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Assessment of landslide susceptibility for civil protection purposes by means of GIS and statistical analysis: lessons from the Province of Modena.

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Abstract

This paper is focused on the analysis of landslide susceptibility for civil protection purposes. A methodology was developed and applied to support measures aiming at landslide risk mitigation. It is based on GIS and the Weight of Evidence (WofE) method, which was preferred among several other statistical approaches as it is considered suitable for large areas (e.g. supra-municipal level), easy to interpret and simple to program. The latter feature is important for implementing a GIS tool aimed to facilitate Civil Protection in an advisable update of susceptibility maps. An application of the methodology was performed in a mountain and hilly area of the Northern Apennines, Italy. It is located in the Province of Modena where landslides represent a critical issue in terms of civil protection due to the recurrent damages to buildings, roads and infrastructures. According to regional Landslide Inventory Map (RER LIM), 7,865 are the occurrences in the area, 22% of which are active and the remaining are dormant, while slide and earth flow are by far the most numerous landslides. Hence, the susceptibility assessment concerned these two types of movements. The choice of the training set, based on active landslides of the RER LIM, took into account possible limitations of input data. The predisposing factors were: lithology, slope, curvature, Slope Position Index, aspect, land use, distance from roads. The validation was conducted through the PRC and SRC curve, and direct checking (comparison with past occurrences, multi-temporal orthophotos and field surveys). The resulting models predicted an acceptable number of landslides. One map for each type of landslides was produced and after combined in a unique document to improve the intelligibility in a Civil Protection framework. Besides, some tests on how to symbolize the map and further results of the research are discussed in the last part of the paper.

Keywords

Landslide; susceptibility assessment; civil protection; GIS; Province of Modena; Italy

1. Introduction

Prediction of landslide susceptibility and hazard for areas not currently subject to landsliding is fundamental for land planning and risk mitigation. At the same time, to detect which areas are most susceptible to landslide, where interventions are required priority, is an interesting challenge as resources are becoming more and more scarce and exceptional weather events which trigger landslides are increasing. Landslide susceptibility and hazard assessment is based on the assumption that hazardous phenomena that have occurred in the past can provide useful information for prediction of future occurrences (Soeters and van Westen, 1996). Many other authors agree on assuming that the same factors which triggered past landslides might cause future slope movements (Guzzetti et al., 1999; Soldati et al., 2009). Two basic methodologies are listed in relation to the analysis of the terrain conditions leading to slope instability (Soeters and van Westen, 1996): 1) direct mapping methodology (experience-driven applied-geomorphic approach), by which earth scientists evaluate direct relationships between landslides and their geomorphological and geological settings by direct observations; 2) indirect mapping methodology which consists of mapping a large number of parameters considered to potentially influence landsliding and subsequently analyzing (statistically) their contribution with respect to the occurrence of slope instability phenomena, in order to identify the relationships between the two. An important role is played by the scale of the analysis (International Association of Engineering Geology, 1976) and by the input data available (number, typology and quality), factor maps, but especially Landslide Inventory Map (LIM) quality (van Westen et al., 2005; Galli et al., 2008; Van Den Eeckhaut and Hervás, 2012). The methods of landslide susceptibility and hazard assessment are subdivided into heuristic, statistical and deterministic approaches (Carrara et al., 1995; Soeters and van Westen, 1996; Guzzetti et al., 1999). In the heuristic approach the expert opinion of geomorphologists conducting the survey is used to classify the hazard. These methods combine the mapping of mass movements and their geomorphologic settings as the main input factor for hazard determination. In the statistical approach the combination of factors which have led to landslides in the past are determined statistically, and quantitative predictions are made for areas currently free of landslides but where similar conditions exist. Finally, the deterministic approach is applicable only when the geomorphic and geological conditions are fairly homogeneous over the entire study area and the landslide types are simple. It is based on physical models (slope stability and hydrologic models), and it is generally applicable in the case of large-scale hazard zoning.

2. Geographic and geomorphologic settings

The study area is located in the Province of Modena (Italy) and it is approximately 1,300 sq km. It is intersected by the Northern Apennines and by the hills at the border of the mountain chain. The altitude ranges from 150 m to 2,165 m a.s.l. and the highest peak is Monte Cimone (Fig. 1). The main river basins are the Secchia, the Panaro and the Reno. Inside the study area there are 25 municipalities with a total population of 194,278 (Province of Modena, 2012). The physical features of the Modena Apennines landscape are the result of geomorphological processes which have been active mainly from the Upper Pleistocene on different lithological types under changing climatic and geodynamic conditions in terms of recurrence, spatial distribution and intensity (Castaldini et al., 2003; Siddiqui and Soldati, 2014). In the study area there are erosional, structural, glacial and anthropic landforms. “Calanchi” (badlands) and landslides are widespread. Selective erosion, combined with geological structures, emphasize the contrast between calcarenitic or flysch rocks and ophiolitic outcrops with the gentle landscape dominated by the marly-clayey substratum. In the upper sector of the Modena Apennines, glacial landforms and moraines, dated to the Last Glacial Maximum, characterize the territory. Lastly, human activities, both quarrying and urbanization, have heavily re-shaped its natural morphological features.

2.1. The landslide issue

Within the above framework, landslides are one of the most important geological phenomena that affect the area. According to the Region Emilia Romagna Landslide Inventory Map (RER LIM), dated to 2006 with last updates in 2011, the total number of landslides in the area is 7,865 (Fig. 2). The total surface affected by landslide is 316 sq km equating to approximately 24.2% of the study area. In total 22% of the affected area is covered by active landslides, while the remaining 78% are considered dormant. Focusing on landslide types (both active and dormant), complex landslides occupy a large area (201 sq km), secondly we have earth flows (60.41 sq km); slides cover an area of 16.8 kmq and DGSDs covers 16.4 sq km; “non-classifieds” extend for 19.46 sq km; the remains 2 sq km about are debris flows, rock falls and topples, as well as lateral spreads. The most frequent landslides are earth flows (2,723) and slides (2,812). The high number of large and periodically reactivated landslides depends primarily on geological causes, linked to the quality of rock masses and their state of physical weathering; the triggers are intense and/or prolonged precipitation events (Castaldini and Ghinoi, 2007). The reactivation of large dormant landslides still represents a threat in terms of hydrogeological risk (Bertolini and Pizziolo, n.d.).

3. Main goals

This research is an attempt to assess susceptibility for different kind of landslides in the Province of Modena (Italy) for Civil Protection purposes. It was conducted in the framework of a wider project, briefly described in the next paragraph, whose main purpose was to re-organize the geographic information system and data related to risks which affect the provincial territory. The principal goals of the research were: 1) investigate if certain slopes, considered stable at the moment, could be prone to landslide; 2) create a “priority scale” of landslide-prone areas where the local Civil Protection could concentrate their efforts to prevent and mitigate damages caused by landslides; 3) identify a simple but effective methodology to assess susceptibility in order to update the map in the future and use it as a WebGIS layer and tool.

The study area was already interested by a susceptibility analysis, based on a model at the scale of Region Emilia Romagna (Generali and Pizziolo, 2012) with some differences in assessment methodology and input data, other then goals, from what is discussed in the present paper.

4. The Risk WebGIS

Since October 2011, the Province of Modena Civil Protection work is supported by the new Geographic Information System (GIS) and advanced geoservices INSPIRE (2007/2/CEE) and OCG (Open Geospatial Consortium) compliant (Nicolini et al., 2012). Born as an evolution of the previous Data Collection System (named SRD), designed in 2001 by National Defence Department (DPCN) in Italy, and those of Emilia Romagna Region other than Province of Modena, the new GIS is intended to store and organize data necessary for assessing events and damage scenarios, during the phase of planning or when emergencies, linked to the hazardous phenomena which affect Province's territory (floodings, landslides, earthquakes, industrial or other relevant incidents, forest fires), happen. The data stored in the geodatabase are mainly from Province of Modena planning instruments (e.g. the main Province's plan, that is named PTCP 2009, emergency and other civil protection plans), but also from other public and private sources, and they concern the entire jurisdiction of Civil Protection that is the whole provincial territory from the plane to the high Apeninnes mountains. The Risk WebGIS application, developed with ESRI standard FLEX programming language, is intended for the diffusion of all the information managed by the new system (both alphanumeric than geographic; both base and thematic layers; both vectorial than raster data). Thanks to this web application, users can display and query thematic data, overlay them with base cartography (CTR – the regional technical map, ortophotos, satellite images, and so on) and print their customized maps. Moreover, the WebGIS provides users with both simple decision support tools, e.g. the one for choosing the best way to reach a location interested by an emergency or to search where Civil Protection facilities are located, than some quite advanced tools (Menu Census 2001; Fig. 3). The latter allow users to get spatial statistics without being specialists, such as information on resident population or on buildings age of a customized area (defined by users drawing a polygon) involved or susceptible to be involved by an emergency. Other than the typical GIS tools for map browsing and querying (zoom, pan, identify etc.), the WebGIS offers different interesting functionalities, some of which are based on external geoservices (e.g. the ones of Google Maps, like Street View, or the Bing ones). While the server engine (and the geodatabase) is physically installed only on a centralized machine in Marzaglia (Modena), where the Unified Centre for Civil Protection of the Province of Modena is located, the data entry client (based on ArcExplorer build 1750, a software solution for browsing GIS data distributed for free by ESRI) is also installed on users computers and available especially for the COCs (the operations centres for civil protection at a municipality level). The first large-scale emergency during which the new system was successfully tested is the 2012 Emilia Earthquake which caused 27 fatalities and damaged approximately 40,000 buildings. The application comprised the following activities: georeferencing and daily updating of the 49 emergency shelters; mapping a further 30 suitable areas for hosting people in case of worsening; and mapping the distribution of approximately 350 interventions (urgent temporary works) necessary to ensure public safety (e. g. shoring, demolition of unsafe buildings, barriers, and so on).

5. Methods for landslide susceptibility assessment

In the present study, a statistical approach, the Weight of Evidence method (Bonham-Carter, 1994) was selected to perform indirect landslide susceptibility assessment. It was selected among several statistical methods as it is considered useful in determining landslide susceptibility in large areas with complex geological and geomorphological settings (Piacentini et al., 2012), it is easy to interpret, simple to program, and patterns with complex spatial geometry can be modelled with the same computational effort as those with simple geometry (Bohnam-Carter et al., 1989). Briefly, in this method positive and negative weights (W^+_i and W^-_i) are assigned to each class of the input factor maps, to indicate if and how much its presence/absence is important for the occurrence of landslides. If the weight W^+_i is positive the presence of the factor (or of a specific classes of it) is favourable for the occurrence of landslides, while if it is negative the presence of the factor is not favourable for the occurrence of landslides. W^-_i is used to estimate the importance of the absence of the factor in relation with the landslide phenomena. So when it is positive, it means that the absence of the factor is favourable for the occurrence of landslides. The total/final weight (W_{map}) of each factor, in a multi-class map where the presence of one factor implies the absence of the other factors of the same map, is defined by the following formula:

$$W_{map} = W^+_i + W_{mintotal} + W^-_i \quad (1)$$

where $W_{mintotal}$ is the total weights in a multiclass map.

In order to quantify the spatial association between a map class and the occurrence of landslide the contrast factor C_w can be used (Bonham-Carter, 1994). It is the difference between W^+_i and W^-_i. The further the contrast factor is from zero, the more the factor is a significant predictor for the analysis. A positive contrast indicates a positive spatial correlation and vice versa for a negative contrast.

6. Input data and sampling activity

Most of the data used for the research illustrated in this paper are from the Cartography Archive of the Region Emilia Romagna (RER) and RER Geological Service (SGSS) and are primarily as follows:

- Landslide Inventory Map (2006, with last updates in 2011);
- Geological Map;
- Land Use Maps (2008 and 1976);
- Street Map 1:5,000 from the Province of Modena;
- Digital Terrain Model 5x5 m.

The top three are all at the scale 1:10,000. Considering the selected statistical approach and the research purposes (civil protection), only the most frequent types of landslides were considered, earth flows and slides (Cruden and Varnes, 1996), in the susceptibility analysis. The two types were modelled separately because their driving factors and failure mechanisms are different. As it is expected that susceptibility maps show the worst case scenario for mass movement initiation, one of the main problems encountered was that in the RER LIM scarps (depletion areas) are usually not mapped. However, the highest elevation points of the branches of each landslide polygon usually fall within the depletion area (Generali and Pizziolo, 2012). Therefore, the upper part of landslides polygons were used as training zones, assuming that they are most similar to scarps. They were extracted (Fig. 4) with a complex but semi-automatized procedure developed using ESRI ArcGIS 9.3.1 and three free extensions packages (Remove Small Polygons by Gonzalez, 2009; Find Adjacent Polygons by Buja, 2009; Topography Tools by Dilts, 2010 and Jenness Enterprise, 2006). For both landslides types, the training sets were divided into two groups thanks to random selection as follows: the calibration set (80% of the sampling polygons) to compute the model itself and the validation set (20% of the sampling polygons) to estimate its predictive power. Only active landslides were included in the training sets (van Westen et al., 2003; Poli and Sterlacchini, 2007). In the case of slides, rockslides were excluded from the analysis (the selection was based on the lithology map). The following analysis was conducted treating the two types of landslides separately as susceptibility assessment has better results if one map for each types of movement, or movements comparable for materials and failure mechanisms, is computed (Zêzere, 2002; Fell et al., 2008).

7. Factor maps

The utilized factor maps were prepared with ArcGIS 9.3.1 and its extensions for raster analysis (mainly Spatial Analyst) converting vector maps (lithology, land use and distance from roads; Fig. 5-a) in to 5x5 m cells raster maps and deriving geomorphic parameters (slope, aspect, curvature and Slope Position Index) maps from DTM 5x5 m (Fig. 5-b). The lithology map was derived from RER Geological Map 1:10,000 (11 classes). The 1976 map was employed for land use as it is the first digitally available one, assuming that the map represents land use at the date of the landslide activation or re-activation (assumption supported by the analysis of the RER Hystoric Archive data). The selection of the 13 classes were operated taking in account two facts: 1) the significance of each land use in respect with landslide phenomena; 2) the compliance with the 2008 land use map classes which is considered to be representative of the current situation. Distances from roads were obtained by buffering a vector map of State, Provincial and local roads (4 classes). The 9 aspect classes are 45° each, while the 9 classes of the two slope steepness maps (different for the two types of considered landslides) were selected on the basis of a pre-analysis of maps with more than 70 classes, one degree spaced. The curvature map classes represent the 9 possible shapes that a hill slope unit can assume (Parsons, 1988) resulting from the combination of profile and forms (concave, convex and plain), represented in two maps derived from DTM in GIS environment and subsequently overlaid using ESRI Spatial Analyst Map Algebra operators. For the Slope Position Index map, the Slope Position Classification tool of ArcGIS extension Topography Tools (Dilts, 2010; Jenness, 2006) was used to compute the 6 classes. As it is a scale dependent factor, 4 different maps were produced using an equal number of circle radiuses for performing the Focal Statistic calculation (Neighborhood type) and the resulting maps were tested in susceptibility models taking into account the dimension of landslide phenomena (SIPI 10 and 20 m for slides, SIPI 50 and 100 m for earth flows).

8. Validation

Subsequently, the above factor maps were combined to obtain 18 scenarios (9 for each landslide types) and they were evaluated using Success Rate Curve (SRC) (Chung and Fabbri, 1999, 2003, 2008; van Westen et al. 2003; Sterlacchini et al., 2011) and Prediction Rate Curve (PRC) (Chung and Fabbri, 1999, 2003, 2008; Sterlacchini et al., 2011) methods. The first one, to evaluate the model fitting performance, is applied by plotting on the x axis the cumulative percentage of susceptible areas (from highest value to the lowest one) and on the y axis the cumulative percentage of landslides occurrences of the calibration set. The latter is a similar plot, but differs from the other as on the y axis the cumulative percentage of landslides occurrences of the validation set is presented. It evaluates the predictive power of the model. The steeper is the curve (SRC or PRC), the best is the result as a greater number of landslides fall into the classes of the map with the highest susceptibility. In order to compare different curves it is possible to use the AUC (Area Under the Curve), which is the extent of the chart area under the curve expressed in percentage.

In this paper only PRC curves are shown and commented, as they are considered particularly interesting for the aim of the paper. Hence, in figures 6 and 7, PRC curve respectively for slides and earth flows, are plotted. They compare the 9 scenarios evaluated for each type of landslides. Analysing the plot in figure 6, PRC curve for slides, it can be noted that as the number of factors of the 9 scenarios increase, the curve becomes steeper. At the same time, the AUC (Area Under the Curve) increases with the increasing of the number of factor maps from 0.74 (scenario 0) to 0.78 (scenarios from 2 to 7). From the curve in the figure 6, considering scenario 4, it can be said that the 30% of the map predicts the 75% of slides in the study area, which is a good result. Analysing the plot in figure 7, PRC curve for earth flows, it can be noted that the 9 scenarios have high value of AUC except for scenarios 0 and 5. This is to be expected for the first (one factor maps), but not for the latter (five factor maps). The scenario 5 differs from the scenario 4 only for one factor (distance from roads), but the AUC of the first is only 0.72, while the AUC of the latter is 0.81. This means that introducing “distance from roads” the prediction rate worse significantly. Considering scenario 4, it can be said that the 30% of the map predicts the 80% of earth flows in the study area, which is a very good result.

9. Computing susceptibility maps

By means of the interpretation of the before mentioned curves, it was decided to use lithology, slope, land use and curvature to compute the final susceptibility maps (scenario 4 in both cases), one for slides and another for earth flows (fig. 8). In order to compute the “actual” susceptibility map, final weights from 1976 were assigned to the 2008 land use map. The following expression was used for both the susceptibility maps (slides and earth flows):

W_{maptot} = (W_{map} Lithology)+(W_{map} Slope)+(W_{map} Land Use 2008)+(W_{map} Curvature) (2)

In fact, in the previous analysis the same factors were found more predictive for both types of landslide though the influence on instability of each classes of those factors is different. In the expression (2), it can be noted that, as already mentioned, the 2008 land use map was considered to be representative of the current situation.

10. Application for civil protection purposes

10.1. Preparation of the map

Aiming to ensure a greater usability for civil protection purposes, the two susceptibility maps were integrated into a unique document and compared with the existing landslides (Fig. 9). The conditional Map Algebra expression in ESRI Spatial Analyst, utilized to perform the integration, was the following:

Con(susc_map_ef>susc_map_es,susc_map_ef, susc_map_es) (3)

where susc_map_ef is the susceptibility map for earth flows and susc_map_es is the susceptibility map for slides.

Briefly, it consists in assigning to each cell of the combined map the highest W_{maptot} value of the two orginal maps. In fact, it is often necessary to assess separately susceptibility for the different type of landslide affecting the area (i.e. for rock falls, small shallow landslides and deep-seated large landslides); these maps may be combined later onto one map (Fell et al., 2008). The susceptibility maps for each types of landslide, computed as illustrated in the above paragraph, could be useful for skilled users, such as geologists and geomorphologists, while the combined map of the (3) expression could be easier to understand for non-specialist users, such as in civil protection where users could be decision makers and disaster managers, rather than technicians. The intelligibility of the map depends also on the adopted symbology, number of classes and colours. To define class intervals is a hard task since it could strongly influence the interpretation of the map and consequently drive civil protection decisions. Anyway, it was considered that if the map is left as the GIS software automatically displays, or the number of assigned classes is too high, non-specialists users must interpret the map by themselves without having adequate knowledge on the real significance of the coloured pixels they are viewing. For this reason, two classification methodologies, among those which are available in ESRI ArcGIS, were experimented in order to define the map legend: Quantile and Natural Breaks (Jenks). A third, Equal interval methodology in which each class has an equal range of values, was dismissed a priori because it was considered not suitable for reprensenting the type of data at issue. In both cases, Quantile and Natural Breaks (Jenks) five susceptibility classes were generated (very low, low, medium, high and very high). Briefly, in the first method each class contains an equal number of features while in the latter the features are divided into classes whose boundaries are set where there are relatively big differences in the data values. In the current case, by using the Quantile methodology the ratio between negative and positive values of map cells' weights appeared more “equilibrate”. The differences between classes seemed emphasized locally. Using Natural Breaks (Jenks) method, a map was obtained in which cells with the value “medium susceptibility” and “high susceptibility” were predominant. As Natural Breaks (Jenks) is a data-specific classification, and suitable for representing unevenly distributed data, the related map was preferred and loaded in the Risk WebGIS of the Province of Modena Civil Protection for a trial period that is still to be concluded.

10.2. Comparison with multi-temporal orthophotos and field data

In order to perform a direct checking of the output maps quality, they were compared with existing landslides in RER LIM (Fig. 8), orthophotos (AGEA 2008 and 2011) and field surveys (fig. 10). The latter were carried out in a sample area and provided good result as is shown in figure 10: landslide clues and warning signs (scarp retrogression, typical morphologies, sags in the road etc.) correspond to the areas of the map classified as medium to very high susceptibility. In addition, the comparison with the orthophotos provided a positive result in most cases for all the three susceptiblity maps (earth flows, slides and combined). Very frequently where landslide from RER LIM are located, the maps' cells are classified as medium to very high susceptibility, even if in some cases they are classified as low susceptibility. The reasons may be different: 1) the susceptibility assessment reported in the present paper did not take into account all types of landslide; 2) the input data might have some lack of information; 3) after the landslide occurrence it might be reached a new equilibrium. In any case, it must be remembered that the three susceptibility maps represent the “initiation points”, namely points or areas where new mass movements could initiate. Therefore, while comparing susceptibility maps with the existing landslides from RER LIM, rather than considering the landslide body it must verified what classes are assigned to the area of scarps and/or upstream of them. An interesting case is shown in Fig. 11 in which the orthophoto a) is the AGEA dated 2008 and b) is the AGEA dated 2011. The map in figures c) and d) is the combination susceptibility map of figure 11. The c) version is obtained with Natural Breaks (Jenks) method while the d) is made by means of Quantile method (see previous paragraph). The polygon with the blue outline is a landslide reactivation. The movement is located in the Secchia Basin near the large and well-known landslide of Boschi di Valoria (Manzi et al., 2004). It is mapped in the RER LIM and classified as active complex landslide. In the 2008 orthophoto (Fig. 11-a) the landslide appears to be dormant; only the scarp is visible. On the contrary, in the 2011 orthophoto its reactivation is conspicuous. The area of the reactivation is classified as "medium", "high" and "very high" susceptibility in both maps (Fig. 11-c and 11-d). In the Quantile version of the map (Fig. 11-d) there is a high compliance with the zone of the scarp. This example (not significant for the issue discussed in the previous paragraph about the symbolization methodology) highlights that the evaluation of the risk on an area like that of figure 11-a could be reviewed from Civil Protection during planning activities by examining the susceptibility map. This is even more important considering that landslide reactivations could damage buildings and infrastructures as in figure 5-b where a road is intersected by the mass movement body.

10.3. The updating issue

One of the main challenges in cartography is to maintain the data steadily updated. The availability of updated data is fundamental for civil protection purposes. For this reason, a simple but effective procedure was developed using Model Builder in ESRI ArcGIS 9.3.1. It is based on the following assumption: the most part of the landslides driving factors, used before for computing susceptibility maps, can be considered static except for land use which is surely subject to a rapid evolution and therefore is dynamic. When a new land use map becomes available, it can be converted in raster and its classes uniformed with those of the 1976 land use map. After that it can be reclassified using weights calculated on 1976 land use map and added to the other weighted maps (slope, lithology and curvature) in order to obtain the new susceptibility map. Thanks to the Model Builder tool "Update SMap" (Fig. 12), even non-specialist users are able to perform these kind of operations for each landslide map (earth flows and slides), and subsequently the two updated maps could be combined into one using the conditional expression (3) in ESRI Spatial Analyst Map Algebra.

10.4. Discussion

The susceptibility analysis led to a better comprehension of the most important factors for slope instability in the study area. It made available new susceptibility maps useful for Civil Protection purposes in Province of Modena that can be loaded as thematic layers in the Risk WebGIS, including the input factor maps (e.g. lithology, slope, aspect, curvature, slope position index and distance from roads). The final susceptibility map documents are good decision support tools suitable for the elaboration of events' scenarios in the framework of Civil Protection forecast and prevention programs. When overlaid with elements at risk (such as buildings, roads and other infrastructures, population etc.), that is easy to be performed with the Risk WebGIS, Civil Protection can obtain damage scenarios useful for the provincial emergency plan on hydrogeological risk. The 1:10,000 map scale, consistent with those of the input data, makes them usable for wide area (supra-municipal) forecast and prevention purposes like provincial territory is. Other than the resultant susceptibility maps, the analysis itself highlighted weak points and gaps of the existing inventory map that could be partly fixed by Civil Protection. In fact, Province of Modena Civil Protection collects data on landslide from municipalities, by means of the SRD (data collecting system), the module connected with the Risk WebGIS, and stores them in the geodatabase. Highlighted gaps could drive a revision of the data collection forms. About the updating issue, the tool implemented for updating susceptibility maps could be used also for a small part of the territory, when new data on land use are available partially, or to design landslide susceptibility scenarios assuming a variation of land use.

11. Final considerations and conclusions

The present paper deals with the issue of risk forecasting in Civil Protection, which consists of activities aimed to study and detect what are the causes of hazardous events, namely landslides, as well as to identify areas particularly prone to mass movements for zoning them and plan measures to mitigate related risk. In the case of the Province of Modena, earth flows and slides happen frequently and are widespread, hence they generate critical situations for the population, damaging infrastructure, especially roads, and sometimes buildings. They often require the intervention of Civil Protection even when they are not extensive. Thus, a susceptibility assessment for these two types of landslides was performed and described in the present paper. Considering the above mentioned limitations due to input data, the resulting models predict an acceptable number of landslides. In both cases, earth flows and slides, the final susceptibility map is the sum of the following weighted factor maps: lithology, slope, land use and curvature. They resulted to be the most important factors which drive landslide phenomena in the study area. In order to take into account current situation, weights calculated by means of the 1976 land use map (assumed to be the situation before the existing landslides occurred) was assigned to those of 2008. Therefore, two susceptibility maps were computed for as many types of landslides. These documents are useful for skilled users but difficult to be interpreted by non-specialists, such as Civil Protection users who were supplied with a third document resultant from the combination of the two maps. In order to increase the intelligibility of the map even more, two classification methods of ESRI ArgGIS were tested to symbolize the map: Quantile and Natural Breaks (Jenks). The range of weight values were grouped into only five legend classes. In fact, an excessive number of classes could confuse the user and lead to a wrong interpretation of the map information content. Both tests on the two classification methods led to good results, but the Natural Breaks (Jenks) method was preferred to continue the test that is still to be concluded. In fact, at this point the map was considered ready to be loaded in the Risk WebGIS of the Province of Modena Province Civil Protection.

The example of figure 11 demonstrates how the susceptibility maps can be useful for Civil Protection in order include in their plans some landslide apparently dormant in certain period of time.

Another issue to be faced was the “updating question”, well known in cartography. Maps risk to age before users become familiar with them. Hence, some custom tools were developed for ESRI ArcGIS with Model Builder assuming that only land use is a dynamic factor. The procedure is simple enough to allow even users with little experience of GIS to update maps.

Having worked on a wide study area (about 1300 sq km), using a quite detailed DTM (5x5), and a statistical method easy to apply (Weight of Evidence) which has also allowed the development of an automated GIS procedure for updating the landslide susceptibility maps, makes what is illustrated in this paper an example for other Civil Protection organizations, other than Province of Modena one. In fact, if on the one hand Civil Protection needs detailed data, on the other hand at a supra-municipal level an overview of hazardous phenomena is required to perform planning activities. In addition, what was done to make the susceptibility maps more intelligible in a context of Civil Protection, issues often not investigate from whom assess landslide susceptibility, responds to the intention of the paper even this point requires to be treated more deeply in future.

In conclusion, the experience conducted in the framework of the research discussed in this paper is exportable to other Civil Protection contexts where the integrated planning among stakeholders (i.e. regions, provinces, municipalities etc.), the constant and dynamic updating of geographic information, as well as an efficient system to share them (namely WebGIS applications), is considered strategic for risk forecasting and preventing, and emergency management.

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Figure captions

Figure 1. Location of the study area in Italy and in Province of Modena.

Figure 2. Landslide tyes and distribution in the study area (elaboration from RER LIM data).

Figure 3. The Risk WebGIS of the Province of Modena Civil Protection and some of its advanced functionalities (Menu Census 2001).

Figure 4. Schematic representation of the main steps utilized to extract the upper part of landslide polygons in ESRI ArcGIS 9.3.1.

Figure 5. The whole set of factor maps introduced in landslide susceptibility assessment performed by using WofE methodology; a) shows vector factor maps; b) shows the DTM derived maps. The figure also reports the list of classes for each factor,

the resultant weights and contrast factor (W^+_i, W^-_i and C_w) for each types of landslides. In figure 5-a for description of lithology classes was preserved the acronymous used in RER Geological Map.

Figure 6. PRC Curve of the 9 scenarios computed for slides (L = lithology; S = slope; U = land use; A = aspect; C = curvature; R = distance from roads; SP10 = Slope Position Index (SIPI) 10 m; SP20 = SIPI 20 m).

Figure 7. PRC Curve of the 9 scenarios computed for earth flows (L = lithology; S = slope; U = land use; A = aspect; C = curvature; R = distance from roads; SP50 = Slope Position Index (SIPI) 50 m; SP100 = SIPI 100 m).

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Figure 10. Direct checking of resultant susceptibility maps quality performed by means of field surveys in a sample area (Corlo Basin in the municipality of Fiorano Modenese).

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Figure 12. The Model Builder scheme of ESRI ArcGIS reporting operations needed to update the susceptibility maps. The tool designed for updating slide susceptibility map is shown in the figure; the one for earth flow map is similar.

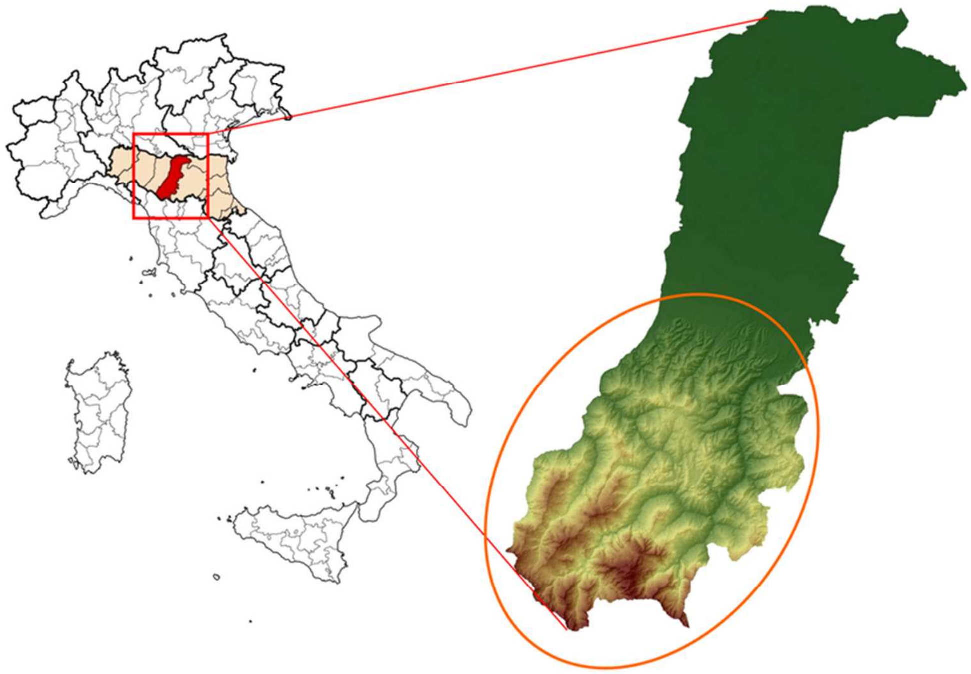


Figure 1. Location of the study area in Italy and in Province of Modena.
72x51mm (300 x 300 DPI)

LANDSLIDE (LS) TYPE	sq km (all LS)	Nr. of poligons (only active)
Slides (S)	16.8	**1854**
Complex landslides (CL)	201	360
Earth flows (EF)	60	**1683**
Debris flows (DF)	0.64	18
Not classified landslides (NC)	19.4	117
DGSDs	16.4	-
Rock falls (RF)	0.03	4
Lateral spreads (LSP)	2.23	-

TOT Nr. of Landslide: 7858
TOT Area of Landslide: 316.5 sq km
Landslide index: 24.2%
Active: 22% of total area of LS
Dormant: 78% of total area of LS

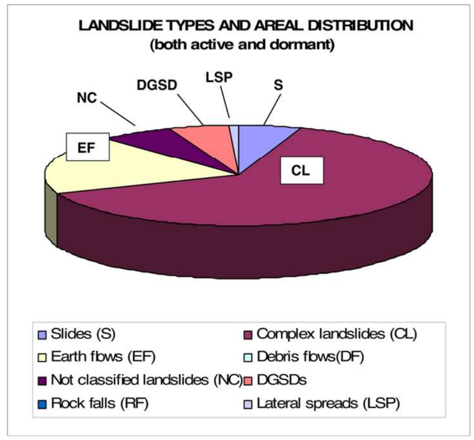


Figure 2. Landslide types and distribution in the study area (elaboration from RER LIM data).
134x74mm (300 x 300 DPI)

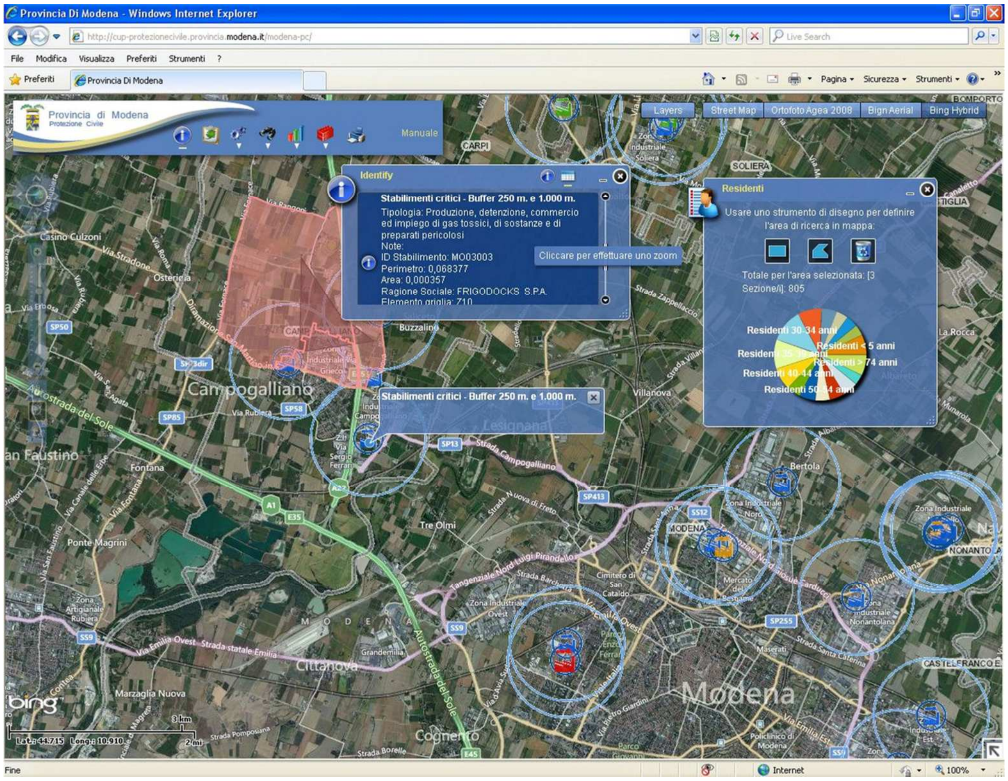


Figure 3. The Risk WebGIS of the Province of Modena Civil Protection and some of its advanced functionalities (Menu Census 2001).
117x91mm (300 x 300 DPI)

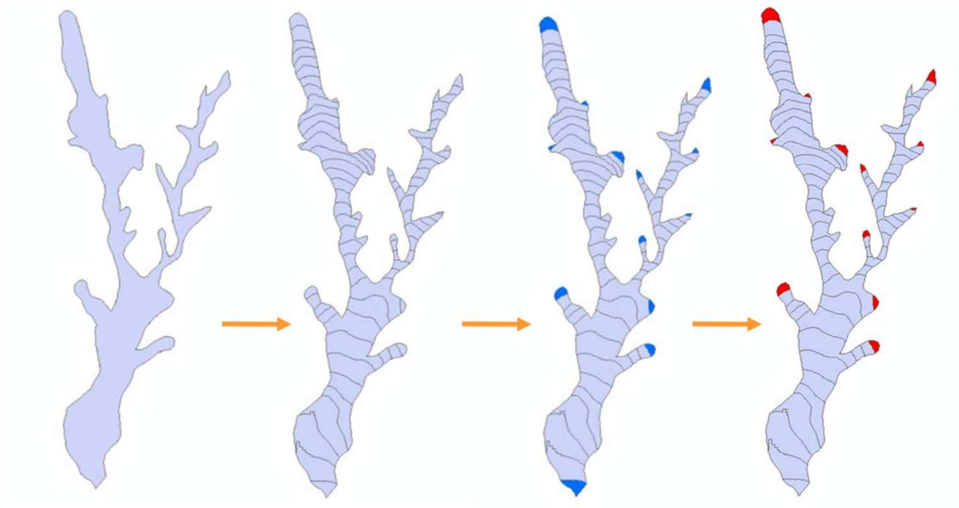
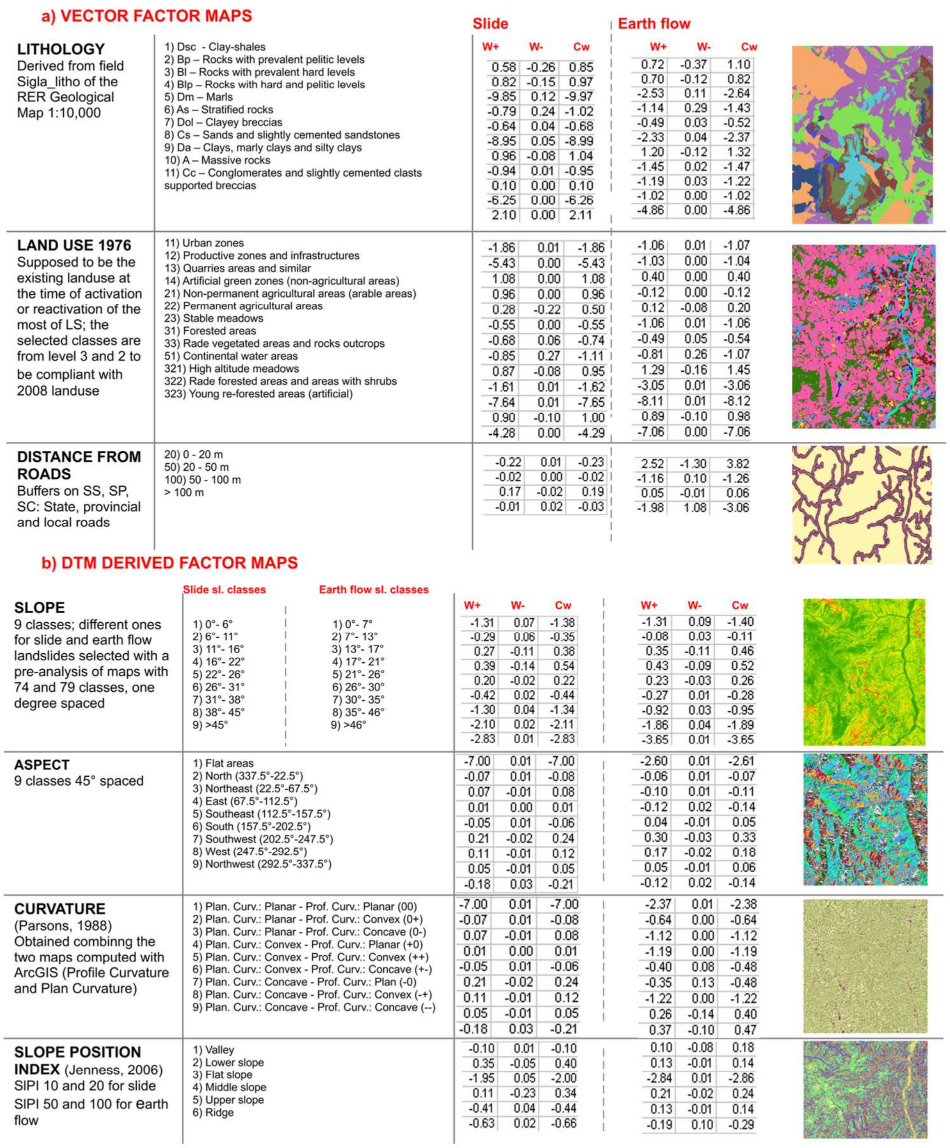


Figure 4. Schematic representation of the main steps utilized to extract the upper part of landslide polygons in ESRI ArcGIS 9.3.1.
92x53mm (300 x 300 DPI)



a) VECTOR FACTOR MAPS

LITHOLOGY
Derived from field Sigla_litho of the RER Geological Map 1:10,000

1) Dsc - Clay-shales
2) Bp – Rocks with prevalent pelitic levels
3) Bl – Rocks with prevalent hard levels
4) Blp – Rocks with hard and pelitic levels
5) Dm – Marls
6) As – Stratified rocks
7) Dol – Clayey breccias
8) Cs – Sands and slightly cemented sandstones
9) Da – Clays, marly clays and silty clays
10) A – Massive rocks
11) Cc – Conglomerates and slightly cemented clasts supported breccias

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
0.58	-0.26	0.85	0.72	-0.37	1.10
0.82	-0.15	0.97	0.70	-0.12	0.82
-9.85	0.12	-9.97	-2.53	0.11	-2.64
-0.79	0.24	-1.02	-1.14	0.29	-1.43
-0.64	0.04	-0.68	-0.49	0.03	-0.52
-8.95	0.05	-8.99	-2.33	0.04	-2.37
0.96	-0.08	1.04	1.20	-0.12	1.32
-0.94	0.01	-0.95	-1.45	0.02	-1.47
0.10	0.00	0.10	-1.19	0.03	-1.22
-6.25	0.00	-6.26	-1.02	0.00	-1.02
2.10	0.00	2.11	-4.86	0.00	-4.86

LAND USE 1976
Supposed to be the existing landuse at the time of activation or reactivation of the most of LS; the selected classes are from level 3 and 2 to be compliant with 2008 landuse

11) Urban zones
12) Productive zones and infrastructures
13) Quarries areas and similar
14) Artificial green zones (non-agricultural areas)
21) Non-permanent agricultural areas (arable areas)
22) Permanent agricultural areas
23) Stable meadows
31) Forested areas
33) Rade vegetated areas and rocks outcrops
51) Continental water areas
321) High altitude meadows
322) Rade forested areas and areas with shrubs
323) Young re-forested areas (artificial)

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-1.86	0.01	-1.86	-1.06	0.01	-1.07
-5.43	0.00	-5.43	-1.03	0.00	-1.04
1.08	0.00	1.08	0.40	0.00	0.40
0.96	0.00	0.96	-0.12	0.00	-0.12
0.28	-0.22	0.50	0.12	-0.08	0.20
-0.55	0.00	-0.55	-1.06	0.01	-1.06
-0.68	0.06	-0.74	-0.49	0.05	-0.54
-0.85	0.27	-1.11	-0.81	0.26	-1.07
0.87	-0.08	0.95	1.29	-0.16	1.45
-1.61	0.01	-1.62	-3.05	0.01	-3.06
-7.64	0.01	-7.65	-8.11	0.01	-8.12
0.90	-0.10	1.00	0.89	-0.10	0.98
-4.28	0.00	-4.29	-7.06	0.00	-7.06

DISTANCE FROM ROADS
Buffers on SS, SP, SC: State, provincial and local roads

20) 0 - 20 m
50) 20 - 50 m
100) 50 - 100 m
> 100 m

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-0.22	0.01	-0.23	2.52	-1.30	3.82
-0.02	0.00	-0.02	-1.16	0.10	-1.26
0.17	-0.02	0.19	0.05	-0.01	0.06
-0.01	0.02	-0.03	-1.98	1.08	-3.06

b) DTM DERIVED FACTOR MAPS

SLOPE
9 classes; different ones for slide and earth flow landslides selected with a pre-analysis of maps with 74 and 79 classes, one degree spaced

Slide sl. classes	Earth flow sl. classes
1) 0°- 6°	1) 0°- 7°
2) 6°- 11°	2) 7°- 13°
3) 11°- 16°	3) 13°- 17°
4) 16°- 22°	4) 17°- 21°
5) 22°- 26°	5) 21°- 26°
6) 26°- 31°	6) 26°- 30°
7) 31°- 38°	7) 30°- 35°
8) 38°- 45°	8) 35°- 46°
9) >45°	9) >46°

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-1.31	0.07	-1.38	-1.31	0.09	-1.40
-0.29	0.06	-0.35	-0.08	0.03	-0.11
0.27	-0.11	0.38	0.35	-0.11	0.46
0.39	-0.14	0.54	0.43	-0.09	0.52
0.20	-0.02	0.22	0.23	-0.03	0.26
-0.42	0.02	-0.44	-0.27	0.01	-0.28
-1.30	0.04	-1.34	-0.92	0.03	-0.95
-2.10	0.02	-2.11	-1.86	0.04	-1.89
-2.83	0.01	-2.83	-3.65	0.01	-3.65

ASPECT
9 classes 45° spaced

1) Flat areas
2) North (337.5°-22.5°)
3) Northeast (22.5°-67.5°)
4) East (67.5°-112.5°)
5) Southeast (112.5°-157.5°)
6) South (157.5°-202.5°)
7) Southwest (202.5°-247.5°)
8) West (247.5°-292.5°)
9) Northwest (292.5°-337.5°)

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-7.00	0.01	-7.00	-2.60	0.01	-2.61
-0.07	0.01	-0.08	-0.06	0.01	-0.07
0.07	-0.01	0.08	-0.10	0.01	-0.11
0.01	0.00	0.01	-0.12	0.02	-0.14
-0.05	0.01	-0.06	0.04	-0.01	0.05
0.21	-0.02	0.24	0.30	-0.03	0.33
0.11	-0.01	0.12	0.17	-0.02	0.18
0.05	-0.01	0.05	0.05	-0.01	0.06
-0.18	0.03	-0.21	-0.12	0.02	-0.14

CURVATURE
(Parsons, 1988)
Obtained combinng the two maps computed with ArcGIS (Profile Curvature and Plan Curvature)

1) Plan. Curv.: Planar - Prof. Curv.: Planar (00)
2) Plan. Curv.: Planar - Prof. Curv.: Convex (0+)
3) Plan. Curv.: Planar - Prof. Curv.: Concave (0-)
4) Plan. Curv.: Convex - Prof. Curv.: Planar (+0)
5) Plan. Curv.: Convex - Prof. Curv.: Convex (++)
6) Plan. Curv.: Convex - Prof. Curv.: Concave (+-)
7) Plan. Curv.: Concave - Prof. Curv.: Plan (-0)
8) Plan. Curv.: Concave - Prof. Curv.: Convex (-+)
9) Plan. Curv.: Concave - Prof. Curv.: Concave (--)

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-7.00	0.01	-7.00	-2.37	0.01	-2.38
-0.07	0.01	-0.08	-0.64	0.00	-0.64
0.07	-0.01	0.08	-1.12	0.00	-1.12
0.01	0.00	0.01	-1.19	0.00	-1.19
-0.05	0.01	-0.06	-0.40	0.08	-0.48
0.21	-0.02	0.24	-0.35	0.13	-0.48
0.11	-0.01	0.12	-1.22	0.00	-1.22
0.05	-0.01	0.05	0.26	-0.14	0.40
-0.18	0.03	-0.21	0.37	-0.10	0.47

SLOPE POSITION INDEX (Jenness, 2006)
SIPI 10 and 20 for slide
SIPI 50 and 100 for earth flow

1) Valley
2) Lower slope
3) Flat slope
4) Middle slope
5) Upper slope
6) Ridge

Slide W+	Slide W-	Slide Cw	Earth flow W+	Earth flow W-	Earth flow Cw
-0.10	0.01	-0.10	0.10	-0.08	0.18
0.35	-0.05	0.40	0.13	-0.01	0.14
-1.95	0.05	-2.00	-2.84	0.01	-2.86
0.11	-0.23	0.34	0.21	-0.02	0.24
-0.41	0.04	-0.44	0.13	-0.01	0.14
-0.63	0.02	-0.66	-0.19	0.10	-0.29

Figure 5. The whole set of factor maps introduced in landslide susceptibility assessment performed by using WofE methodology; a) shows vector factor maps; b) shows the DTM derived maps. The figure also reports the list of classes for each factor, the resultant weights and contrast factor (W^+_i, W^-_i, and C_w,) for each types of landslides. In figure 5-a for description of lithology classes was preserved the acronymous used in RER Geological Map.
135x167mm (300 x 300 DPI)

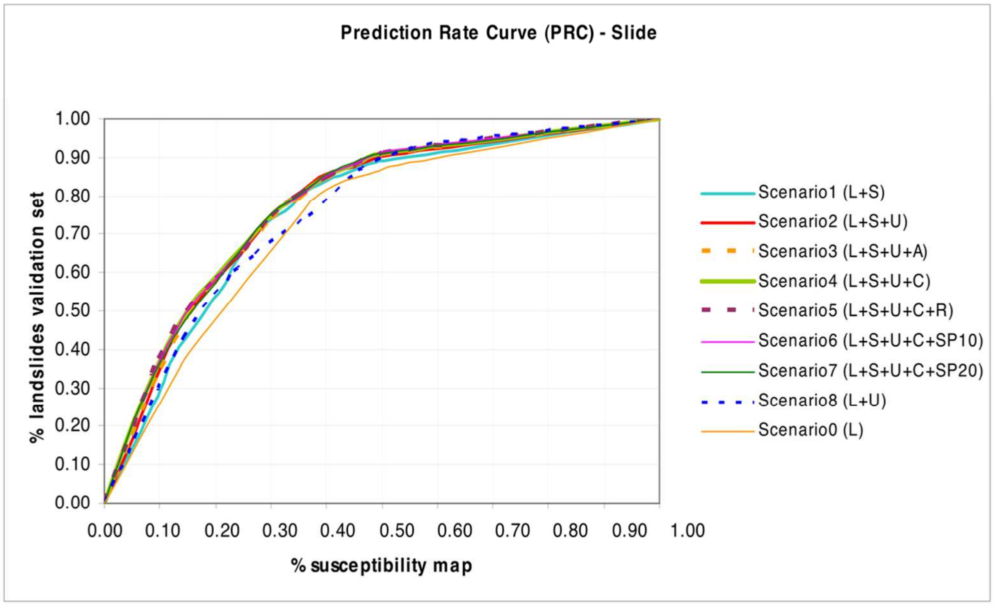


Figure 6. PRC Curve of the 9 scenarios computed for slides (L = lithology; S = slope; U = land use; A = aspect; C = curvature; R = distance from roads; SP10 = Slope Position Index (SlPI) 10 m; SP20 = SlPI 20 m).
107x65mm (300 x 300 DPI)

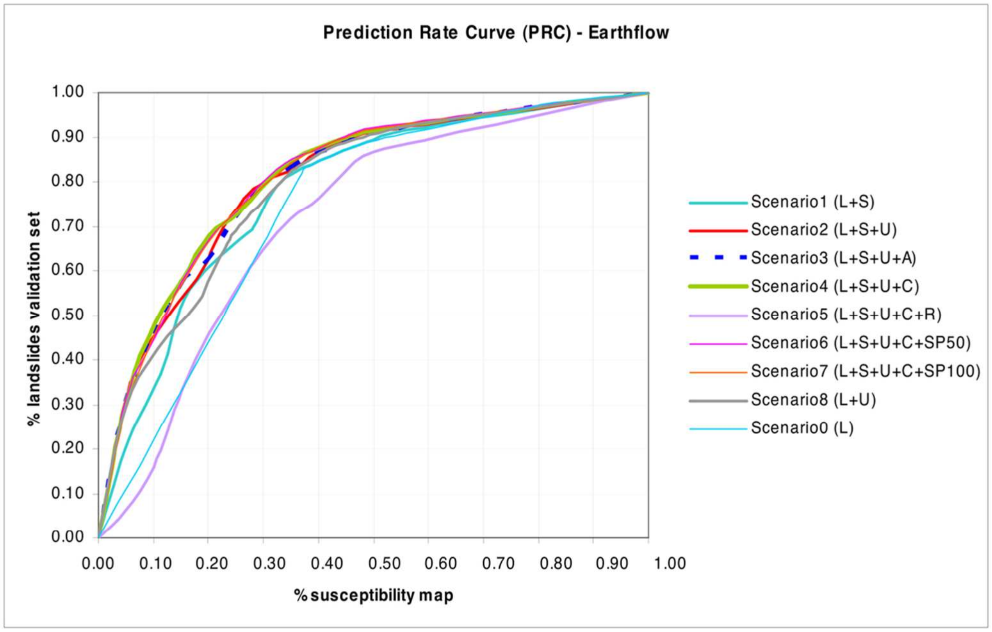


Figure 7. PRC Curve of the 9 scenarios computed for earth flows (L = lithology; S = slope; U = land use; A = aspect; C = curvature; R = distance from roads; SP50 = Slope Position Index (SlPI) 50 m; SP100 = SlPI 100 m).
104x67mm (300 x 300 DPI)

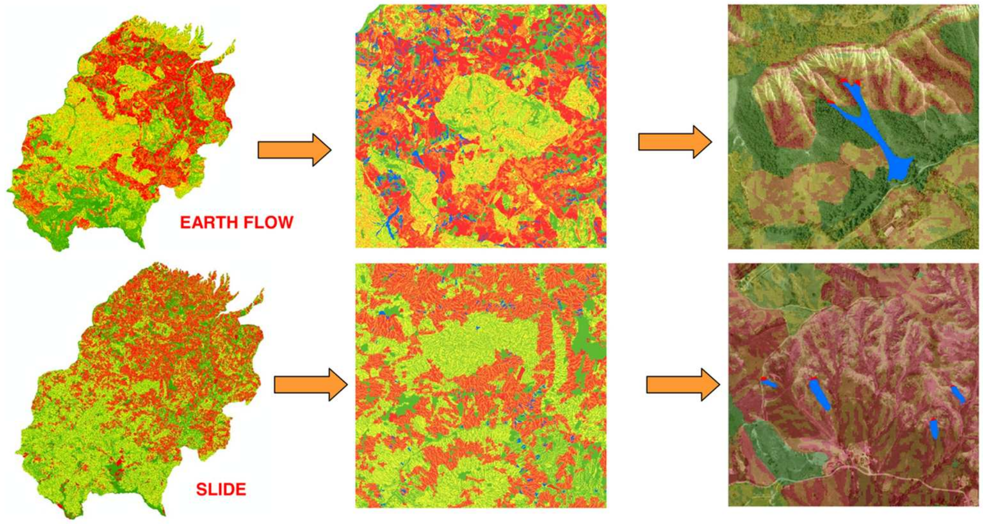
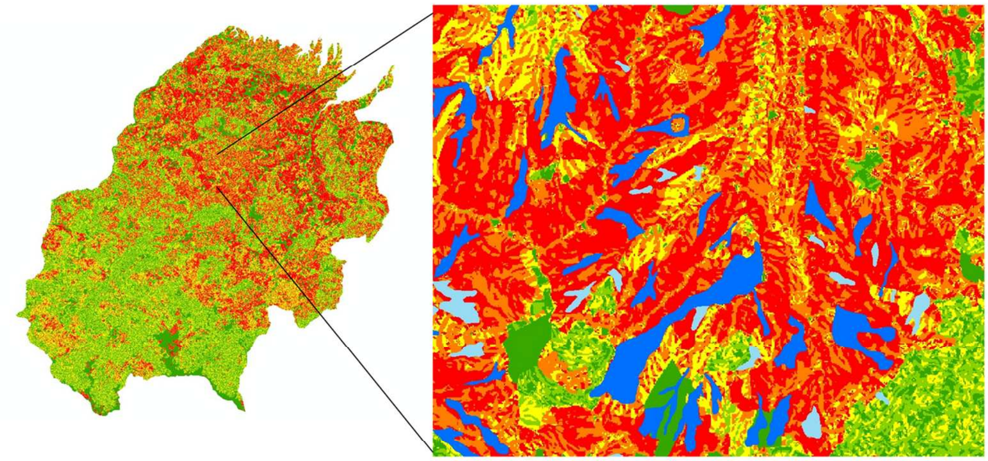


Figure 8. Susceptibility maps for the two types of landslide and a comparison with the existing landslides (red/blue polygons in the third image).
118x62mm (300 x 300 DPI)



MAP ALBEBRA: Con(susc_map_ef>susc_map_es, susc_map_ef, susc_map_es)

Figure 9. The combination of the two susceptibility maps (the existing landslides are in blue and cyan).
119x67mm (300 x 300 DPI)

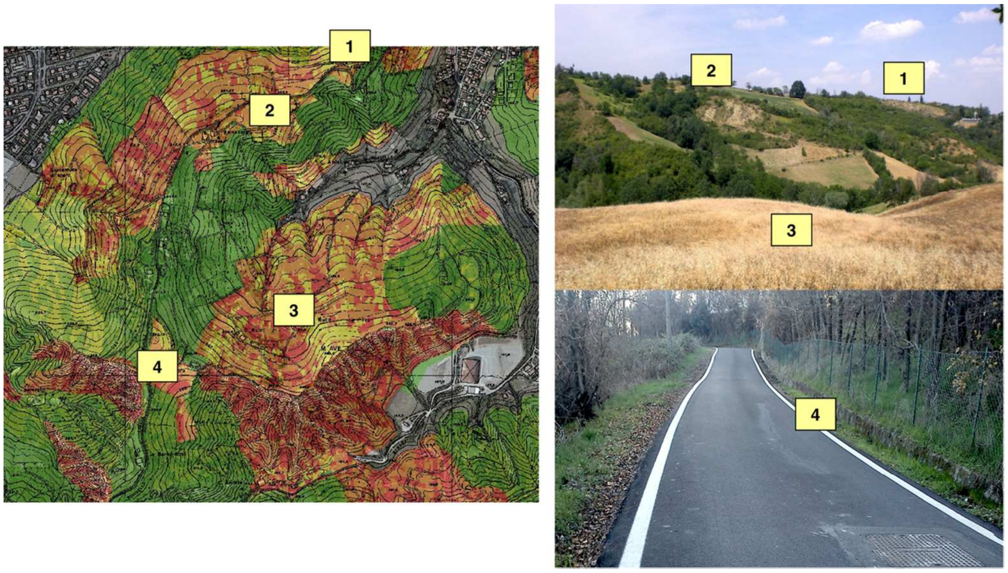
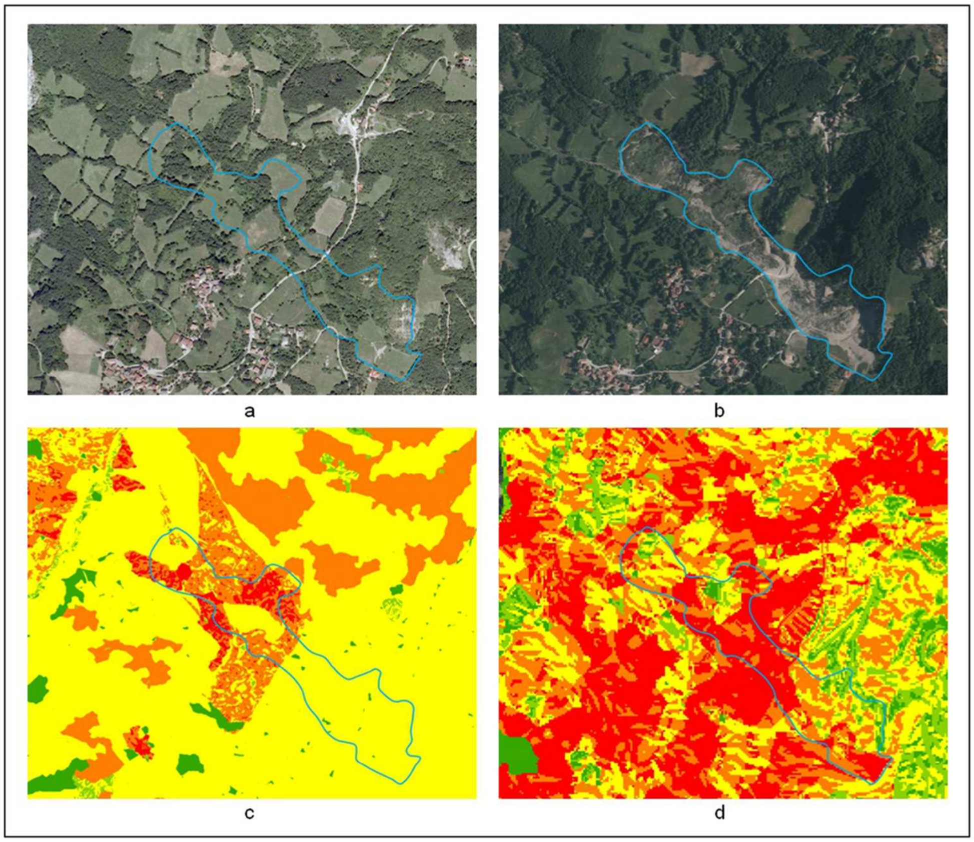


Figure 10. Direct checking of resultant susceptibility maps quality performed by means of field surveys in a sample area (Corlo Basin in the municipality of Fiorano Modenese).
112x63mm (300 x 300 DPI)



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102x89mm (300 x 300 DPI)

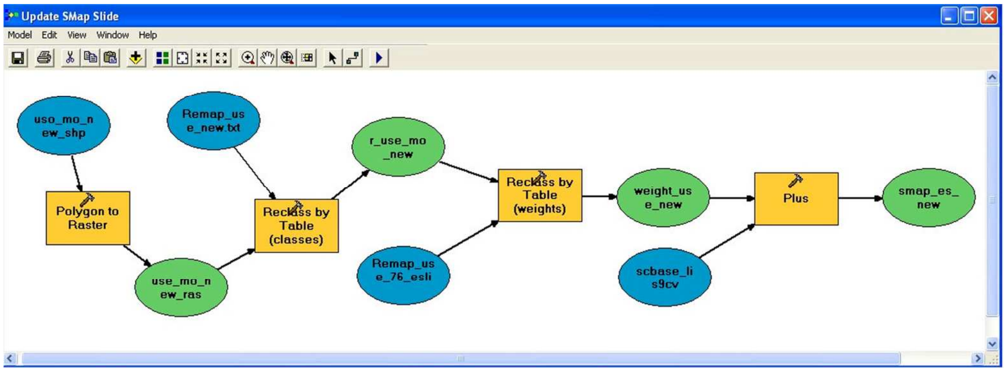

Figure 12. The Model Builder scheme of ESRI ArcGIS reporting operations needed to update the susceptibility maps. The tool designed for updating slide susceptibility map is shown in the figure; the one for earth flow map is similar.
146x53mm (300 x 300 DPI)