores in a small number of hazard classes.

Appropriate scale: Medium scale, although possible on the regional and the large scale as well.
The method is quite general to apply on a large scale, and on the regional scale the necessary landslide occurrence map is difficult to obtain

Evaluation: very useful
The weights are assigned in an objective way and each factor can be dealt with separately. The GIS is very suitable to apply this method which involves a large number of map crossings and attribute data manipulation.
- The importance of certain combinations of parameter classes can be tested quite easily.
- For creating the final summed weighting map one should take care not to include many parameters without clear relationships as they will obscure the final result.

Relevant literature:
Brabb, (1972,1984,1987), Radbruch-Hall (1979), Newman et al (1978), Mark, Newman and Brabb (1988), Lessing et al (1983), Choubey & Litoria (1990)

SUSCEPTIBILITY MAP BASED ON MAP CROSSING



C2: *MULTIVARIATE STATISTICAL ANALYSIS*

Introduction:

Multivariate statistical analyses of important causal natural factors for landslide occurrence may give a relative contribution of each of these factors to the degree of hazard within a defined land-unit. The analyses are based on the presence or no presence of stability phenomena within these units, which may be automatically defined catchments or interpreted geomorphological units.

Many methods have been proposed in the literature. Some of these, such as discriminant analysis or multiple regression, will require the use of external statistical packages connected to the GIS. Others, such as the information value method or the landslide probability method, can be treated within the GIS. For the numerous and repetitive calculations batch files are indispensable.

- Landslide probability mapping

This method is based on work done in the field of mineral exploration by Agterberg et al (1988,1990) and Chang et al (1990)

In this method, point phenomena (landslides) are regarded along with several underlying factors. These factors are treated as binary input maps. Weights are assigned to the binary maps using Bayes rules for conditional probability. These weights are added to the log of the odds of the prior probability, to give the log of the odds of the posterior probability. The final product is a predictor map giving the posterior probability of the point phenomena occurring for each pixel, which in turn is based upon the unique overlap of all input binary pattern maps (Moshe 1991)

- Information value method

Another rather simple and reliable statistical technique requires also a database of landscape factors which can be collected for different landunits. The analysis is based on the presence (1) or absence (0) of landslides on a certain site or within a land unit (Yin and Yan 1988). It can be used for both alpha-numerical and numerical data. It has to be decided for each land unit whether the variable is present or not present. The relative importance for the occurrence of landslides of each variable (Xi) is calculated in terms of an information value Ii, which is the log of the landslide density per parameter, as compared to the overall landslide density.

- Multiple regression

The most common statistical method is a correlation between landscape factors and landslide incidents by means of a multiple regression according to the following equation:

Y= bo + b1X1 + b2X2 + b3X3.......+ bmXm

where Y is the dependent variable meaning the presence (1) or absence (0) of a landslide and X1-Xm are the independent variables or the causal factors of the landslide occurrence.

- Discriminant analysis

A discriminant analysis is carried out for two groups (in this case stable areas and unstable areas). The analyses result in a discriminant function:

Ds=B0 + B1X1 + B2X2 + B3X3 +.....BnXn

where X are the values of the landslide factors and Bi the coefficients. The resulting Ds value for each landunit will indicate its hazard. The frequency distribution of stable and unstable landunits is used to check the result.

Input data:

All methods require a landslide distribution map (4) and a landunit map. On the regional scale this is a Terrain Mapping Unit map (1), on the medium and large scale these can be geomorphological units or subunits (2 or 3) or catchments (23).

Furthermore a large set of parameters is used, comparable to the list given in table 3. One approach, as used for example in the information value method, separates all the different classes of maps into individual parameters. This will result in a long list of parameters

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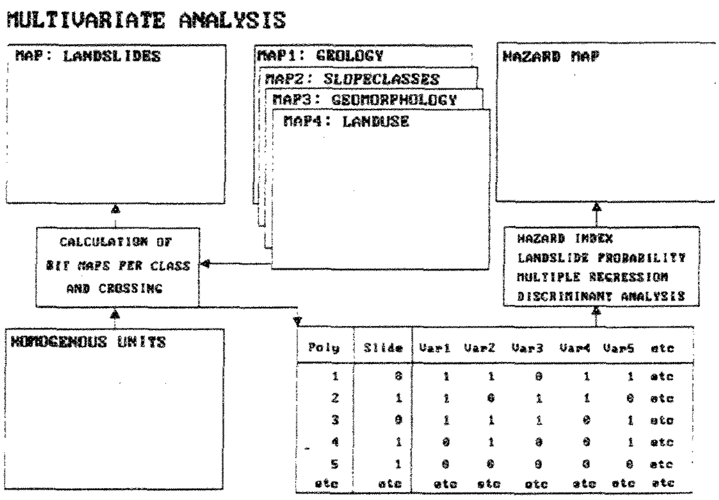
C2: *MULTIVARIATE STATISTICAL ANALYSIS continued*

<u>GIS techniques:</u>
- The first step is the determination of the list of factors that will be taken into account. As many input maps (such as geology) are alpha-numerical types, they will have to be converted in numerical values; either a 1 (presence) or a 0 (absence) for each parameter class (such as slope class, geological unit, etc). This may result in a large number of parameters.
- Crossing the landunits map with the landslide map and separating the stable and the unstable units in two groups.
- Crossing the landunits map with the bit maps for each parameter class, and storing the result in a large matrix.
- Exporting the matrix to an external statistical package for further treatment, or the calculation of the information value, or the probability based on the matrix data.
- For each landunit a total score is calculated. The frequency distribution of stable and instable classified units is checked to see whether the two groups are correctly separated.
- Classifying the score values in a few simple groups.

<u>Appropriate scale:</u> Medium
Although the techniques could be applied using datasets of different details, the use becomes quite restricted at the regional scale, where an accurate input map of landslide occurrences may be absent, and where most of the important parameters cannot be gathered in the field at a satisfactory accuracy.
At large scales different factors will have to be used (such as watertable, soil profiles). They are very difficult to obtain over a relatively small area.

<u>Evaluation:</u> Useful technique
- The method is objective and can be verified
- The GIS is extremely useful for the numerous map crossing and table joinings that have to be performed, especially when batch files are used. However, with PC-based GIS systems the large volume of data may become a problem.
- Most of the techniques require that the data are not interrelated which is an invalid assumption for data dealing with the earth surface.
- The "black box" model approach doesn't give insight in the physical background of the causative factors.

<u>Relevant literature:</u>
Carrara et al, (1974,1978,1982,1990), Neuland (1976), Davis (1986), Kobashi and Suzuki (1988), Mulder (1987,1991), Moshe (1991)



Poly	Slide	Var1	Var2	Var3	Var4	Var5	etc
1	0	1	1	0	1	1	etc
2	1	1	0	1	1	0	etc
3	0	1	1	1	0	1	etc
4	1	0	1	0	0	1	etc
5	1	0	0	0	0	0	etc
etc	etc	etc	etc	etc	etc	etc	etc

D1: *DETERMINISTIC MODELS AND GIS*

Introduction:
The methods described sofar do not give information on the degree of hazard in those areas where no landslides are present. Especially the areas on hazard maps that are mapped as potentially unstable should be tested using geotechnical models. These models need information on: the strength values of c and phi, the depth of potential sliding surfaces, the slope angle and the maximum pore pressure conditions on the slip surfaces.The GIS can be used in the following ways:
- Using the infinite slope model directly in the GIS. The model calculates the safety factor for each pixel.
- From the GIS maps a number of profiles are selected semi-automatically and are exported to external slope stability models, working with circular slip surfaces.
- From the GIS maps data is gathered along a predefined grid, and exported to external 3-dimensional slope stability models.

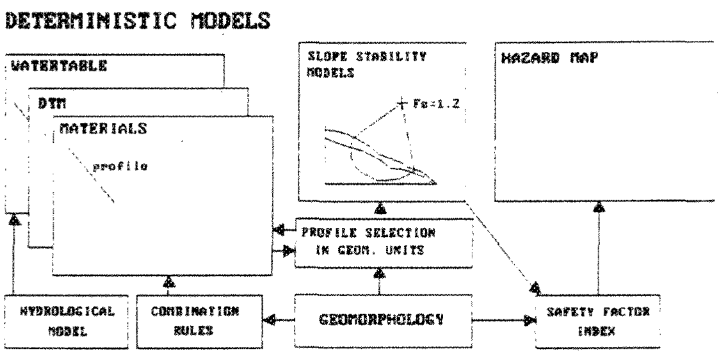
Input data:
- Material sequences (14) characterized by values for C and phi, which are obtained from backanalysis, or laboratory analysis
- A detailed slope angle map, derived from very detailed DTM's (7)
- Potential watertable (25) surfaces are obtained from hydrological models.

GIS techniques:
- Creating a material map from the combination of geomorphological units, lithological units, slope angles and field observations.
- Applying groundwater models for representative profiles within geomorphological units, and extrapolating these over the whole terrain, based on parameters such as slope angle, length and concavity
- Selecting profiles from the input data, and exporting them to external models in which the safety factor is calculated for various potential slip surfaces.
- The results of the calculations are used to characterize the geomorphological units.

Appropriate scale: Large
On the regional and the medium scale the detail of the input data, especially concerning groundwater, soilprofile and geotechnical descriptions are insufficient. Even on large scale the method can only be used as an indication.

Evaluation: Useful
The variability of the input data can be used to calculate the probability of failure for those landunits where other techniques do not give clear results.
The resulting safety factors should never be used as absolute values. They are only indicative and can be used to test different scenarios of slip surface and groundwater depths.

Relevant literature:
Van Asch et al (1991), Mulder (1991), Wagner et al (1988)



E1: *LANDSLIDE FREQUENCY*

Introduction:
All methods treated sofar do not result in real hazard maps, when the definition of Varnes (1984) is taken into account. The probability of occurrence on a certain place within a certain time period is only possible when a relation can be found between the occurrence of landslides and the frequency of triggering factors, such as rainfall or earthquakes.
Landslide frequency can be assessed by the following techniques:
- using antecedent rainfall indexes, which is a statistical relation between the dates of landslides and the accumulated amount of rainfall over the period preceding the failure.
- using hydrological models to calculate critical values of groundwater levels or depths of wetting fronts.

Input data:
- Meteorological records: daily rainfall, temperature, evapotranspiration.
- Landslide records taken from insurance companies, newspapers or fire/resque departments

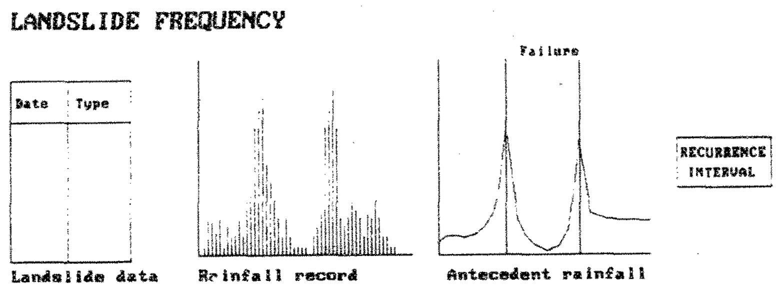
GIS techniques:
- Calculating antecedent rainfall values
- Correlating these with landslide events and identify certain threshold values, for which the return period is calculated.

Appropriate scale: Large scale
On a regional scale it may be difficult to correlate known landslides in one place with existing rainfall records from a different part of the area.

Evaluation: Moderate
- The spatial part of the GIS is hardly used in this technique.
- It is often very difficult to obtain reliable landslide records. If landslide records are available from newspapers, firebrigade or insurance records, these data mostly refer to occurrences within cities which have caused damage. Most of the landslides which have not caused damage, are unknown, whilst in a populated area there may be many more triggering factors than just rainfall.

Relevant literature:
- Crozier 1986, Neary & Swift (1987), Wieczorek (1987), Capecchi & Focardi (1988)

Schematic representation of the technique:



Discussion and conclusions

The various techniques presented in this paper are intended as tools for a more objective method for hazard zoning. They do, by no means, substitute for detailed field knowledge on the observed factors for landslide occurrence.
Qualitative approaches of hazard analysis can be applied on all three scales, although it is most suitable for the medium and regional scale. However the full capabilies of GIS are not optimally used with qualitative methods, and it is merely utilized for data storage, updating and output.
The use of statistical methods in landslide hazard analysis in principle is possible on all three scales. With increasing scales of analysis the parameters that determine the distribution of landslides will loose their meaning, or will have to be sampled at a much higher detail. On the regional scale it is important to find a relation with lithological units, but on the large scale the detailed soil profiles are becoming much more important. Also the units that are used to sample the parameters are different on the regional and the larger scales. On the regional scale these will be the Terrain Mapping Units, while on the medium and large scale the detailed geomorphological elements should be used.
The use of deterministic models in hazard analyses is only possible on a large scale. It does not aim at calculating in an absolute way the safety factor at each site in the terrain. This is not realistic because the amount of data necessary to assess the exact spatial distribution of the parameters is insufficient in most cases. They are used as indexes to characterize geomorphological units.
Finally an overview is given of the various methods in table 5.

Method - = poor 0 = moderate + = good < = small > = large	REGIONAL	MEDIUM	LARGE	INPUT	EXTERNAL	STORAGE	ANALYSIS	GIS USE
Landslide occurrence	0	+	+	0	-	+	-	0
Landslide density	0	+	+	0	-	+	+	+
Landslide activity	-	+	+	0	-	+	0	+
Qualitative hazard	+	+	+	>	-	+	0	0
Simple map crossing	0	+	0	>	-	+	+	+
Multivariate analysis	0	+	0	>	+	+	+	+
Deterministic models	-	-	+	<	+	+	+	+
Landslide frequency	-	+	+	<	0	-	0	0

Table 5: Summary of GIS based techniques for hazard assessment on three different scales. Indicated are the usefullness on three scales, the need for external software, the importnace of using GIS for data input, storage, analysis and output, and the overall applicability.

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