PREDICTING REGIONAL LANDSLIDE HAZARD

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KEY WORDS: Landslide hazard, multivariate models, numerical cartography, basin geomorphometry.

Regional landslide hazard evaluation has been attempted by research institutions and government agencies for a long time. To achieve this goal, many techniques have been proposed or tested; however, at present there is no agreement on these methods. Despite the conflicting views, all the approaches are founded upon a single conceptual model: slope-failures in the future will be more likely to occur in those geological, geomorphological and climatic conditions which led to past and present instability. Clearly, it is not easy to detect and map these instability conditions and build up reliable models to forecast future landslide occurrence in space and time.

The identification and mapping of past and present landslide bodies constitute a preliminary fundamental step of each approach for predicting future slope-failures. The experience gained from hundreds of surveys carried out in different parts of the word (VARNES et al., 1984; BRABB, 1984) has demonstrated that trained investigators can successfully detect and map most of the landslides occurring in an area. However, old, dormant landslide bodies reshaped by subsequent erosional processes and landslide areas intensively modified by farming activity or covered by dense vegetation, cannot easily be identified and classified. This introduces a factor of uncertainty that cannot be readily incorporated in the subsequent phases of the analysis (CARRARA et al., 1992). Despite this severe limitation, inventory maps remain very useful for a preliminary assessment of the actual instability conditions of a region.

Of the factors that play an important role in generating slope-failures, only few can be cost-effectively acquired, mapped and used in landslide assessment (VARNES et al., 1984). Morphological factors, such as slope geometry and basin/subbasin characteristics, provide fundamental information on landslide form and processes. However, their acquisition over wide areas by traditional techniques is very time-consuming and generally inaccurate. Rock composition, texture, structure, degree of weathering, fracture density/orientation, bedding attitude and stratigraphic setting, are all major determinants of the mechanical characteristics of the slope-forming materials and, consequently, largely control landslide typology and activity. Likewise, the past and present geodynamic history, among which the degree of seismicity, exert a significant role on landslide processes. Unfortunately, in many landslide assessment projects, rock-unit properties and classification are simply derived by aggregating stratigraphic formations depicted on existing old, locally inaccurate, geological maps. Conversely, rock-units should be defined on the basis of their geomechanical behaviour. Hence, the need for field and laboratory surveys aimed at collecting simple but relevant physical characteristics of each rock type.

When landslide and instability factor data are acquired, the region under investigation has to be partitioned into terrain-units, namely, those spatially homogeneous domains to which all land characteristics and landslide occurrence are referred for the subsequent analyses. In hazard assessment, geomorphological units, grid-cells, unique condition units and slope units are the most relevant appraisals to region subdivision. The first is derived from the well-known land-system/land-unit approach to resources evaluation whose main drawback lies in its intrinsic subjectivity. The second, that has found wide application among raster-based GIS users, is the easiest technique to implement and use but face unmanageable problems of data analysis as the grid-cell number increases beyond a certain threshold value. The third, which fully exploits the most basic GIS function, that is, map overlay, is readily obtained by the subsequent intersection of all the input information layers (CHUNG et al., 1995); the approach, however, needs a carefully-designed classification and reduction of the input data. The fourth, which can be automatically derived from high-quality DTMs (CARRARA, 1988), is the most geomorphologically meaningful but quite complex to apply. It is worth noting that hazard models and terrain-units are conceptually and operationally interrelated; hence, in several cases the choice of a hazard prediction method is the consequence of the type of terrain-unit selected.

Landslide predictive models can be built up through direct or indirect methods. The first essentially consists in the geomorphological mapping; the second includes both the index (heuristic) and the statistical procedures. Each method incorporates significant advantages and drawbacks. The geomorphological mapping is relatively fast and cost-effective but is fully dependent on the experience of the surveyor. The index method is based on a priori knowledge of the causes of landsliding in the area under investigation. Clearly, its reliability is directly dependent on how well and how much the acting geomorphological processes are known. Since in most cases the corpus of know-

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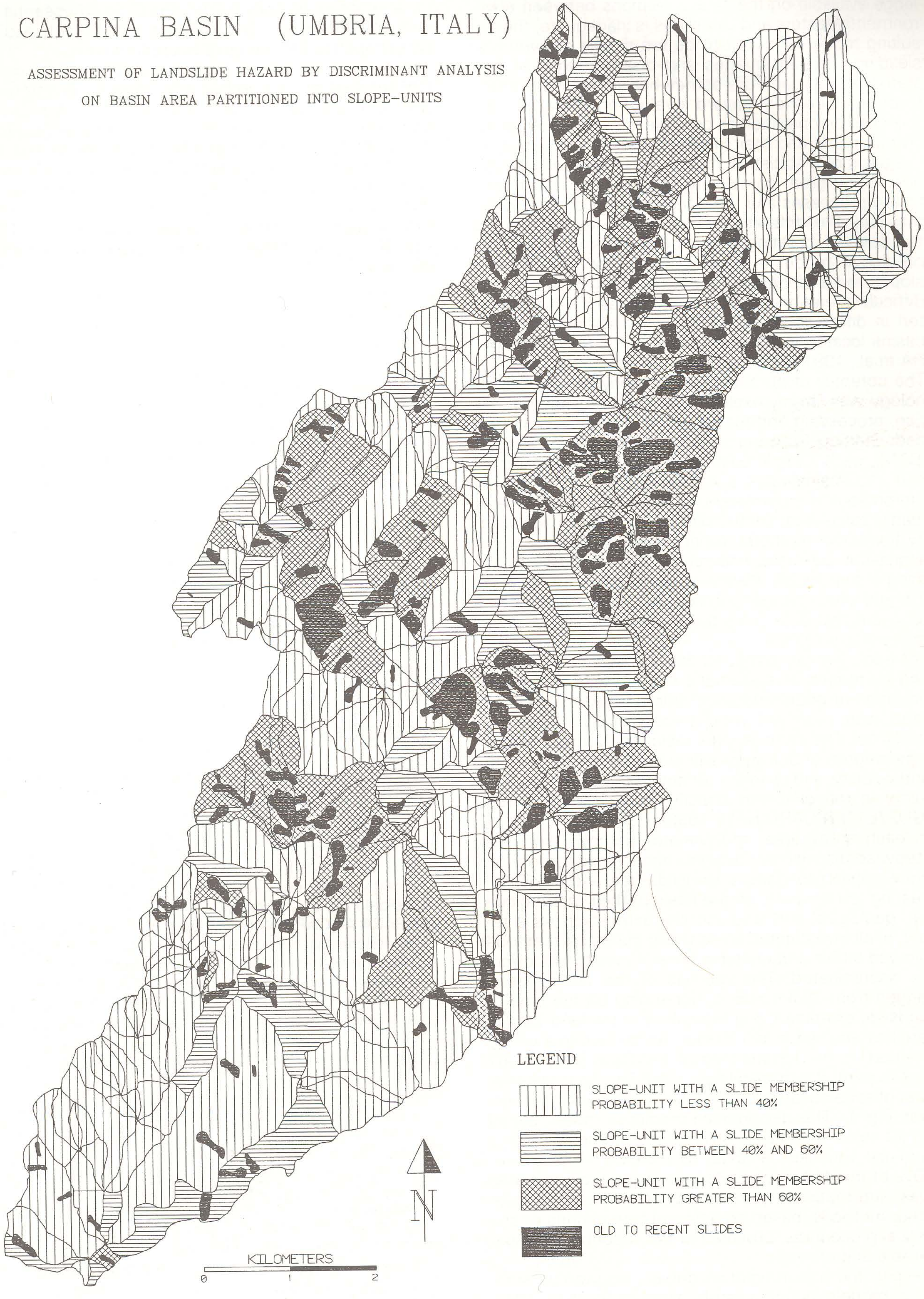

Fig. 1. Carpina basin (Umbria, Central Italy). Slide hazard map derived from a discriminant predictive model applied to the basin area partitioned into 414 slope-units.

ledge available on the causal relations between environmental factors and landslides is inadequate, the resulting model turns out to be too simple or even misleading. The advantages and disadvantages of the statistical approach are somewhat similar, with a difference: landslide hazard evaluation becomes as objective an operation as possible, since the instability determinants and their interrelations are evaluated on the basis of a statistical multivariate model. However, due to the great complexity of identifying the slope-failure processes and the difficulty in collecting systematically the different factors related to landsliding, the task of creating a geological-geomorphological predictive model enabling actual/potential unstable slopes to be identified over large areas, may well be difficult operationally. This is what has been attempted in different small (50-200 km^2) sample drainage basins located in Southern and Central Italy (CARRARA et al., 1991, 1995).

The potential of numerical cartography and GIS technology was largely exploited for the efficient acquisition, processing and manipulation of all the data needed. Starting from high-fidelity digital terrain models (DTM), each sample basin was automatically partitioned into main-slopes (CARRARA, 1988). The major morphological parameters of each slope-unit were readily calculated; some correspond to those acquired by traditional methods, others are unique since their acquisition by manual techniques is too time-consuming or impossible. Hence, all these parameters were merged with relevant lithological, structural and hydrogeological data collected in the field or by aerial photo-interpretation.

For each sample basin, landslide maps were produced by means of systematic field surveys and interpretation of photos flown in different years. A simple form was designed which was compiled for each landslide. The form entries included: landslide typology, degree of activity, relative age, estimated depth and velocity, and an index reflecting the degree of certainty in mapping and classifying each slope-failure (GUZZETTI & CARDINALI, 1990).

In each study area, multivariate methods, such as stepwise discriminant analysis and logistic regression were applied to classify landslide-free and landslide-bearing terrain-units, on the basis of their morphological, geological and land-use characteristics. As a result, in all investigated areas these statistical methods allowed stable and unstable terrain-units to be correctly discriminated. The success of the classification ranged from 75% to 85%, depending on the type of landslide examined, and the quality of the land characteristics entered in the model. As an example of the method, in the hazard map of the Carpina basin (67 km^2 in size), the probabilities, grouped into three classes, of slide occurrence are displayed for each terrain-unit (Fig. 1). This discriminant predictive model, based on 20 input lithological, structural, morphological and land-use variables, enabled to correctly classify over 80% of the 414 slope-units into which the basin area was automatically partitioned. A comparison with other methods, based on different terrain-units or statistical procedures, proved that this model is the most reliable and efficient.

Despite the high prediction power, multivariate statistical models require a careful strategy for data collection, manipulation and analysis: relevant instability factors can be single out only through a experimental design based on a clear knowledge of both the input data characteristics and the basic properties of the statistical method applied. Furthermore, being essentially data-driven, these functional methods cannot readily be extrapolated to the neighbouring regions.

The experience gained from the application of both GIS technology and multivariate models, in different pilot drainage basins, indicates that this approach, although not lacking limitations, is the most feasible and cost-effective for evaluating the landslide hazard on a regional scale. Within the framework of the activities of the Italian National Group for Hydrogeological Protection (GNDCI), a long-term project attempting to extend such a procedure to a very wide region, 4100 km^2 in size, the Upper Tiber basin area, was recently initiated.

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