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Remote sensing and GIS technology in landslide hazard mapping in the Colombian Andes

Methods of mapping zones that are susceptible to landslides have been based in the past upon interpretation of aerial photographs in combination with field surveys. Prior to the launching of the United States' Landsat satellite and, especially, France's SPOT satellite, remote sensing was used very little for landslide susceptibility mapping as its characteristics have been unsuitable until now.

The Geological Application of Remote Sensing project in the Chicamocha valley of Colombia demonstrates the use of remote sensing in mapping the zones that are susceptible to landslides. The mapping is based on the interpretation of a hybrid SPOT and Landsat stereopair, calculation of a digital elevation model from the remotely sensed data, production of quantitative geomorphologic information, and digital classification of the types of land use. Finally, the various map files—geomorphology (slope, exposure, and drainage), lithology, land use, and faults—are combined by the use of a geographic information system in order to produce the final product.

This experiment shows that, provided stereoscopy can be obtained, remote sensing from space forms a complement to field surveys and is a highly effective tool for this type of mapping at scales ranging from 1:25,000 to 1:50,000.

Introduction

Among natural hazards, landslides present a major danger for most Latin American countries, especially in areas of the Andes where the risk is increased by human settlement. Research is being conducted in order to improve the methods of mapping the areas that are vulnerable to landslides, and current approaches are based on geological and structural studies, geomorphology, and modeling.

Aerial photographs, because of their excellent spatial resolution and stereoscopic capacity, have been regarded as an extremely important tool that is complementary to field surveys in compiling landslide inventories. However, they are often old, and for economic or administrative reasons, new photography is not feasible everywhere. In addition, although aerial photographs are a valuable statement of previous conditions, they tend to be somewhat ineffective for

identifying and mapping susceptible areas on a regional scale. This is due to their analogic character and to the fact that the photographs provide limited access to the large variety of triggering factors.

Given this situation, we have studied a new approach to mapping landslides that is based upon available satellite products. By using digital images provided by the French SPOT satellite's High Resolution Visible (HRV) instrument, we first applied this method in the area of La Paz, western Bolivia (Scanvic, 1990), which was surveyed earlier in great detail in 1976. After this first application, we realized the need to improve the method, and a second experiment was initiated in a similar Andean area in Colombia. This study is being carried out under the auspices of the Geological Application of Remote Sensing (GARS) project. It is sponsored internationally by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and by the International Union of Geological Sciences (IUGS) with the participation of the French Centre National d'Etudes Spatiales (CNES), the French Bureau de Recherches Géologiques et Minières (BRGM), the French UPCM, the Colombian Instituto de Investigaciones en Geociencias, Minería y Química (INGEOMINAS), and the Netherlands International Institute for Aerial Survey and Earth Sciences (ITC).

The GARS project

The GARS project in Colombia is conducting landslide susceptibility mapping in the upper Rio Chicamocha valley. The area includes a considerable number of large landslides, particularly debris flows, some of which are active today. These threaten the town of Paz del Rio and the railway line that transports coal and iron from the mines to be used in the manufacturing of steel in Belencito. In a preliminary study (see Guillaude and others, 1991), the method used a digital elevation model that was compiled from topographical maps, field observations, and field mapping.

In the second phase, new developments in BRGM have made it possible to carry out the landslide susceptibility mapping by using a geographic information system (GIS) that is based only on remote sensing data. The GIS operates by means of specific raster-mode software, Synergis, that was developed by BRGM. The sequence of processes enabling the assessment and mapping of potentially hazardous zones is as follows:

- (1) Acquisition of remote sensing data. Because of weather problems, only one image of the stereo SPOT XS pair (right view) has been acquired. A Landsat Thematic Mapper (TM) vertical image (left view) of 30-m resolution has been substituted for the second image of the SPOT pair.
- (2) Calculation of a digital elevation model from combined SPOT and Landsat data. The model has an accuracy of 40 m in the X and Y axes and 20 m in Z.
- (3) Data processing and color-composite restitution at a scale of 1:50,000.
- (4) Visual interpretation. Lithology, faults, landslides, and head scarps of debris flows are extracted from the landscape and are restored by stereoscopy.

All this information has been digitized, geocoded, and, when necessary, transformed into raster mode. The Chicamocha valley is underlain by north-south-striking, generally well exposed sedimentary rocks, and the lithological map based on remote sensing is of better quality than the previous map that was based on field observations. The fault pattern appears to be more complex than expected, particularly with respect to the east-west fractures, which are represented poorly on existing documents but are a normal consequence of the compression of the Nazca plate. For convenience, the fault map was transformed into fault density in raster mode.

Particular attention has been paid to mapping the head scarps of debris flows, as these are considered to be indicators of ground instability and can be used in determining, by the use of statistical methods, the critical conditions of the various permanent hazard factors. Digital classification of the SPOT image has distinguished seven classes of land use, four for vegetation and three for bare soil and human settlements. By applying three-dimensional software to the SPOT and Landsat digital elevation model, we have produced maps that provide basic quantitative geomorphologic information, that is, slope, exposure, and drainage, the last of these being transformed into drainage density in raster mode. Lastly, panoramic views have been created by combining the digital elevation model and the corresponding SPOT orthoimage. Processing is based on a specific software, Vue 3D, developed in France by ISTAR. This software makes it possible to select the different parameters such as azimuth, look direction, and altitude, for example.

Statistical analysis

At this stage, the five raster-mode files that correspond to the permanent hazard factors (lithology, slope, land use, faults, and drainage) were put into the Synergis GIS data base, and an analysis was performed by using these multiple variables. First, head scarps of debris flows were transformed into a surface by giving the same thickness of one pixel to each observed feature. These were then used to pilot a statistical method that determined separately, for each of the hazard factors, the critical conditions of relative landslide susceptibility. The statistical results show that the most effective parameters are lithology, slope, and land use. According to the results, the image pixels were characterized next in terms of the landslide susceptibility value for each of the five hazard factors, the sum making it possible to map the total relative susceptibility (see figure).

This method allows us to combine the different factors easily into a GIS and to compare each one directly with all the others. It is possible, for instance, to classify each factor as a function of its respective susceptibility independently from the group. For example, the susceptibility of one lithologic unit can be compared to the susceptibility of a certain slope class, and their relative weight in landslide dynamics can be calculated. This method has been applied systematically to single pixels, and the susceptibility map was drawn. This map is, naturally, adjusted to known landslides; susceptibility is defined on the basis of head-scarp criteria; and its purpose is prediction. If we assume that the same phenomena produce the same results, susceptibility mapping delineates potentially unstable zones that are not yet disturbed by landslides. Such mapping can be regarded as a land-monitoring document, particularly in terms of planning for possible hazards.

Conclusions

Although improvement is still possible in the methods of evaluating the weight of certain factors such as faults and drainage, the objectives of the project have been reached for the Chicamocha valley test site. We have demonstrated that the processing and interpretation of remote sensing data make it possible to map landslide hazards at scales that range from 1:25,000 to 1:50,000. In order to do this, a stereopair of images is vital, but only limited field control is necessary.

The document resulting from this initial study has been assessed by comparison with published maps and by field control in selected areas. This assessment has shown the validity of this type of mapping in the conditions of the Andean region.

On the basis of these results, a similar method of mapping has been applied with success in northwestern Taiwan. In addition, the assessment of radar capacity for improving landslide identification and mapping is planned.

References

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LANDSLIDE SUSCEPTIBILITY MAP Paz del Rio (Colombia)

Location map

- Very high susceptibility
- High susceptibility
- Medium susceptibility
- Low susceptibility
- Very low susceptibility
- Contour lines and elevation
- Tasco Town, village
- X=1'130.000 Geographic coordinate

*Map computed
by BRGM*

Landslide susceptibility in the vicinity of Paz del Rio, Colombia.

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Dr. Olivier Rouzeau has worked in the Remote Sensing Department of the French Bureau de Recherches Géologiques et Minières (BRGM) since 1986. A geologist and image processing and GIS specialist, he dedicates most of his work to the development of new methodologies for environmental studies (hazard maps, erosion maps).

Dr. Jean-Yves Scanvic is a geologist and the deputy to the head of the Remote Sensing Department of BGRM. He participated early in the development of earth resources satellite applications in 1968 with the French Spatial Agency (CNES). He is the author of a book in French on the geological applications of remote sensing.

Dr. C.C. Weber is a past Secretary General of the International Union of Geological Sciences (IUGS), and as such, he coordinated the activities of numerous multinational scientific commissions. In particular from 1980 to 1984, he presented to UNESCO the International Geological Correlation Programmes, many of which have an environmental component such as sea-level variations. He is Chairman of the IUGS-UNESCO program on the geological applications of remote sensing. In addition, Dr. Weber has lectured at the universities of Rennes and Paris VI and has published 97 papers and books, most of which have appeared in international scientific publications.

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