DIGITAL ELEVATION MODELS FOR LANDSLIDE SUSCEPTIBILITY MAPS

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ABSTRACT

The economic impact of landslides is greater than commonly recognized. The need for methodologies and techniques for reducing landslide hazards is growing everywhere and in particular in the developed countries.

In this paper we present the results of an experiment intendend to use the information on the landslide distribution, obtained from the interpretation of aerial photographs, combined with the slope-angle information, derived from a digital elevation model, to prepare simple but cost-effective landslide susceptibility maps.

INTRODUCTION

In many countries of the world the economic losses and casualties due to landslides are greater than commonly recognized (1,2,3). The development of methods and techniques to assess the degree of landslides susceptibility is therefore an important challenge for the earth scientists.

The recent development of hardware and software packages to conveniently analyze geographic and geologic data (4), combined with the availability of digital elevation models (DEMs) of acceptable quality, have made possible the realization of statistical multivariate models for the realization of landslide susceptibility and risk maps (5,6).

Statistical models are difficult to prepare because a large number of variables must be collected and converted in digital format (5,7), making the production of models very expensive and feasible only for small areas. Few experiments have been carried out to test the possibility to prepare statistical models for large areas at small scales, using only few basic variables (i.e. slope or lithology) with encouraging results (8).

The purpose of this work is to explore the possibility of using slope-angle, which is one of many parameters that can be easily and quickly computed from DEMs, as a predictor of landslide-prone terrains for small areas at large scales.

THE LANDSLIDE INVENTORY

The study area that we have selected for this experiment is located in Central Italy, near the town of Gualdo Tadino. The area is underlined by 3 different lithologic complexes: an alternance of sandstones and shales of the Marnoso-Arenacea Formation (upper Paleocene--upper Miocene) (31.3%), the thinly bedded limestones and marls of the Umbria-Marche stratigraphic sequence (Lias-lower Paleocene) (46.5%) and quaternary alluvial deposits (22.2%).

For the 188 km^2 study-area we have prepared, as a part of a larger project, a landslide inventory map at 1:25.000 scale. The map reports the location of 178 landslide deposits that were identified on black and white aerial-photographs flown in 1954 at 1.33.000 scale.

Landslide deposits are not distributed homogeneously in space. They are more abundant (up to 8 landslides/km^2) in the area of outcrop of the Marnoso-Arenacea Formation and less abundant in the area underlined by limestones and marls. No landslides were found in the alluvial deposits.

The boundaries of the landslide-deposits on the inventory map were digitized and successively transformed to a raster mesh with grid cells of 100 meters spacing. 848 cells (4.5%) were classified as landslide cells.

THE SLOPE MAP

It has long been known that slope angle is the dominant characteristic of the earth surface geometry and that mean slope is the most significant attribute of topography (9). Degree of slope was considered by many Authors (5,7,8,10) as one of the principal factors controlling the spatial distribution of landslides. In order to examine the importance of slope-angle in the study area a slope map was generated from a DEM made available by the Regione dell'Umbria.

The original DEM, generated as a by-product of the production of orthophoto-maps at 1:10.000 scale, consisted of 5756 elevation points located on a triangular grid with about 200 meters spacing. These data, considered as scattered elevation points, were re-gridded, using a commercial computer program, to a square-grid of 18824 elevation values, spaced every 100 meters.

Slope angle was calculated iteratively fitting a quadratic equation to a 3 by 3 window of elevation data and the computed value was assigned to the central point of each window (11). Figure 1 shows the frequency distribution of slope-angles. The distribution is right-skewed, like most of the slope distributions on Earth, and shows larger frequencies in the range 0-30%, with maximum at 5%.

The map produced is not strictly a slope map because the mathematical model produces slope values that probably do not represent the actual slope on the topographic surface. For the purpose of this work we have assumed that the calculated slope correlates wel with actual slopes for a substantial number of grid cells, but the value of slope for any single cell may be different (8).

THE MODEL

In order to estimate how well we can map landslide-prone terrains using the slope-angle information we performed a logistic regression analysis. This kind of regression estimates the effect of an independent variable on a dichotomous dependent variable (12). In our case the independent variable was slope-angle and the dependent variable the occurrence of a landslide deposit in any single cell of the model.

We have experimented with polynomial of slope-angle of power from 2 to 4 and the results are summarized in Figure 2. The probability values for the 3 models are low (less than 9%) indicating that slope-value alone is not sufficient to explain all landslide occurrences. The 4^{th} order model was used to prepare a landslide probability map, re-coding each grid cell of the slope map according to the correspondent probability value. The quality of this probability map was checked against the original data-base of landslide-deposists, counting the number of landslide cells that fell in each category of the probability map. We found that more than 80% of the landslide-deposits fell on cells of 5% or higher probability and that only 1.8% of the landslide-deposits fell on cells with probability less than 3%.

The probability map is particularly good in the area of outcrop of the Marnoso-Arenacea Formation and less good in the area underlained by limestones and marls. This evidence, due to the fact that landslide-deposits are more abundant in the Marnoso-Arenacea Formation, supports the well known idea that lithology is an important factor in the explanation of landslides distribution, and that it can greatly improve the quality of the regression model (5).

FINAL REMARKS

Slope maps, quickly and cheaply derived from DEMs by computer, can be used to prepare landslide probability maps. In order to consider these probability maps as susceptibility maps the following assumptions must be made:

- the computed slopes well correlate with the actual slopes;
- the landslide distribution reflects the actual distribution of landslides on earth;
- landslides should be the result of common effects (rain, earthquake etc.) that are expected to remain constant in the time-period for which the model is prepared. Paleo-landslides formed in different climatic and morphologic conditions, as well as landslides triggered by unusual or uncommon events, should not be used in the preparation of landslide probability models.

REFERENCES

1. Fleming, R.W. and Taylor, F.A., "Estimating the costs of landslide damage in the United States", U.S. Geological Survey Circular, no. 832, 1980, pp. 21.
2. U.S. Geological Survey, "Goals and tasks of the landslide part of a ground-failure hazards reduction program", U.S. Geological Survey Circular, no. 880, 1982, pp. 49.
3. Schuster, R.L. and Fleming, R.W., "Economic losses and fatalities due to landslides", Bull. Assoc. Engineering Geology, Vol. 23, no. 1, 1986, p. 11-28.
4. Burrought, P.A., "Principles of geographical information systems for land resources assessment", second ed., Claredon Press, Oxford, 1987, pp. 193.
5. Carrara, A., "Multivariate models for landslide hazard evaluation", Mathematical Geology, Vol. 15, no. 3, 1983, p. 403-426.
6. Bernknopf, R.L., Campbell, R.H., Brookshire, D.S., and Shapiro, C.D., "A probabilistic approach to landslide hazard mapping in Cincinnati, Ohio, with applications for economic evaluation", Bull. Ass. Engineer. Geol., Vol. 25, no. 1, p. 39-56.
7. Carrara, A., Agnesi, V., Macaluso, T., Monteleone, S., Pipitone, G., Reali, C., and Sorriso-Valvo, M., "Modelli geomatematici per la valutazione della pericolosità connessa ai fenomeni di instabilità dei versanti", Geologia Applicata e Idrogeologia, Bari, Italy, Vol. 20, no. 2, 1985, p. 63-91, in italian.
8. Brabb, E.E., Guzzetti, F., Mark, R. and Simpson, R.W. Jr., "The extent of landsliding in northern New Mexico and similar semi-arid regions", Landslides in a semi-arid environment: studies from the inland valleys of southern California, Sadlers and Morton Eds., Inland Geological Society Pub., 1989.
9. Pike, R.J., "The geometric signature: quantifying landslide-terrain types from digital elevation models", Mathematical Geology, Vol. 20, no. 5, 1988, p. 491-511.
10. Campbell, R.H., "Debris flows originating from soil slips during rainstorms in southern California", Quart. Jour. Engineering Geology, Vol. 7, 1974, p. 339-349.
11. Thorne, C.R., Zevenbergen, L.W., Burt, T.P. and Butcher D.P., "Terrain analysis for quantitative description of zero-order basins", Erosion and Sedimentation in the Pacific Rim. IAHS Pub. no. 165, Corvallis, August, 1987, p. 121-130.
12. SPSS, Inc., "SPSSx User's guide edition 2". SPSS. Chicago, 1986, p. 602-619.

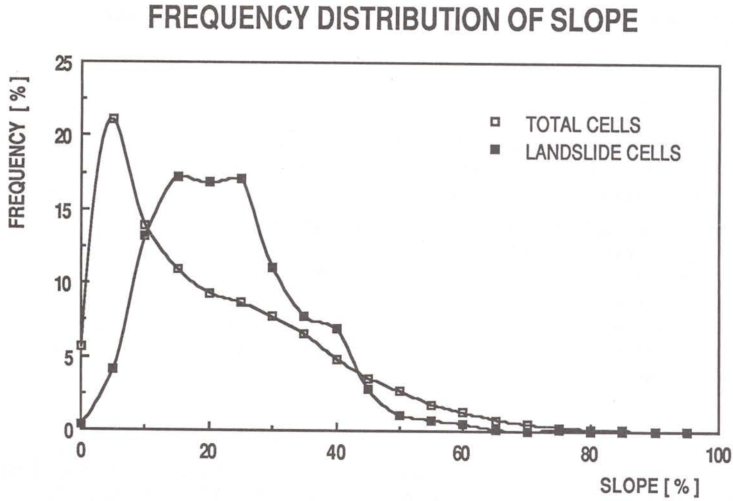

Figure 1. Frequency distribution of slope. Open squares: frequency distribution for the entire population of cells (18824 cells). Black sqaures: frequency distribution for landslide cells (848 cells, 4.5% of the entire population).

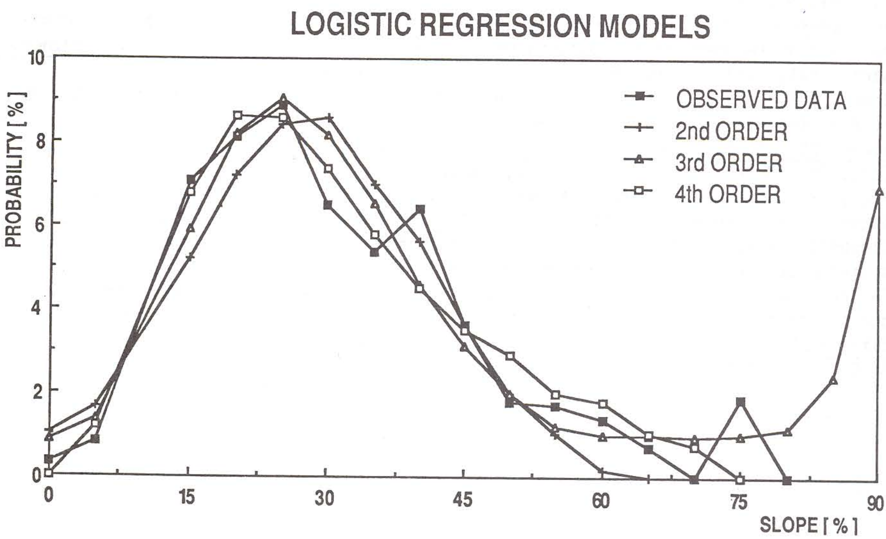

Figure 2. Logistic regression models for slope and landslide deposits in the Gualdo Tadino area of central Italy.