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Qualitative landslide susceptibility assessment in small areas

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Abstract

The paper shows the application of heuristic methods to assess qualitatively the landslides susceptibility of an area located at the end of the flowslides path. Numerical analyses have been performed to study the flowslide propagation phase and landslides susceptibility maps of the studied area have been obtained. Focusing the attention on a zone located at the end of the flowslides path, qualitative susceptibility analyses have been applied using two heuristic methods. The comparison of obtained results highlighted how heuristic methods strongly depend on the judgement of the person carrying out the analysis.

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Keywords: Qualitative susceptibility; heuristic methods; laboratory tests; landslide propagation phase; susceptibility maps

1. Introduction

The assessment of landslide susceptibility is an essential tool to define the classification, volume (or area) and spatial distribution of landslides, which exist or potentially may occur in an area [1]. Several authors have emphasized that mapping landslide susceptibility should include both recognition of landslide initiation areas and assessment of runout (flowing and stopping phases) behaviour of the landslide material [2,3,4].

Qualitative approaches include landslide inventory mapping or expert evaluation and are based entirely on the judgement of the person carrying out the analysis. In particular, in the heuristic methods, the expert opinion of the person carrying out the zoning is used to assess the susceptibility and hazard. These methods combine the mapping of

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the landslides and their geomorphic setting as main input factors for assessing the hazard. Two main types of heuristic analyses can be distinguished: geomorphic analysis and qualitative map combination.

In geomorphic analysis, the susceptibility or hazard is determined directly by the person carrying out the study on individual experience and the use of reasoning by analogy. For instance, the susceptibility may be defined on the base of the density of the landslide deposits (proportion of the area covered by the deposits). Therefore, the decision rules are difficult to formulate because they can vary from place to place.

In qualitative map combination, the person carrying out the study uses expert knowledge to assign weighting values to a series of input parameters. These are added according to these weights, leading to susceptibility and hazard classes. Susceptibility classes may then be defined in different ways, for instance: the presence of four, three, two, one or any instability factors corresponding, respectively, to very high, high, moderate, low or very low susceptibility. These methods are common, but it is difficult to determine the weighting of the input parameters [1].

In order to perform the landslides susceptibility assessment, a procedure has been proposed and it has been applied in an area located between Scilla and Favazzina (Italy), regularly and historically involved in weather-induced flowslides [5,6]. The flowslides inventory map of the area has been drawn using the landslide inventory-based method in order to identify the distribution of existing landslides mapped from historical data of landslides occurrences. This analysis allowed identifying some flowslides features that have been used later, in order to individuate hypothetical flowslides trigger zones. Numerical simulations have been performed and rapid flowslides susceptibility maps have been obtained for a specific rheological behaviour of the material involved in the flowslides and for a fixed basal erosion coefficient of the channel.

The paper shows an application of two heuristic methods to assess, qualitatively, the susceptibility of an area at the end of the flowslides path, where the main elements at risk are located.

2. Rapid flowslides susceptibility zoning

An historical analysis of the landslides classified as rapid flowslides occurred in the study area has been carried out. The available data allowed to characterize the rapid flowslides trigger zones and to identify some susceptibility descriptors, such as inclinations and lithological features, used in the next analyses.

In particular, considering the slope inclination values and the lithological features that have been involved in the occurred flowslides and taking into account some geomorphic evidences (such as crowns, deep eroded gullies and steep slopes), hypothetical trigger zones have been identified in the area. The results of these analyses allowed drawing the inventory map of the area, where real and hypothetical trigger zones of flowslides are shown [7,8,9].

Successively, the flowslides propagation phase has been simulated by means of numerical analyses. In particular, the SPH numerical code [10] has been used, allowing the evaluation of the path (runout), the velocities and the heights during the propagation phase of the flowslides [7,8,9]. The prediction of runout distances, velocities and heights of the flowslides represents a mean to define the involved areas and to provide the information for the identification and design of appropriate protective measures [11].

For the use of the SPH numerical code, it is necessary to define the rheological model that represents the behaviour of the soil-water mixtures involved in the rapid flowslides.

For this purpose, the soils involved in rapid flowslides occurred in the studied area have been sampled in different trigger zones. The soils have been classified as inorganic silt of medium compressibility with sand (ML) and as silty sand (SM) according to the USCS (Unified Soil Classification System). The average values of the Plastic Index and of the Liquid Limit for the analysed soils have been 9,23% and 33,27%, respectively. The soils grading envelope of the analysed soils is shown in Fig. 1.

Viscometer tests have been carried out in order to obtain the rheological law of the soil-water mixtures involved in the flows. The tests have been performed changing the solid concentration by volume C_v, defined as the ratio between the solid particles volume and the total volume of the soil-water mixture. In particular, C_v values ranged between 35% and 45%. The tests results demonstrated that the rheological model that best interprets the experimental data is the Bingham law, which depends on two parameters, namely the yield stress τ_0 and the Bingham viscosity μ_b.

The obtained rheological law has been used in the numerical analyses to study the propagation phase. Input parameters for the SPH simulations have been Bingham's law coefficients, erosion coefficient and initial volume of the trigger mass.

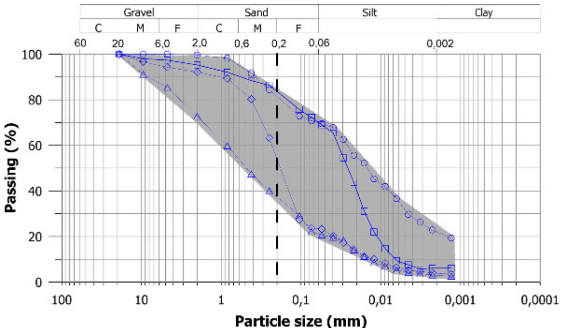

Fig. 1. Soils grading envelope.

In particular, the rheological parameters have been varied as a function of the solid concentration by volume C_v. The range of variation of C_v has been chosen as a function of the typical values of flowslides [12]. In the performed numerical analyses, the erosion phenomenon has been taken into account using the Hungr's equation [13] depending on the erosion coefficient E_s, defined as the "growth rate". This basal erosion coefficient has been calibrated and the best results have been achieved for values of E_s equal to 0,001 m^{-1} and 0.002 m^{-1} [14,15].

Performing several numerical simulations for all trigger zones, ten susceptibility zoning maps have been drawn, where the flowslides paths for different C_v and E_s values have been highlighted [7,8,9].

3. Qualitative susceptibility assessment

Focusing the attention on a control area located at the end of the flowslide paths, among those obtained by the numerical simulations, for E_s equal to 0,001 m^{-1} and 0.002 m^{-1} (Figs. 2a and b), the qualitative susceptibility analysis has been performed.

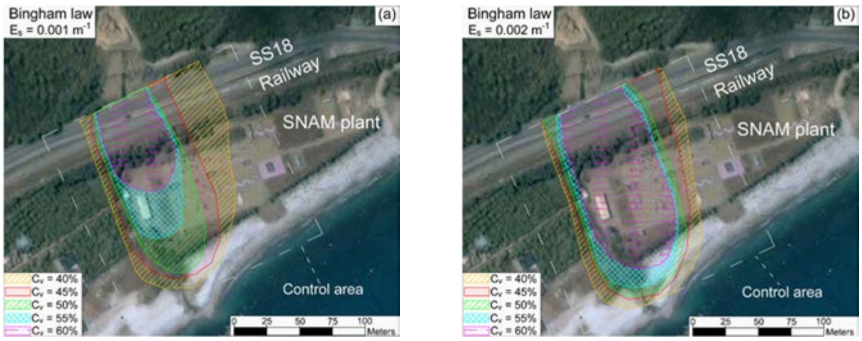

Fig. 2. Runout areas at the end of the flowslides path for E_s = 0.001 m^{-1} (a) and E_s = 0.002 m^{-1} (b).

The Figs. 2a and 2b show the flowslides deposits for each considered C_v value and for the different E_s, obtained by means of numerical simulations. In this control area, three main elements at risk, namely the main road SS18, the railway and the SNAM plant, are located.

It can be noticed that the runout zone of the hypothetical flowslide with a solid concentration by volume equal to 40% is the largest, while narrower accumulation zones correspond to higher values of solid concentration by volume. Moreover, considering the same solid concentration by volume, the runout zones are wider in the case of erosion coefficient E_s equal to 0.002 m^{-1} (Fig. 2b).

As previously stated, two different heuristic methods have been applied to assess qualitatively the susceptibility of this area.

In the first one, the control area has not been discretized and four susceptibility classes have been chosen. The classes have been selected as a function of the number of zones of accumulation obtained for the different C_v values overlapping in the area (Table 1).

Table 1. Susceptibility classes in the first heuristic method.

N° of overlapping accumulation zones	Susceptibility class
≥ 4	High
3	Moderate
2	Medium
1	Low

In the second method, the control area has been discretized in square meshes, each one with 20 meters long side, (Figs. 3a and 3b) and the susceptibility classes (SC) have been considered, as follows:

$$SC_i = mean\ value\left[W_i^j = f\left(D_{dep} = \frac{A_i^j}{A_i}\right)\right] \qquad \forall \begin{cases} i = 1....n_{mesh} \\ j = 1....n_{C_v} \end{cases} \tag{1}$$

where W_i^j is the susceptibility class weight for each C_v value and for each mesh; D_{dep} is the density of flowslide deposit for each C_v value; A_i is the area of the i-th mesh; A_i^j is the deposit area for each C_v in the i-th mesh.

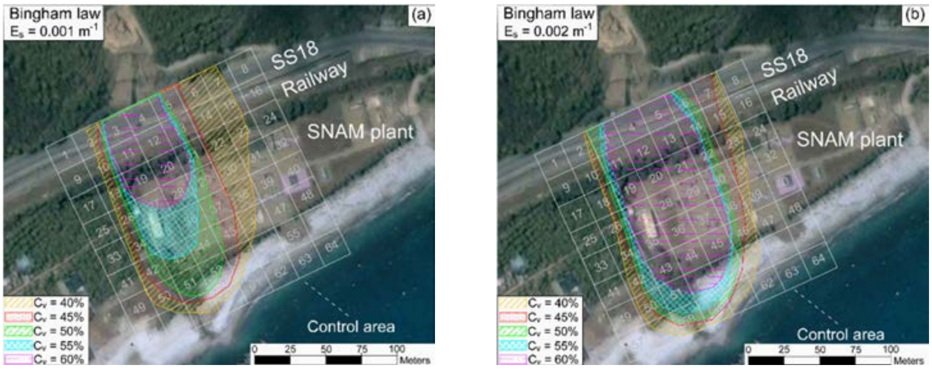

Fig. 3. Runout areas at the end of the flowslides path for $E_s = 0.001\ m^{-1}$ (a) and $E_s = 0.002\ m^{-1}$ (b) for discretized control area.

The values of W_i^j and the susceptibility classes have been evaluated by the correlation shown in Table 2 and in Table 3.

Table 2. Correlation between density of flowslide deposit (D_{dep}) and weight of susceptibility class W_i^j.

$W_i^{j.j}$	D_{dep}
4	D_{dep} > 0,5
3	0.1 < D_{dep} < 0,5
2	0.01 < D_{dep} < 0,1
1	D_{dep} < 0,01

Table 3. Susceptibility classes in the second heuristic method.

SC values	Susceptibility class
$3 > SC \leq 4$	High
$2 > SC \leq 3$	Moderate
$1 > SC \leq 2$	Medium
$SC \leq 1$	Low

3.1. Results

The results obtained by the qualitative landslide susceptibility assessment are shown in Fig. 4 for the first proposed method and in Fig. 5 for the second proposed method, for Es = 0.001 m^{-1} and Es = 0.002 m^{-1}, respectively.

In the first method (Figs. 4a and 4b), it has been chosen to analyse only the areas inside the accumulation boundaries, while in the second one (Figs. 5a and 5b) the susceptibility analysis has been carried out for the entire control area.

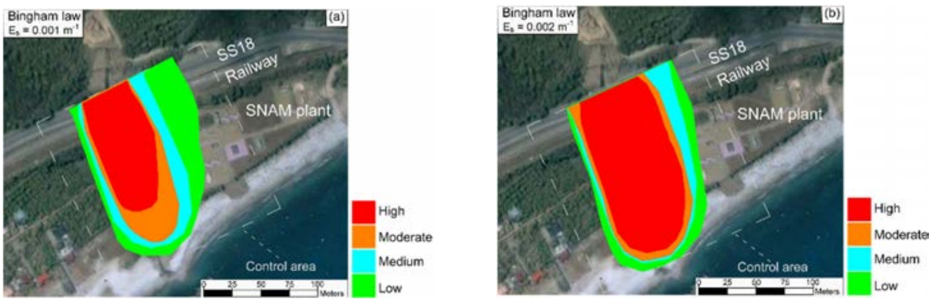

Fig. 4. Qualitative susceptibility classes for the first method for E_s = 0.001 m^{-1} (a) and E_s = 0.002 m^{-1} (b).

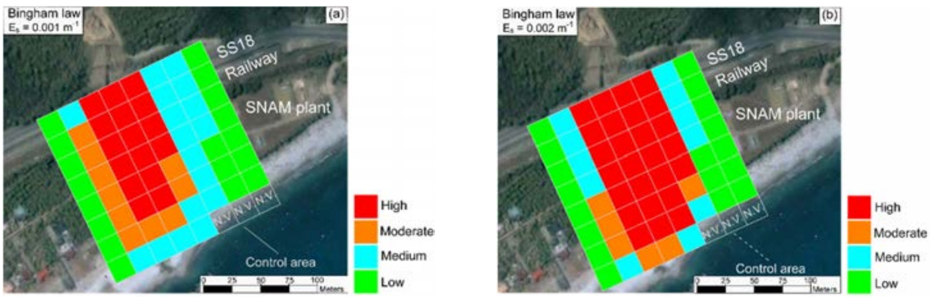

Fig. 5. Qualitative susceptibility classes for the second method for E_s = 0.001 m^{-1} (a) and E_s = 0.002 m^{-1} (b).

The comparison of the results shows that, inside the control area, the extension of the zone with high susceptibility (red area in the maps of Figs. 4 and 5) depends on the E_s and on the used method; anyway a zone is ever classified as high susceptibility zone regardless the used method and E_s.

4. Conclusions

The paper showed the application of two heuristic methods to assess qualitatively the landslides susceptibility of an area located in Southern Italy, based on field sampling, laboratory tests and numerical simulations. The analyses, performed for the control area in the runout zone of the rapid flowslides, highlighted how heuristic methods strongly depend on the judgement and experience of the person carrying out the analysis.

The methods, applied to a runout zone among those obtained by several numerical simulations, could be also used for the other runout zones in the analysed area, allowing to assess qualitatively the flowslides susceptibility of wider zones.

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