GIS-based multivariate statistical analysis for landslide susceptibility zoning: a first validation on different areas of Liguria region (Italy)

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6.9% of the territory is catalogued as landslide by the IFFI national inventory of landslide (ISPRA, 2013)

Several approaches to assess landslide hazard (Fell et al., 2008):

- **heuristic analysis** → based on geological and geomorphological criteria and local observations collected by an expert

- **statistical methods** → usually correlate an inventory of landslides occurred in the past with factors which are supposed to be responsible of slope failure (Cascini, 2008)

- process-based methods and numerical analysis → local analysis
The type of landslides involved in this study are **slides** and **flows** (according to the UNESCO WP/WLI, 1993)

→ associated to intense meteorological events

- affecting limited thickness of the loose soil
- local contributing factors related to humans (e.g. road cuts)

not only emergency management but also prevention

Land use planning supported by **landslide susceptibility zoning**
The aim
Landslide susceptibility zoning on wide area through GIS-based multivariate statistical analysis
To express objectively the landslide susceptibility in accordance with many factors

The present research
Criticality analysis of the zoning procedure to develop a guideline for the landslide susceptibility zoning, as an instrument to non-GIS and non-statistical expert users for the choice of factors to be considered.

Software GRASS GIS 7.0
Overview

- Predisposing factors to landslide
- Logistic multiple regression
- Critical analysis
- Conclusions
## Literature analysis

### Predisposing factors to landslide

<table>
<thead>
<tr>
<th>geological</th>
<th>Morphological</th>
<th>anthropogenic</th>
<th>climatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithology</td>
<td>stratigraphy</td>
<td>Distance from tectonic alignments</td>
<td>Soil type</td>
</tr>
<tr>
<td>Natali et al. (2010)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Pradhan &amp; Lee (2010)</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Paudíč &amp; Bednářik (2002)</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Lee (2007)</td>
<td>(x)</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Dahal et al. (2008)</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Cencetti et al. (2010)</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Dai &amp; Lee (2002)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ayalew &amp; Yamagishi (2005)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

1. Slope
2. Land use
3. Lithology
4. Aspect
5. Accumulation
6. Elevation above sea level
7. Distance from road network
8. Climatic aggressivity $F_{FAO}$

Proven factors of instability

Raster maps (20x20 m) **reclassified** for the area that you want to submit a zoning
Bivariate analysis

- to reduce number of classes
- to have monotonic (increasing or decreasing) trend of variables

<table>
<thead>
<tr>
<th>Land use classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Other</td>
</tr>
<tr>
<td>2. Buildings</td>
</tr>
<tr>
<td>3. Agricultural areas</td>
</tr>
<tr>
<td>4. Wood</td>
</tr>
<tr>
<td>5. Sparse vegetation</td>
</tr>
<tr>
<td>6. Bare soil/rock</td>
</tr>
</tbody>
</table>

\[
P(\text{evento}|x) = \frac{P(\text{evento} \cap x)}{P(x)}
\]
Bivariate analysis

Predisposing factors to landslide

a) $F_{\text{FAO}}$

b) $\log(\text{accumulation})$

c) aspect

d) slope

e) lithology

f) distance from road

g) Elevation

h) land cover
Logistic multiple regression

Generalized linear model (GLM), appropriate for dichotomous data (0 = absence of landslide, 1 = presence of landslide)

\[
P(evento|X) = \frac{1}{1 + e^{-Z}}
\]

\[
Z = \text{logit}(evento) = \beta_0 + \beta_1 \cdot X_1 + \cdots + \beta_p \cdot X_p
\]
Logistic multiple regression

1st phase: Calibration

\[ P(evento|X) = \frac{1}{1 + e^{-Z}} \]

\[ Z = \text{logit}(evento) = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p \]

inventory of landslide (IFFI) associating:
P=1 if landslide area
P=0 if NOT landslide area

chosen factors

Estimation of regressions coefficients
Logistic multiple regression

2nd phase: Application

\[ P(\text{evento}|X) = \frac{1}{1 + e^{-Z}} \]

\[ Z = \text{logit}(\text{evento}) = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p \]

Calculated landslide susceptibility

Estimated regressions coefficients

chosen factors
Critical points of the procedure

- Classification of chosen factors $\rightarrow$ bivariate analysis
- Selection of the independent variables of the regression model (factors)
- Choice of the proper area to calibrate the coefficient of the regression model
- Definition of a criterion of classification of the susceptibility values
Test area

Liguria Region (Italy) and its 4 Provinces

- Genova
- Savona
- Imperia
- La Spezia
Selection of the independent factors

Defined the calibration area...

AIC index (Akaike’s Information Criteria)

If the adding of a variable has a positive effect on the model, the values of AIC have to decrease
The proper area to calibrate

Defined the factors...

$R^2$ correlation coefficient → indication of the influence factor of the j-th factor on the susceptibility

- Slope
- Land use
- Lithology
- Accumulation
- Aspect
- Elevation
- Distance to roads
- $F_{FAO}$

Critical analysis

Dicca - Polyt

Versity of Genoa - Italy
Factors vs calibration area

Regression coefficients bj → reliability of the factors

Reliable factors
- slope
- Land use
- accumulation
- Distance from road
Factors vs calibration area

Lithology map

Importance of spatial variability of factors

FFAO map
Factors vs calibration area

$R^2$ correlation coefficient → indication of the influence factor of the j-th factor on the susceptibility

- **Critical analysis**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Piemonte</th>
<th>Liguria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>0.000136</td>
<td>0.000659</td>
</tr>
<tr>
<td>land use</td>
<td>0.000172</td>
<td>0.000342</td>
</tr>
<tr>
<td>lithology</td>
<td>0.007310</td>
<td>0.000227</td>
</tr>
<tr>
<td>dist road accumul.</td>
<td>0.000054</td>
<td>0.000196</td>
</tr>
<tr>
<td>aspect</td>
<td>0.000045</td>
<td>0.000143</td>
</tr>
<tr>
<td>elevation</td>
<td>0.001521</td>
<td>0.000033</td>
</tr>
<tr>
<td>FFAO</td>
<td>0.001026</td>
<td>0.000032</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.0070</td>
<td>0.0010</td>
</tr>
</tbody>
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Classification of the susceptibility values

Estimated values of susceptibility

- Relative results
- Very small values (order of $10^{-9} - 10^{-8}$)

Classification in 3 susceptibility level

low   moderate   high
Results and validation

- Low
- Moderate
- High

↑ signs of instability
↑ incipient sliding
Results and validation
Results and validation
First conclusions

• Importance of preliminary analysis of the characteristics of the area to be subjected to zoning → bivariate analysis

• Reliable factors: slope, land use, accumulation, distance to roads

• Importance of spatial variability of factors

• Strong influence of the characteristics of the calibration area on zoning results

• Calibration area: not too small, to be representative of all the conditions present in the area to be subjected to zoning, but of more homogeneous characteristics as possible
Future work

• Guidelines for the susceptibility zoning for non-GIS and non-statistical expert users

• Maps with indications of most suitable design solutions according to the characteristics of the critical zones
Thank you for your attention

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