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A multi-scale approach to cost/benefit analyses of landslide prevention vs. post-event actions

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Abstract

The main aim of this paper is to test economic benefits of landslide prevention measures vs. post-event emergency actions. To this end, small and large scale analyses were performed in a training area located in the North-Eastern Italian pre-Alps that was hit by an exceptional rainfall event occurred in November 2010. At the small-scale, landslide susceptibility was initially assessed using a simple probabilistic analysis, which allowed to highlight the main landslide conditioning factors and the most hazardous areas. However, this approach revealed to be quite insufficient to reach planned goals, so a large-scale case-by-case analysis was performed: a study case was defined, according to landslide occurrence frequency and assessment of elements at risk. Numerical modeling demonstrated that remedial works carried out after the landslide – water-removal intervention such as a drainage trench – could have improved slope stability if applied before its occurrence. Then, a cost-benefit analysis was finally employed. It defined that prevention would have been economically convenient compared to a non-preventive and passive attitude, allowing a 30 % saving relative to total costs. Therefore, this kind of approach could be actually used as a mean toward preventive soil protection not only within the investigated case study, but also in all those hazardous areas where preventive measures are needed.

1 Introduction

Landslides are one of the most dramatic natural issues along with earthquakes, floods and weather-related events. For this reason, hazard and risk assessment has been the main aim of a large number of scientific papers (Corominas et al., 2014 and reference therein), focusing on geomorphological (Baek and Kim, 2014; Cardinali et al., 2002; Devoto et al., 2014) and multi-disciplinary or statistical approaches (Sterlacchini et al., 2007; Dai et al., 2002). The level of risk is generally defined as the intersection of hazard with the value of the elements at risk by way of their vulnerability (Crozier and

Glade, 2006; Alexander, 2002). This assumption is generally based on a great number of variables: vulnerability of element at risk is closely related to the type of landslide, and frequency-based hazard assessment often relies on a few decades of knowledge on slope instabilities. Fortunately, last years' measurements have been thoroughly collected thanks to GIS databases, web information sharing and a greater awareness of landslide matter. This attitude allowed some authors to calculate the costs of damages due to slope instabilities within many environments around the world: from 1972 to 2007, landslides and rock-falls cost EUR 520 million and caused 32 fatalities in Switzerland (Hilker et al., 2009), while in the United States a USD 1–2 billion expense in economic losses and about 25–50 deaths yr^{-1} have been estimated (Schuster and Fleming, 1986), e.g. USD 9 million expense in only direct cost losses in Colorado during 2010 (Highland, 2012). Historical researches indicate that more than 50 593 people died, went missing or were injured in 2580 landslides and floods in Italy, where 26,3 % of the 8102 municipalities have been hit by slope instabilities between AD 1279 and 2002 (Guzzetti et al., 2005): economic loss related to the single destructive landslide at Ancona (Marche Region) in 1982 was estimated at USD 700 million (Alexander, 1989). At the global scale, 2620 landslides were recorded during the 7 year period 2004–2010, causing a total of 32 322 fatalities (Petley, 2012). Besides this historical data, the need for landslide damage prediction is very strong if we want to implement preventive measures against slope instabilities, even at large-scale: within a small test site of about 20 km^2 wide area in north of Lisbon (Portugal), cumulative risk expressed in direct costs for building and roads were calculated to be about EUR 5 million (Zêzere et al., 2008); in southern India, the triggering of many landslides hanging over 20 km long roads could cost from USD 90 840 to 779 500, with an average annual total loss estimated to USD 35 000 (Jaiswal et al., 2010). These expenses highlight how much people need protective measures toward landslide and flood prevention, which cause every year USD billions in damages and economic losses. This need can be summarized in the term *risk management*, referred as the full range of procedures and tasks that ultimately lead to the implementation of rational policies and appropriate measures for risk reduction (Crozier and Glade, 2006). One important task in risk management is the evaluation of benefits from preventive actions which can encourage authorities and population to invest money for preventing damage due to slope failures. To this end, the estimation of the most landslide prone area and of the effectiveness of possible preventive measures is needed. In this work, we tried to achieve this goal through a small- and a large-scale approach: the former has been applied to identify where slopes are more prone to fail within a study area 110 km^2 wide, using a simple statistical analysis; the latter has been employed because of the impossibility to deal with our goals at regional scale, which can not supply sufficient information on the behavior of unstable slope. Numerical and cost-benefit analyses were performed in a slope instability triggered by an exceptional rainfall event, to define if preventive measures could avoid landslides occurrence and if they could effectively carry an economic benefit, as a result of an effective risk management methodology.

2 Case study

In recent years, Italy has been hit by several exceptional rainfall events, causing damages at public and private buildings, infrastructures and activities. One of these events hit the Province of Vicenza (Veneto Region) in November 2010, with a maximum cumulative rainfall of about 500 mm in two days and a mean of 336 mm over the area. In the following days, a great flood hit plain territories and 500 warnings of landslides were received at the Soil Protection Division, distributed over 20 municipalities. Many of these slope failures affected the Marosticano area, a 110 km^2 territory located in the Norh-East sector of the Province. Here, landslides were classified as "rotational/translational slides" and "earth flows" (following the classification proposed by Varnes, 1978). These failures involved mostly silty-clay soils, the weathering products of Late Paleocene-Early Miocene extrusive magmatic rocks. Alteration of basic bedrock led to the typical geological and geomorphological environment within Vicenza's pre-Alps hilly belt, where basalt and tuffaceous rock outcrops are sporadic because a variable thickness of

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eluvial and colluvial deposits is present (Fig. 1). The November 2010 event highlighted the partial lack of preventive and maintenance works, a soil defense attitude which has still to be acquired by Authorities and population at the present time, but is more needed today than in the past: because the frequency of exceptional rainfall event in Italy has increased in the last decades (Floris et al., 2013), with a damaging event about every 20 years (Floris and Bozzano, 2008); thus, the November 2010 event represents only one element of this developing trend. As a result, without any kind of soil protection, Vicenza's administration had to face EUR 300 million of remediation work and about EUR 1 billion of infrastructure and building losses. In this paper, we tried to understand if preventive actions could be realized before the November 2010 rainfall event within specific environments where slope instabilities occurred in the Marosticano area.

3 Small-scale analysis

In order to understand where landslides spread within the Marosticano area, a probabilistic spatial analysis was performed. This represented the first step toward landslide prevention, because it would have been impossible to decide where to intervene without a clear overview on landslide susceptibility and on more hazardous areas. Statistical analysis was employed assuming that landslide occurrence is generally determined by landslide-related factors, and that future landslide will occur under the same conditions as past landslides (Chung et al., 1995; Lee and Pradhan, 2006). A very common bivariate analysis known as "Frequency Ratio" was adopted: spatial landslide predictability was calculated from the analysis of the relation between landslides and most important landslide-related factors (Lee and Pradhan, 2007; Zhu and Huang, 2006). In order to achieve the final map, landslide inventory data-set and environmental factor data-layers were collected from Italian web-portals and geodatabases. Morphometric (elevation, slope, curvature, aspect) and non-morphometric (river distance, road distance, lithology and land use) environmental factors were considered. Such as the majority of probabilistic spatial analysis, every single factor needed to be reclassified and divided in sub-categories of values; a table was then created for each landslide-related factor and filled with the following values:

$N^{L}_{pix}(X_i)$	number of pixels where landslide occurred within class *i* of factor *X*
$\sum_{i=1}^{n} N^{L}_{pix}$	total pixels where landslide occurred within the entire area
$N_{pix}(X_i)$	number of pixels where landslide did not occur within class *i* of factor *X*
$\sum_{i=1}^{n} N_{pix}$	total pixels where landslide did not occur within the entire area

and *n* is the number of factors in the study area.

Frequency Ratio Index (FRI) represents the ratio of the landslide occurrence probabilities to the non-occurrence probabilities for a given class within a factor. FRI is calculated using Eq. (1) (Jaafari et al., 2014; Lee and Min, 2001; Lee and Pradhan, 2007):

$$\mathrm{FRI}_n = \frac{\frac{N^{L}_{pix}(X_i)}{\sum_{i=1}^{n} N^{L}_{pix}}}{\frac{N_{pix}(X_i)}{\sum_{i=1}^{n} N_{pix}}}. \qquad (1)$$

The larger the ratio is, the stronger the relationship between landslide occurrence and the given factor attribute (Jaafari et al., 2014). A value of 1 represents an average value, but a value > 1 means that the percentage of the landslide is higher than the area without landslide and refers to a higher correlation with conditioning factors; a value < 1 means lower correlation. Landslide susceptibility index (LSI) is then obtained summing all factor index contributions, as in Eq. (2) (Yalcin et al., 2011):

$$\mathrm{LSI} = \mathrm{FRI}_1 + \mathrm{FRI}_2 + \mathrm{FRI}_3 + \ldots + \mathrm{FRI}_n. \qquad (2)$$

Thus, LSI allows to create a susceptibility map and define which areas are more prone to fail, given a specific geological, geomorphological and anthropic environment and landslide type. This methodology can be useful to provide a small-scale overview of those areas which are worthy of later investigations at the larger scale. The statistical analysis was conducted using ESRI ArcGIS™ software and its toolbox "Spatial Analyst". A model with Model Builder™ package were also built to speed up data processing and to automate repetitive needed steps.

Result and discussion

FRI was calculated for each class belonging to eight landslide-related factors. For morphometric factors, every class was carefully chosen after repeated analysis, performed to isolate the best landslide pre-conditioning range of values. In this particular case, a temporal validation was chosen (Chung and Fabbri, 2003): the model was built with an input dataset of landslides which occurred before the November 2010 event, then predictability and validation assessments were made using a test dataset of landslides occurred during the same event. First input dataset was obtained after a search for landslide perimeter data and triggering areas (Trigila, 2014), scanning every available source (field survey, orthophoto and GIS shading capabilities). The only available data for the test dataset was point features, so a buffer of 10 m around each element was applied (Adami et al., 2012). Table 1 shows that earth flows are predisposed by altered basaltic rocks, slope angle between 13–23° and elevation from 245 and 420 m. Higher and steeper slopes are more susceptible to translational or rotational slides, which usually happen on altered tuffaceous bedrock. Success Rate Curve (Fig. 2) shows what part of the assessed hazardous area is actually an unstable area. It represents the cumulative percentage (fraction; y axis) of landslides in the input dataset with respect to susceptibility classes (expressed as portion of the study area with susceptibility above a given value; from greater to lower; x axis): a hypothetical curve coinciding with a diagonal from 0 to 100 % would be equivalent to a totally random assessment, so the further up away the Success Rate Curve is from that diagonal the better the model has been created (Remondo et al., 2003). Curves for slides and earth flows are both far up from the diagonal, so the result is quite convincing. Then, we used the November 2010 landslides to test the forecasting power of this model: a 10 m buffer was applied to punctual data, to better represent slope instability areas. Figure 3 shows that the validation dataset did not perform as well as the first one, but both curves are higher than the random diagonal, so results are acceptable even in this case. Susceptibility map confirmed the results of statistical analysis, as shown in Fig. 4: most susceptible areas for translational-rotational slides are located at greater elevation and slope, nearer the roads than earth flows, which occur at lower elevation and slope. Analysis confirmed what occurred during the November 2010 event: heavy rainfall caused instabilities mainly along roads (90 % of the total damage), so they need to be kept under control and be protected with preventive works.

Thus, probabilistic analysis is a helpful tool to obtain different ranges of landslide susceptibility and display them in a map; this method is also a powerful way to get an overview over landslide factors related to each type of movement. However, small-scale approach itself can not define where to act with preventive works: indeed, results of spatial analysis showed that the majority of the study area would need to be defended – regardless of money and time – in order to take care for all the most susceptible environments. Therefore, a change of approach is needed: preventive works must be planned at large-scale, with regards to those specific slopes which show instabilities occurred in the past. This is an important factor in Italian and Venetian territories, where landslide are consequent upon partial or complete reactivation of existing landslide bodies, often triggered by rainfall (Floris and Bozzano, 2008). Although risk assessment is not the purpose of this paper, we must highlight that large-scale analysis have to be based on a risk evaluation too, not only on a solid but limited statistical analysis. Until this process of case-by-case survey is completed, preventive multi-methodology approach will ever stuck at a small-scale analysis and never get done.

4 Large-scale analysis and numerical model

At the large scale, we chose to focus our attention on roto-traslational slide occurred in the Carrè municipality: this landslide is located on an unstable slope which was affected by past and recent instabilities – including during the 2010 event – forcing authorities to demolish an old house and rebuild the main road, with a total direct cost of EUR 60 000. Landslide body lies above a basaltic bedrock and involves a few-meters thick eluvium-colluvium layer. It is about 100 m long × 50 m wide, with a 1 m high main scarp (Fig. 5). Field data resulted in a supposed shear surface located within first shallower meters, where silty-clay soils do not possess adequate strength parameters to sustain the ground on the top when water table rises.

Thus, once this highly susceptible environment was selected, we aimed to define if a specific preventive work employed *before* the 2010 event could have either avoided landslide or not. Numerical model was here implemented in order to study slope stability along with remedial measure which was actually realized *after* the slide: a drainage trench, whose planned task it was to reduce water table by 2 m from the surface and get rid of the most important landslide triggering factor. Analysis was performed with Itasca's FLAC® 7, a finite-difference software for numerical modeling of 2-D continua. It's a commonly used code in geosciences because of numerous constitutive models implemented, which allow to study deformation and yield in every node of the grid: each one of these nodes follow a linear or non-linear tension-deformation rule, in response to forces or boundary conditions. The analysis began with a well-defined conceptual model built on the whole available geological and geotechnical knowledge. Slope was represented by 3 different lithotypes: a basaltic bedrock at the bottom, a clay-mineral rich eluvium interface "B" in the middle and a colluvium horizon "A" at the top. This geotechnical setting was deducted from field observations and laboratory tests, along with other technical and geophysical surveys performed by local Authorities. Chosen profile was imported and boundary fix conditions were set. Slope condition was then modeled using a back-analysis: we had at our disposal ranges of strength parameters from previous works and remedial project, and we also knew approximately where slip surface was localized; thus, strength parameters were retro-calculated, first assuming a surficial water table; this choice was made because it was supposed as the conceivable limit condition for the slope during the 2010 event. Secondly, the water table was reduced by 2 m by the drainage trench, as project indicated.

Results

After numerous attempts, a totally wet slope collapsed with parameters in Table 2. Slope was unstable only if the eluvium layer “B” was set with low-strength parameters: this assumption was quite consistent with the presence of a silty-clay layer (Toaldo, 2014). Shear forces were concentrated in this thin layer where soil did not have sufficient shear strength, so movement was allowed. This result was considered acceptable, since we obtained a shear surface and a morphological setting comparable to field surveys and observations (Fig. 6). Instability was also confirmed by the calculated Factor of Safety $(\text{FoS}) < 1$. Same parameters were re-utilized in the second model, where we reduced the water table by 2 m for a 30 m distance, simulating the planned drainage trench and its activation. This securing measure stabilized the slope, with a $\text{FoS} > 1$ (Table 3). Thus, if Carre’s administration had created the drainage trench before the landslide event and not after it, this preventive work could have avoided landslide itself. A part of those EUR 60 000 could have been saved, along with other tens of thousands Euros spent in incalculable indirect costs (emergency actions, social cost due to inaccessibility of the road).

5 Cost-benefit analysis

After we assumed that a drainage trench could have effectively avoided landslide occurrence during the 2010 event, the next step was to understand if this kind of preventive work could have been also economically convenient. Thus, drainage trench costs were compared with the total cost of all remedial measures (which included the re-shaping of the slope and the drainage trench itself) applied after the landslide occurrence, a total amount of EUR 60 000. In order to achieve this goal, we used the so-called cost-benefit analysis (CBA): this approach is generally employed in economy, and is aimed to compare the economic efficiency of various alternatives used to reach a specific objective. This method verifies if benefits brought by one alternative are greater or lesser than the related costs (Momigliano and Nuti, 2001). Cost-benefit methodology permits a multi-year analysis, and for this reason every monetary resource has to be carried back to the first time of policy implementation. In order to get all amounts fully comparable through years, it's necessary to apply a discount rate. Equation (3) is employed to determine the value (Present Value, PV) of a X monetary resource available at future time t, assuming a r discount rate:

$$\mathrm{PV}(X) = \frac{1}{(1+r)^t} X. \tag{3}$$

Considering the flow of C_t costs and B_t benefits, the real expenses comparison is expressed by NPV (Net Present Value), defined as the difference between the amounts of benefits and costs through years, as in Eq. (4) (Frattini and Crosta, 2006):

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}. \tag{4}$$

Thus, the cost-benefit analysis allowed us to compare the preventive costs with the total remedial costs of Carre landslide. In a process like this, the definition of all amounts has been a critical point: C_t costs were set to preventive drainage trench expenses, obtained from remedial works project; on the other hand, due to the impossibility to calculate the indirect costs of losses, we set B_t benefits to the total amount of remedial works. 20 years was the limit time of the analysis, which corresponded to the return period of exceptional rainfall events in the study area. CBA permitted us to consider the annual maintenance cost too: protective measures management generally reveals to be as fundamental as prevention itself, because the lack of surveillance can be considered as much as a preparatory factor. This amount was set to EUR 400 year^{-1}, because many inspections could be realized by sight or with basic instrumentations. Here, a discount rate of 1.6 % was applied, obtained from the website of Economy and Finance Italian Department and referred to 15 years BTP EUR *i* bonds (15 years represent the nearest interval to our 20 years preventive policy).

Economic overview

Table 4 shows results obtained from the cost-benefit analysis applied to Carrè landslide: local administration spent EUR 57 000 in remediation costs, while the preventive works amount would have cost EUR 17 652. Thus, considering a 20 years policy and a EUR 400 year^{-1} maintenance expense, a total amount of EUR 17 277 would have been saved (the 30 % of total remediation costs). This amount must be kept under advisement especially by local administrations, which could have addressed these funds toward other activities or soil protection plans – possibly other preventive works. We supposed that geological, geomorphological and geotechnical considerations could be even valid for other landslides, which happened within the same background and environment conditions of Carre (similar lithology, slope angle, land use, road distance and rainfall intensity); thus, the cost-benefit methodology was employed on three landslide sites in Molvena municipality, located a few kilometers from Carrè: drainage intervention was assumed, and economic study proved that on the total EUR 130 000 spent in remediation works, about 40 % would have been saved with a preventive policy.

6 Conclusions

In this paper, we dealt with three kind of analyses, all aimed to implement a high-grade preventive policy: first, at small scale, we used a probabilistic approach, which considered landslides along with the natural variability of geological, geomorphological and geotechnical features of soils involved in slope-failures. This method allowed us to understand which factors are related to landslides occurrence. The key index of this approach, called "Frequency Ratio Index", provided classes of values within each factor which are more inclined to cause landslide events. The definition of slide and flow susceptibility maps, along with the obtained indexes, allowed us to give a solid basis to the observations related to the 2010 rainfall event, which hit the Province of Vicenza: probabilistic model defined that areas near the roads and placed over basaltic and tuffaceous alterations were generally the territories more frequently hit by landslides, as effectively occurred during the November 2010 event. This method allowed a first sorting of hazardous environments, which had to be precisely pointed out through a large-scale approach: this was a needed step to complete the entire project. We indicated that attention must be moved on a case-by-case basis; people have to act with preventive works according to two components: landslide frequency and risk assessment. Local administrations have to focus their attention on already failed slopes, especially where there is a greater concentration of elements at risk. Slope-scale analysis is required, so we chose Carrè landslide to our purpose: it moved frequently in the past, destroyed an old house and the provincial road. Numerical model demonstrated that a drainage trench could have been a good preventive measure to improve slope stability if applied before the landslide itself. Prevention costs were compared to those relative to remedial works, usually applied after the landslide occurrence. Finally, it was possible to define a saving of 30 % on the total amount, surely a great economic improvement for local administrations (confirmed by cost-benefit analyses performed within the environment of Molvena). Thus, if Vicenza's municipalities had act before the 2010 event, an important amount of money would have been saved, and possibly re-utilized for other purposes. In this work, we paid attention on preventive measure such as a simple drainage trench, without considering any kind of more invasive work, which could have needed a more onerous and heavy planning: a systematic analysis for all the most dangerous slopes represents the natural continuation of this multi-methodology approach, along with a greater field survey of landslide related factors and a landslide mapping at higher scale.

The case study we dealt with in this paper can effectively contribute to improve our awareness and knowledge on prevention benefits. It is a real evidence, which proves that avoiding landslide occurrence represents a sustainable policy, dealing with the social side of risk mitigation. This methodology can also provide an economic point of view over landslide global issue, giving the appropriate tool to Authorities to face this ever growing problem. Afterwards, prevention is effectively possible – from the economic point of view to the architectural one- and could represent an efficient way to defend every defenseless territory.

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Table 1. Highest Frequency Ratio Indexes obtained from each factors classes. Almost every value is greater than 1, indicating a good correlation between landslides and their predisposing factors.

Factors	Rot/Transl. Slides from	to	FRI	Earth flows from	to	FRI
Elevation	420 m	577 m	12.2	245 m	420 m	1.7
Slope	23°	33°	2.3	13°	23°	1.5
Curvature	13	107	1.7	−6	−2	1.4
Road distance	25 m	50 m	1.7	75 m	100 m	1.6
River distance	200 m	300 m	2.0	300 m	400 m	1.8
Aspect	135° N	225° N	6.2	135° N	225° N	1.2
Lithology	Ialoclastite		2.7	Basalt		2.5
Land use	Sparse vegetation		1.4	Sparse vegetation		2.2

Table 2. Strength parameters assigned to lithotypes involved within Carre landslide in the case of water table at the ground surface, as instability occurred.

	A	B	Bedrock
Model	Mohr–Coulomb	Mohr–Coulomb	Mohr–Coulomb
Density [$\mathrm{kg\,m^{-1}}$]	1900	1900	2700
Bulk modulus [Pa]	5×10^6	1×10^6	3×10^{10}
Shear Modulus [Pa]	2×10^6	5×10^5	1×10^{10}
Cohesion [Pa]	1×10^4	6×10^3	6×10^7
Tension [Pa]	1×10^4	6×10^3	1×10^7
Friction angle [°]	23	15	31

Table 3. Factor of safety in different water table conditions.

Water table position	Factor of safety
Water table at the ground surface	< 1
Water table at −2 m from the surface, due to the action of a 30 m-long drainage trench	> 1

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Table 4. Cost-benefit analysis for Carre landslide: total remedial costs of EUR 57 000 were considered as a benefit, which had to be reduced by the prevention and maintenance costs. Final saving was obtained summing all years' savings.

			Discounted amounts		
Year	Cost	Benefit	Cost	Benefit	Net present value
1	EUR 17 652.00	EUR 0.00	EUR 17 363.76	EUR 0.00	EUR −17 363.76
2	EUR 400.00	EUR 0.00	EUR 387.04	EUR 0.00	EUR −387.04
3	EUR 400.00	EUR 0.00	EUR 380.72	EUR 0.00	EUR −380.72
4	EUR 400.00	EUR 0.00	EUR 374.51	EUR 0.00	EUR −374.51
5	EUR 400.00	EUR 0.00	EUR 368.39	EUR 0.00	EUR −368.39
6	EUR 400.00	EUR 0.00	EUR 362.38	EUR 0.00	EUR −362.38
7	EUR 400.00	EUR 0.00	EUR 356.46	EUR 0.00	EUR −356.46
8	EUR 400.00	EUR 0.00	EUR 350.64	EUR 0.00	EUR −350.64
9	EUR 400.00	EUR 0.00	EUR 344.91	EUR 0.00	EUR −344.91
10	EUR 400.00	EUR 0.00	EUR 339.28	EUR 0.00	EUR −339.28
11	EUR 400.00	EUR 0.00	EUR 333.74	EUR 0.00	EUR −333.74
12	EUR 400.00	EUR 0.00	EUR 328.29	EUR 0.00	EUR −328.29
13	EUR 400.00	EUR 0.00	EUR 322.93	EUR 0.00	EUR −322.93
14	EUR 400.00	EUR 0.00	EUR 317.66	EUR 0.00	EUR −317.66
15	EUR 400.00	EUR 0.00	EUR 312.47	EUR 0.00	EUR −312.47
16	EUR 400.00	EUR 0.00	EUR 307.37	EUR 0.00	EUR −307.37
17	EUR 400.00	EUR 0.00	EUR 302.35	EUR 0.00	EUR −302.35
18	EUR 400.00	EUR 0.00	EUR 297.41	EUR 0.00	EUR −297.41
19	EUR 400.00	EUR 0.00	EUR 292.56	EUR 0.00	EUR −292.56
20	EUR 400.00	EUR 57 000.00	EUR 287.78	EUR 41 008.39	EUR 40 720.61
Discount Rate		1.60 %	Σ Net Present Value		EUR 17 277.75

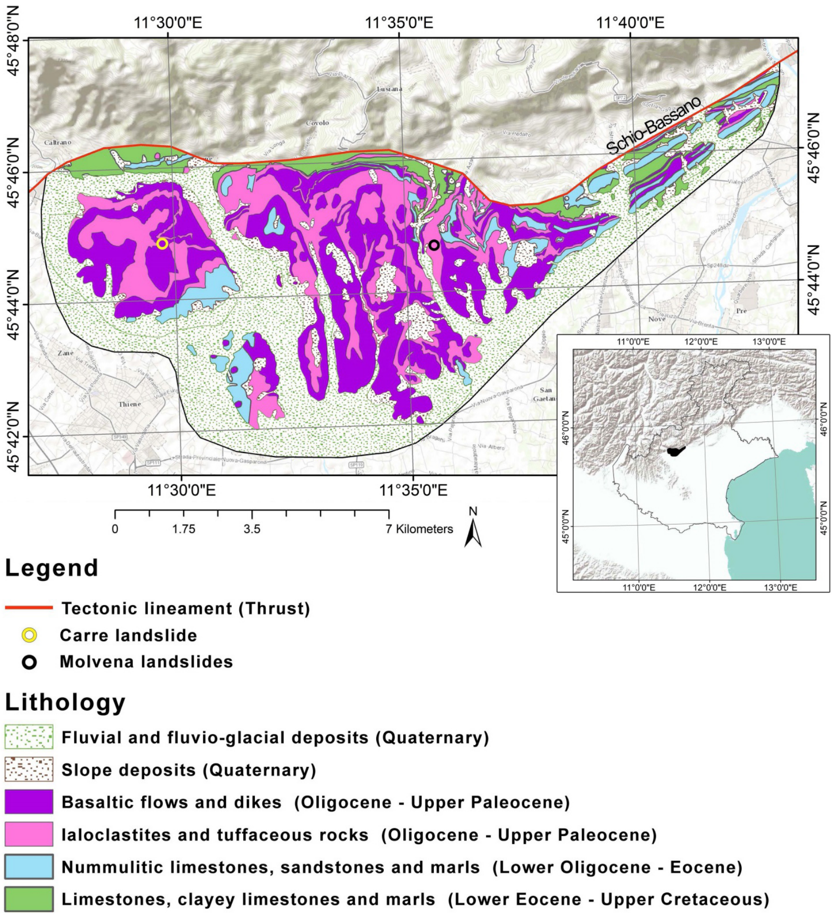

Figure 1. Lithology and location of the study area. Location of landslides (Carrè and Molvena) considered in the cost/benefit analysis is also indicated.

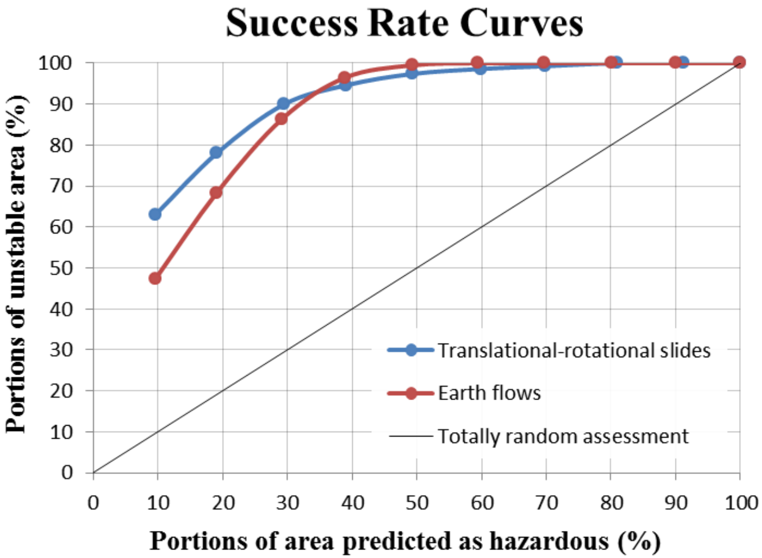

Figure 2. Success rate curves showing how the model fit the instability conditions of the study area.

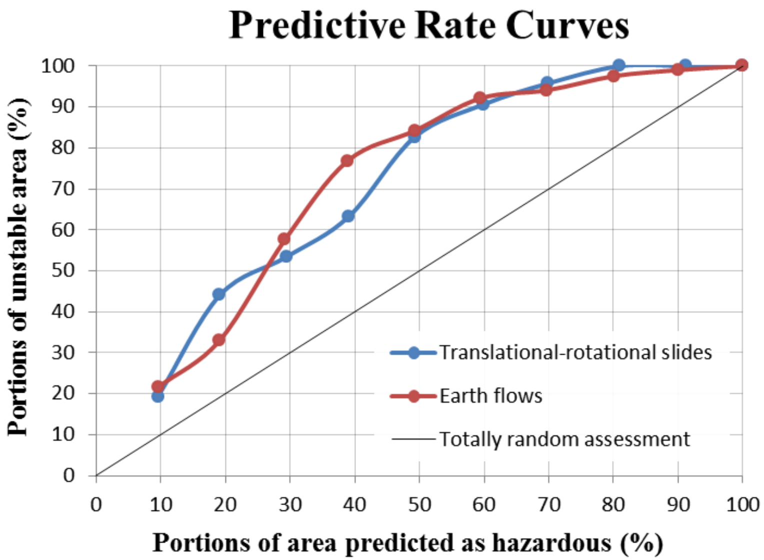

Figure 3. Predictive rate curves showing how the forecasting model fit the instability conditions of the study area, using a different temporal data-set as validation.

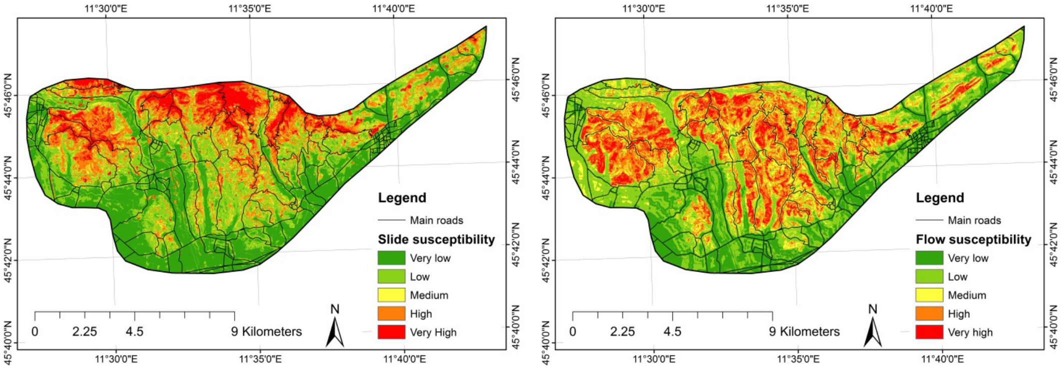

Figure 4. Translational-rotational slide and earth flows susceptibility maps. The classification of susceptibility is based on the results of the validation, interpreting Predictive rate curves of Fig. 3.

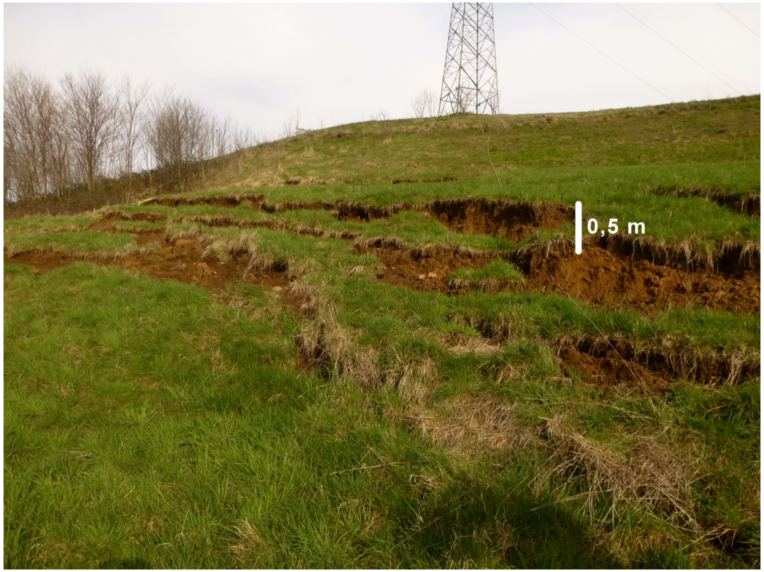

Figure 5. Main scarp of Carrè landslide.

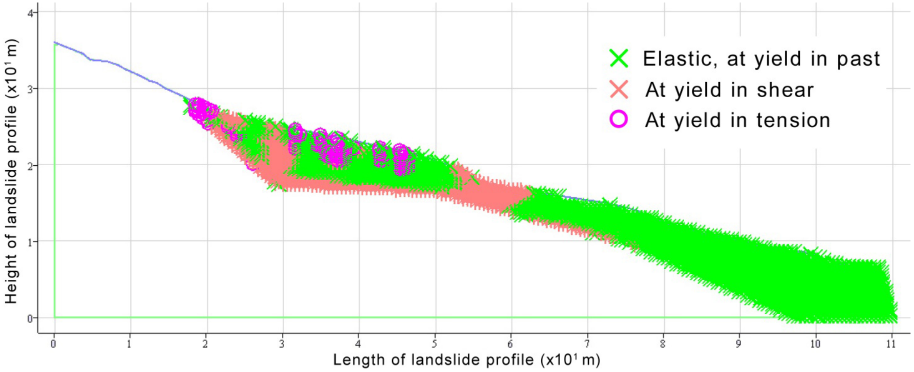

Figure 6. Distribution of plasticity zones within Carre landslide in the case of water table at the ground surface. Tension yield is coherent with field observations (Fig. 5).