GEOGRAPHIC INFORMATION TECHNOLOGY TO ASSESS LANDSLIDE HAZARD IN REGIONAL ENVIRONMENTAL PLANNING

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The Geological Survey of the Lombardia Region has promoted a research initiative aimed at mapping landslides and the associated hazard in four areas of the Region (Fig. 1, Tab. 1). The aim of the project is twofold: to prepare detailed landslide inventory maps; and to assess landslide hazard at the basin scale. Landslide inventory maps were prepared through the interpretation of aerial photographs of different types (colour, black & white), scale and vintages. Limited field surveys were carried out to test the reliability of the interpretation. In producing the inventory maps, all the available information on pre-existing studies on mass-movement and technical investigations carried out at specific sites was collected and carefully evaluated. For two of the study areas (Staffora basin and Lecco Mountains) historical information on landslide events occurred in the 20th century was also acquired.

For each study area thematic maps, including rock type, structural setting and land use (Tab. 2) were prepared by compiling or processing existing maps and data. Digital terrain models (DTM) with a ground resolution of 20x20 m were prepared by interpolating contour lines digitised from the 1:10,000 scale regional technical maps. For the Seriana valley area, a DTM is currently being prepared using photogrammetric techniques and high-altitude photography. All thematic information, including DTM data, was stored into a widely-used GIS for further processing and analysis.

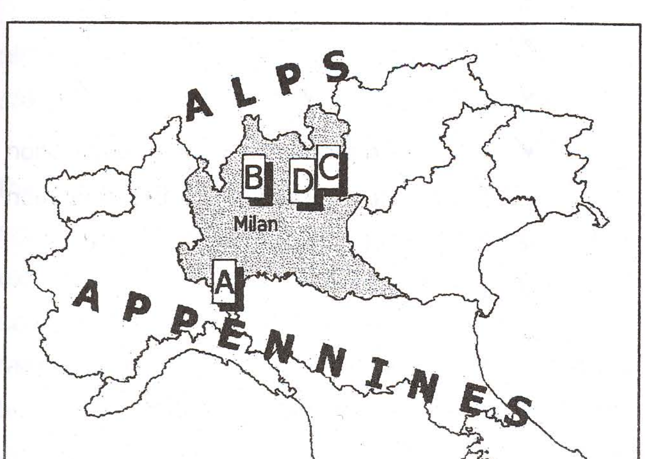

Fig. 1. Location of the study areas:
A = Staffora basin
B = Lecco Mountains
C = Camonica Valley
D = Seriana Valley

Table 1 – Physiographic and geological settings of the study areas.
Symbols:. ✓ = present, ✓✓ = abundant.

	Staffora basin	Lecco Mountains	Camonica Valley	Seriana Valley
Physiography	Apennines	Alps	Alps	Alps
Area extent	300 km^2	730 km^2	1480 km^2	270 km^2
Elevation range	150 – 1500 m	200 – 2600 m	400 – 3500 m	600 – 3000 m
Rock types				
Clay	✓✓			
Marl	✓✓	✓	✓	✓
Sandstone	✓			
Limestone		✓✓	✓✓	✓✓
Metamorphic		✓	✓✓	✓
Shallow failures				
Soil slip	✓✓	✓✓	✓✓	✓✓
Debris flow	✓	✓✓	✓✓	✓✓
Debris avalanche		✓✓	✓✓	✓✓
Rock fall	✓	✓✓	✓✓	✓✓
Rock slide		✓	✓	✓
Deep failures				
Slide	✓✓	✓	✓	✓
Earth flow	✓✓			
Complex	✓✓	✓	✓	✓

Table 2 – Themes for hazard assessment. Symbol: ✓ = task completed.

Theme	Staffora basin	Lecco Mountains	Camonica Valley	Seriana valley
DTM	20x20 m grid from contour interpolation	20x20 m grid from contour interpolation	20x20 m grid from contour interpolation	in preparation by digital photogrammetry
Terrain subdivision	✓	✓	✓	✓
Terrain morphometry	✓	✓	✓	✓
Landslide map	✓	✓	✓	✓
Lithological map	✓	✓	in preparation	in preparation
Structural map	✓	✓	in preparation	in preparation
Land use map	✓	✓	in preparation	✓
Historical data	✓	✓		
Hazard map	✓	✓		

The assessment of landslide hazard in the Staffora basin

For the Staffora basin a predictive model of landslide occurrence was developed. To accomplish this task, the basin area was automatically partitioned into main slope-units (i.e. right/left sides of elementary sub-basins) through a specifically-designed software module which, starting from a high-quality DTM, generates fully connected and complementary drainage and divide networks, and a wide spectrum of morphometric parameters of channels and slopes. Main slope units were then subdivided according to the main rock types cropping out in the basin. In this way, the study basin resulted partitioned into 2245 *terrain-units*. Forty geological-morphological factors were selected, by a stepwise procedure, as *predictors*, and the presence/absence of landslide deposits within each terrain-unit as *predicted* (dependent) variable of a discriminant function. The outcomes of the analysis indicate that such a mix of environmental factors is capable of predicting, with a reliability of the 77%, which terrain units are affected by or free of landslide deposits (Fig. 2). This model, which can be called *geomorphological*, is essentially founded upon the data provided by of the landslide inventory map and the other environmental maps.

Among many public administrators, natural catastrophes, such as landslides, are primarily evaluated on the basis of historical records which can fairly accurately dates slope-failure events, but in general allow for detecting not the landslide itself, but the damage produced.

Owing to the substantial difference in the structure and spatial frequency of these two types of information, their directed comparison constitutes a difficult or impossible task. However, the comparison can be much better performed between the statistical models that predict landslide deposits (Fig. 2) or the location of sites where historical information recorded a damage induced by landsliding (Fig. 3). The second model, which can be named historical, was generated using the same set of predictors and the presence/absence of historical sites within each terrain-unit as predicted variable of the discriminant function (Fig. 3).

By overlying the maps of Fig. 2 and 3, it comes out that their level of mismatch is almost equal to 30% with a relevant number of terrain-units classified as *unstable* and *stable* by the geomorphological and historical models, respectively.

Such a model discrepancy may be referred to different sources of error both in the landslide inventory map and in the historical records. In particular, it is poorly unknown the extent to which the inventory reflects the actual landslide distribution, the extent to which the available historical records report the actual number of events that caused damage to man-made structures. In addition; the time window of the inventory map (say over 1,000 years) can be readily confronted with the time window of the historical data (100 years). All these issues will require further investigations and analyses to achieve a coherent framework within which these two sources of landslide information can be fully compared and subsequently integrated.

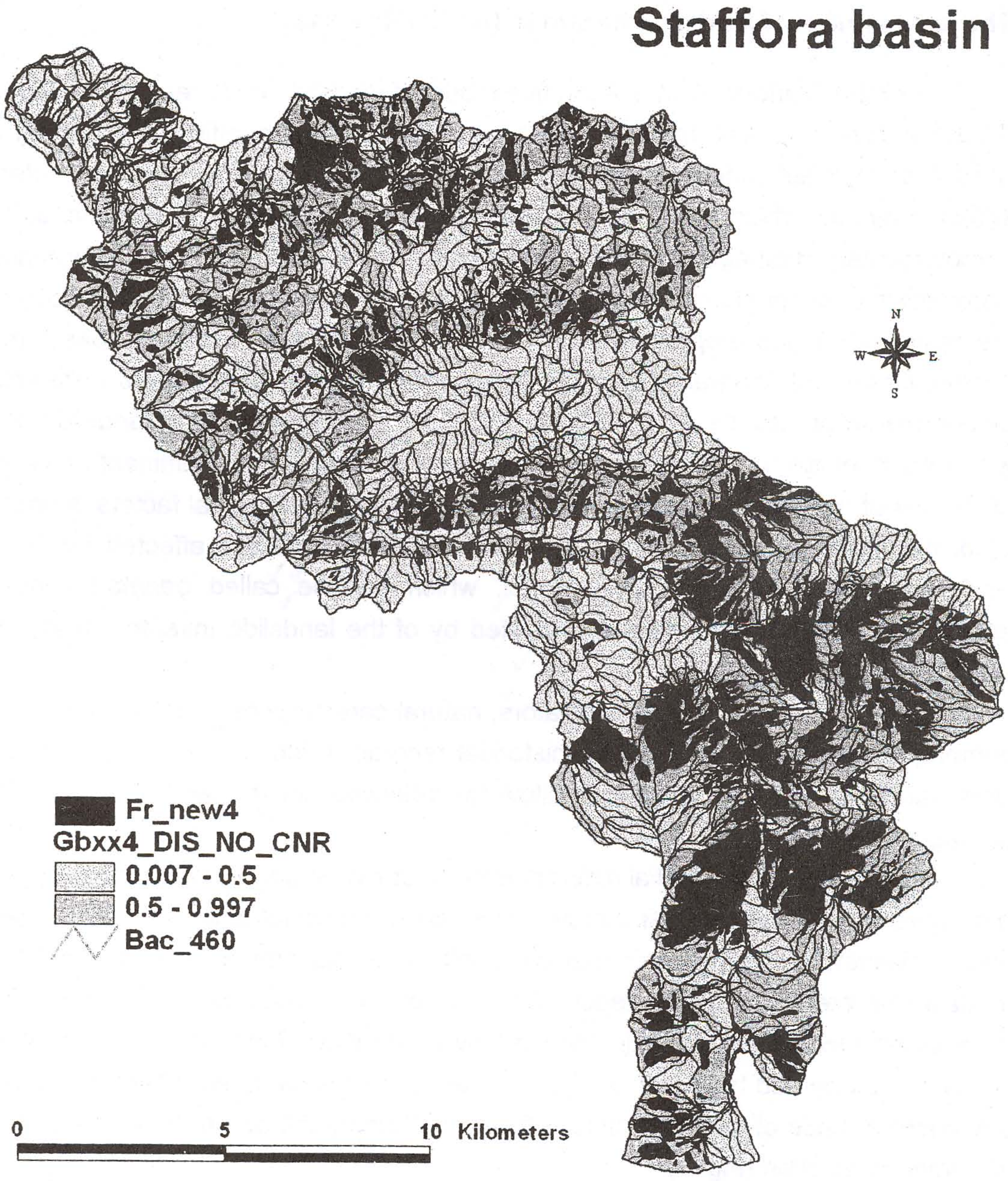

Fig. 2. Staffora basin. Multivariate model of landslide occurrence based on a discriminant function where 40 geological-morphological factors were selected as **predictors**, and the presence/absence of ***landslide deposits*** (solid black) within each terrain-unit as **predicted** (dependent) variable. Light and dark grey colours indicate terrain-units with a probability of landslide occurrence less and greater than 0.5, respectively. Landslide deposits in solid black.

Fig. 3. Staffora basin. Multivariate model of sites historically affected by landsliding based on a discriminant function where 39 geological-morphological factors were selected as **predictors**, and the presence/absence of sites (solid black dots) within each terrain-unit as **predicted** variable. Light and dark grey colours indicate terrain-units with a probability of site occurrence less and greater than 0.5, respectively.