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Multi-Temporal Landslide Susceptibility Maps and Future Scenarios for Expected Land Cover Changes (Southern Apennines, Italy)

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Abstract

Human activities, including extensive land use practices, such as deforestation and intensive cultivation, may severely affect the landscape, and have caused important changes to the extent of natural forests during the last century in Southern Italy. Such changes had a strong influence on the frequency of occurrence of natural hazards, including landslides. Being one of the most significant control factors of slope movements, any variation in land cover pattern may determine changes in landslide distribution. The study area is the Rivo Basin which is located in Molise (Southern Apennines of Italy), a region severely affected by landslides. We prepared multi-temporal land cover and landslide inventory maps, aimed at developing different susceptibility maps to evaluate the effects of land cover changes in the predisposition to landslides. Based on the observed land cover trends in the study area, we simulated future scenarios of land cover in the attempt to assess potential future changes in landslide distribution and susceptibility. By investigating the relationship between the spatial pattern and distribution of past land cover settings and location factors (as elevation, slope, distance to settlements), we were able to calibrate a land cover change model to simulate future scenarios. The obtained results give important information both regarding the impact of past trends of land cover changes on landslide occurrence and possible future directions. They could be useful to provide insights toward a better land management for the study area, as well as for similar landslide-prone environments in Southern Italy, contributing to establish good practices for future landslide risk mitigation.

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Introduction

Spatial and temporal distribution of landslides occurrence is strongly influenced by natural and human factors. One of the most important factors is the land cover that controls not only the spatial distribution of landslides, but also their effects and impacts on elements at risk. Therefore, landslide hazard and risk should be considered through a dynamic approach, by taking into account global and local changes (such as those regarding the land cover).

Land cover is a highly dynamic factor, it changes due to natural and anthropogenic actions such as economic development, population growth or decrease and land management (Promper et al. 2014). It can be considered also one of the most rapid drivers of global change (Slaymaker et al. 2009) and may be subjected to rapid modifications (Reichenbach et al. 2014).

In Italy, due to the profound social and economic rearrangements in a post-war environment, many significant changes have occurred after World War II. The most significant ones concerned industrialization and urbanization with extensive abandonment of hilly and mountainous rural areas (Antrop 2004; Mazzoleni et al. 2004). In other sectors, the increase of agricultural and breeding lands in lowland areas was observed (Falcucci et al. 2007). This made it possible to meet the growing demand of goods by the increasing population, in order to maximize food production and reduce the related costs (Falcucci et al. 2007; Pelorosso et al. 2011; Bracchetti et al. 2012).

In this study, we analyze local changes in land cover and landslide distribution (in terms of where and how) for a small catchment, the Rivo basin, located in the Molise region of Southern Italy.

The attention toward understanding the influence of land cover changes on mass movement distribution is rising in the research community. There are for instance recent studies in different regions of the world analyzing the effects of past land management and land cover changes on slope stability (Bruschi et al. 2013; Guns and Vanacker 2014; Reichenbach et al. 2014). Furthermore, several works address future projections as well (Promper et al. 2014).

The aim of this study is to capture the types and distribution of past land cover changes for two time intervals (1954–1981, 1981–2007) and their effects on slope instability. With this purpose, three landslide inventory maps for these two time spans have been produced and used to obtain landslide susceptibility maps by means of the Spatial Multi-Criteria Evaluation (SMCE) approach. The obtained maps have been compared in order to detect the location and severity of the effects of land cover changes on landslide predisposition. Furthermore, we developed a spatially explicit land cover change allocation model, to simulate a plausible scenario for 2030. Based on historic trends, these projected land cover changes are used to understand future effects on landslide susceptibility.

Understanding the past and future land cover changes in the study area could give important information, useful for decision-makers especially in those areal sectors where multi-temporal analysis has never been carried out. Furthermore, given the influence of land cover changes on the landslide hazard and the distribution of elements at risk as well, a multi-temporal analysis can produce suitable data for land-management strategies and risk reduction measures.

Study Area

The Rivo basin is located along the Adriatic side of the Molise region, in a hilly-low mountain sector, characterized by elevations ranging from 230 to 980 m a.s.l. It has an extension of 82 km^2 and is part of the Trigno River catchment which crosses most of Molise region in NE-SW direction, perpendicular to the Adriatic coastline (Fig. 1). The Rivo catchment is subject to a warm temperate climate (Aucelli et al. 2006) and characterized by monthly temperatures between 8 and 30 °C, with mean annual precipitations ranging from 600 to 850 mm and mainly concentrated between October and February.

From a geological standpoint, the Rivo basin is located in the sheet 393 “Trivento” of the Geological Map of Italy in scale 1:50,000 (ISPRA). The outcropping geological formations consist mainly of clays and marly clays, sands and sandstones, marls and marly limestones and, locally, of limestones and limestone breccias (Aucelli et al. 2001).

The variety and distribution of these lithologies are related to the tectonic setting of the area which also strongly influences its morphology. In general, harder lithologies like marly limestones, limestones and limestone breccia give origin to the highest peaks emerging from the surrounding gentle hilly landscape, which dominates the area and is mainly shaped in the weaker clays (Borgomeo et al. 2014).

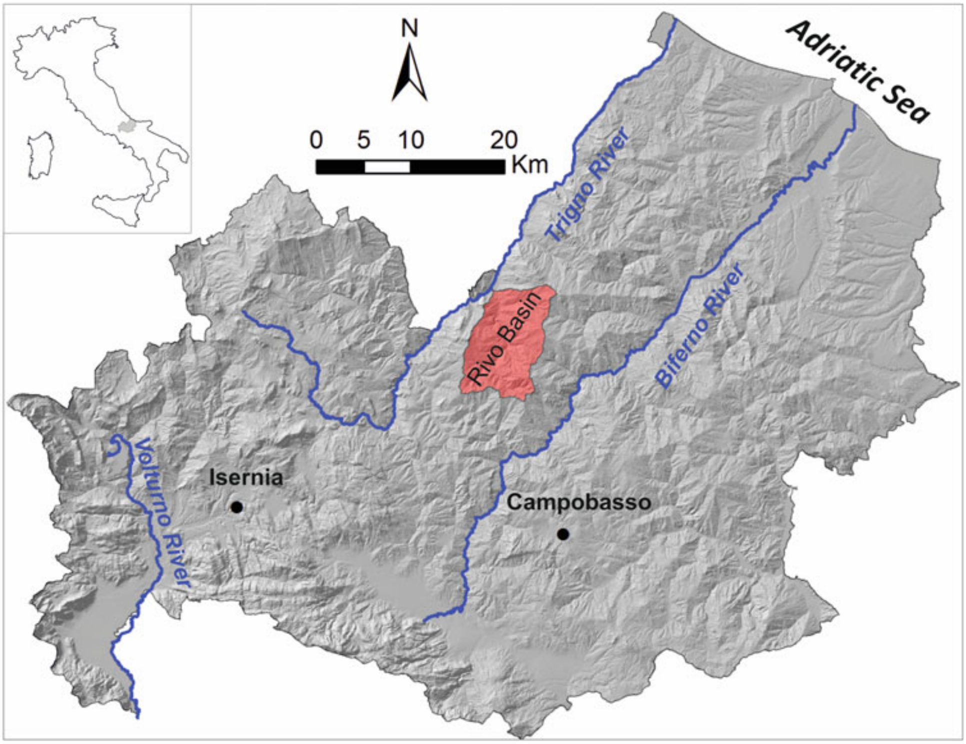

Fig. 1 Study area location in the Molise region (Italy)

The slopes formed by weak lithologies with predominantly clay component are widely affected by landsliding and other mass movements. Landslides are mainly represented by earthflows and complex earth-slide-earthflows, and are primarily triggered by rainfall (Rosskopf and Aucelli 2007; Borgomeo et al. 2014). These movements are typically located along slopes that are directly connected to river incisions and, therefore, often affected by undercutting. They are mostly dormant and relatively shallow (maximum depth 4 m).

Data and Methods

The work is structured in three main parts, namely the landslide and land cover mapping for the selected past years, the related landslide susceptibility analysis, and the evaluation of future scenarios (land cover and related landslide susceptibility projection).

Multi-Temporal Land Cover and Landslide Mapping

The analysis of land cover changes was carried out through the following steps: 1—aerial photo interpretation and production of homogenous land cover maps; 2—analysis of land cover changes and landscape dynamics through the use of parametric indices; 3—landscape pattern stability analysis based on land cover type, by means of the evaluation of rates, sizes and shapes of the various changing patches.

The analyses were conducted using the GIS software ESRI Arcgis 10.0 to investigate a total time interval of 53 years (1954–2007) divided into two distinct periods, 1954–1981 and 1981–2007, respectively.

As concerns the years 1954 and 1981, the aerial photographs from the Italian Geographic Military Institute (IGMI) (http://www.igmi.org/) were scanned in digital format with a resolution of 800 dpi. For the year 2007, an integration of the 2003 aerial photographs and the 2007 orthophotos was used. The aerial photographs were ortho-rectified using the ERDAS LPS software. The ortho-rectification was based on a DEM (Digital Elevation Model) with 5 × 5 m cells. In order to obtain a good accuracy, for each aerial photograph at least 12 GCPs (Ground control point) together with 20 Tie points (points of connection) and 3 control points (check points) were detected.

Land cover mapping was operated at scale 1:5000, choosing a Minimum Map Units (MMU) of 50 × 50 m (Bracchetti et al. 2012) with each cell having a size equal to 2500 m^2, in order to facilitate the photo-interpretation. The distinguished land cover classes are settlements, cropland, forest land, grassland, wetland, shrubland and bare land (modified after the IPCC-GPG-LULUCF classification, see Marchetti et al. 2012). Choice of the classes was essentially linked to two factors: (1) the difficulty to distinguish the sub-classes in low-quality aerial photo sets, and (2) more sub-classes with similar contribution to the slope stability are combined into a single class.

As regards landslides, one of the key elements of the work was to detect with the maximum possible accuracy only the landslides developed in the selected period of time and environment (i.e. land cover type). Therefore, only the landslides that showed evidence of recent movement, such as clear scarp and deposit zones, and related change in the vegetation pattern, were considered. These landslides were mapped by contouring the entire body and classified according to Cruden and Varnes (1996).

The multi-temporal landslide database was built by using a digital stereoscopic visualization (digital photogrammetry) that simplifies the acquisition of features which can be stored directly in a GIS database, and reduces the acquisition time and associated errors (Ardizzone et al. 2013).

Multi-Temporal Landslide Susceptibility

The multi-temporal landslide susceptibility analysis was carried out using the Spatial Multi-Criteria Evaluation (SMCE) approach. This is an expert based, semi quantitative approach integrated in the open source GIS software ILWIS (ITC 2007). The SMCE approach is based on the conceptual model of the Analytical Hierarchical Process (AHP) developed by Saaty (1980). The SMCE application helps users to perform multi-criteria assessment for a defined problem. The model is organized by using a criteria tree whose root represents the problem defined by the user, whilst its branches are the sub-goals or alternatives. The user is guided towards a criterion weighting and standardizing process by the software tool in which the criteria are spatially defined by maps, and the final output is a composite index map which is calculated by adding up the performance of all cell values of the different criteria for the particular alternative (Castellanos Abella and van Westen 2007).

The use of this approach was driven by the aim to obtain comparable final maps through an equable methodological approach between the past landslide susceptibility and the future 2030 scenario, hence, a no-landslide site dependent method was required to perform the analysis. Another convenience of this method is represented by the fact that the expert plays a key role in the weighting procedure, and the variables weights can be maintained constant in each performance.

For this application, seven predisposing factors have been selected. The geomorphological conditions of the study area are represented by slope gradient, internal relief, aspect and altitude; these factors are coupled to the distances to roads, lithology, and land cover. In addition, in order to evaluate the possible contribution of rainfall in the observed changes of the multi-temporal susceptibility, rainfall data coming from the Trivento raingauge station have been preliminarily analyzed.

The SMCE was performed for each investigated year starting with the definition of the problem and the set up of the criteria tree. The factors were standardized using the direct ranking method and the factor's classes applying the maximum standardization method based on the landslides density for each class.

To validate the susceptibility maps, the area under curve (AUC) of the receiver operating characteristic (ROC) curve was used. This method is based on obtaining a curve by plotting the true positive rate (sensitive) against the false positive rate (1-specificity) at various threshold settings (Pourghasemi et al. 2012).

Land Cover and Landslide Susceptibility Scenario for 2030

A spatially explicit land cover allocation model in Dinamica EGO, a raster based GIS platform (Soares Filho et al. 2002), was developed. The model was divided into two parts: spatial land cover allocation and non-spatial scenario demand (amount of land cover).

First, the spatial part was calibrated. We performed an analysis of spatial drivers on past land cover changes. Using the Bayesian method weights of evidence (WoE), we analyzed the significance of the following location factors: distance to settlements, distance to roads, elevation, slope, aspect and curvature. Afterwards, a cellular automata (CA) allocation algorithm with the observed long-term land cover trends (1954–2007) was calibrated. CA models are often used in detailed scale land change studies, as they can successfully simulate decision making. For example, future urban expansion is the more likely situation to occur near existing settlements. The model was trained with the observed landscape metrics of land cover changes, i.e. the mean size of new urban, forest, cropland, etc. patches. In this way it was possible to capture a more realistic spatial pattern of the potential future changes.

The non-spatial scenario demand part was also based on the observed changes, with slight modification. Future forest land, grassland, cropland, shrubland and settlement changes all followed the past trends. Bare areas were considered stagnant. Although there had been an increase in cropland between 1954 and 2007, we allowed the model to simulate a decrease in cropland until 2030. This finds its reason in the recent ongoing forest expansion which represented the most significant process in terms of spatial extent. For this reason forests at the expense of cropland areas, as they were the most suitable for expansion. Although the non-spatial part is an extrapolation of past trends, we wanted to analyze the potential consequences of the continuation of the observed land cover change processes.

The landslide susceptibility scenario was obtained using the abovementioned methodology for the other time intervals. In this case, the density scores used as class weights for the geomorphological factors were the same as before, while for the roads and the land cover the mathematical projections of the landslide densities for each class were used.

Results

Land Cover and Landslide Distribution Maps

From the observation of the obtained maps, it was possible to catch the land cover distribution in 1954, 1981 and 2007, respectively (Fig. 2). The land cover in 1954 was composed by croplands, occupying more than 50% of the whole area, followed by forest land and grassland with approximately 21 and 14%, respectively.

The comparison of the maps highlighted that over the entire analyzed period (1954–2007) major changes concern the expansion of forest land and the reduction of grassland, shrubland and bare land.

The relative increment of forest land consists in more than 11%, whilst grassland and bare land are reduced by two-thirds. The histogram in Fig. 2 shows that the relative increments in forest land occurred rather steadily during the entire analyzed period, while the reduction of grassland and shrubland was greater during the second period (1981–2007). Other land cover classes such as settlements, wetland and bare land had a very small extension in 1954 and their overall changes were very small; nonetheless the relative increase of settlements was about ten times greater, whilst wetland decreased of about two-thirds. Analyzing the

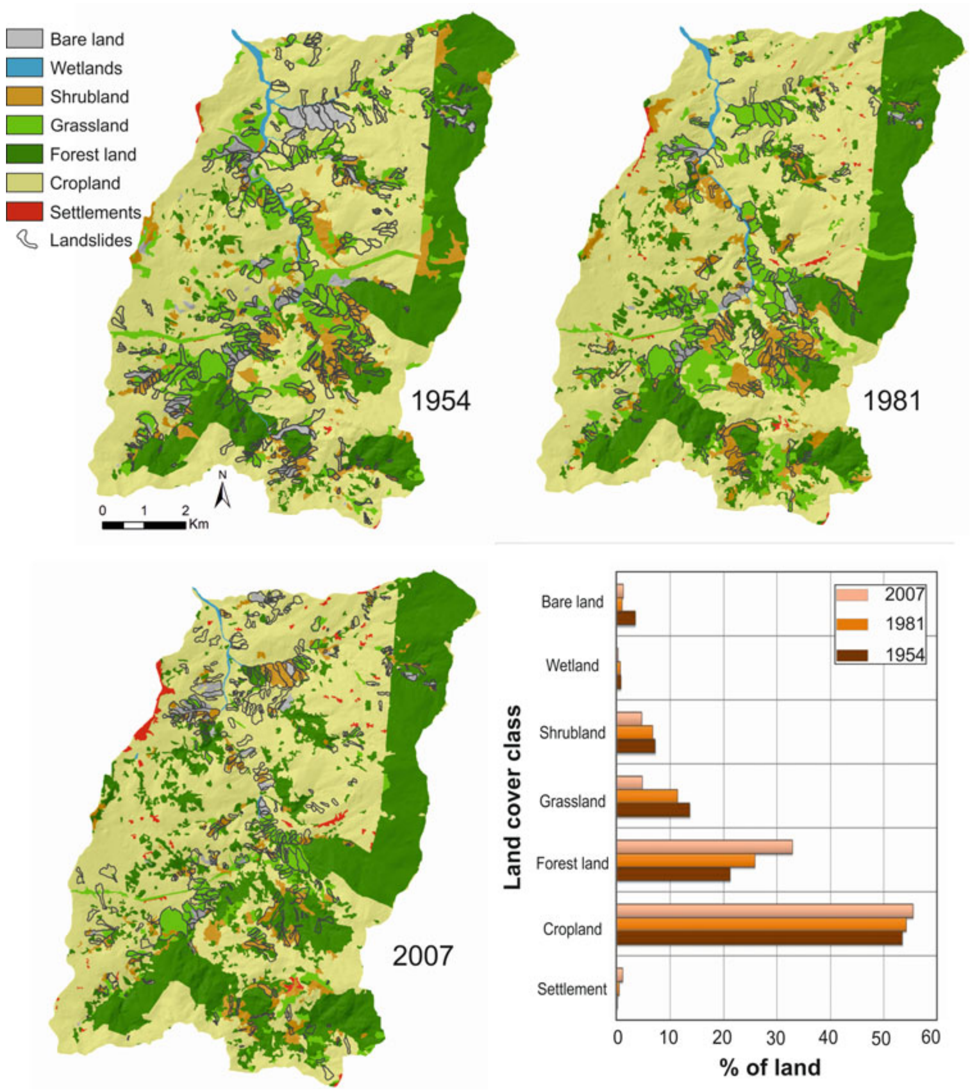

Fig. 2 Multi-temporal land cover maps (1954, 1981 and 2007). Extent (in percentage) of land cover classes during each year is reported in the histogram

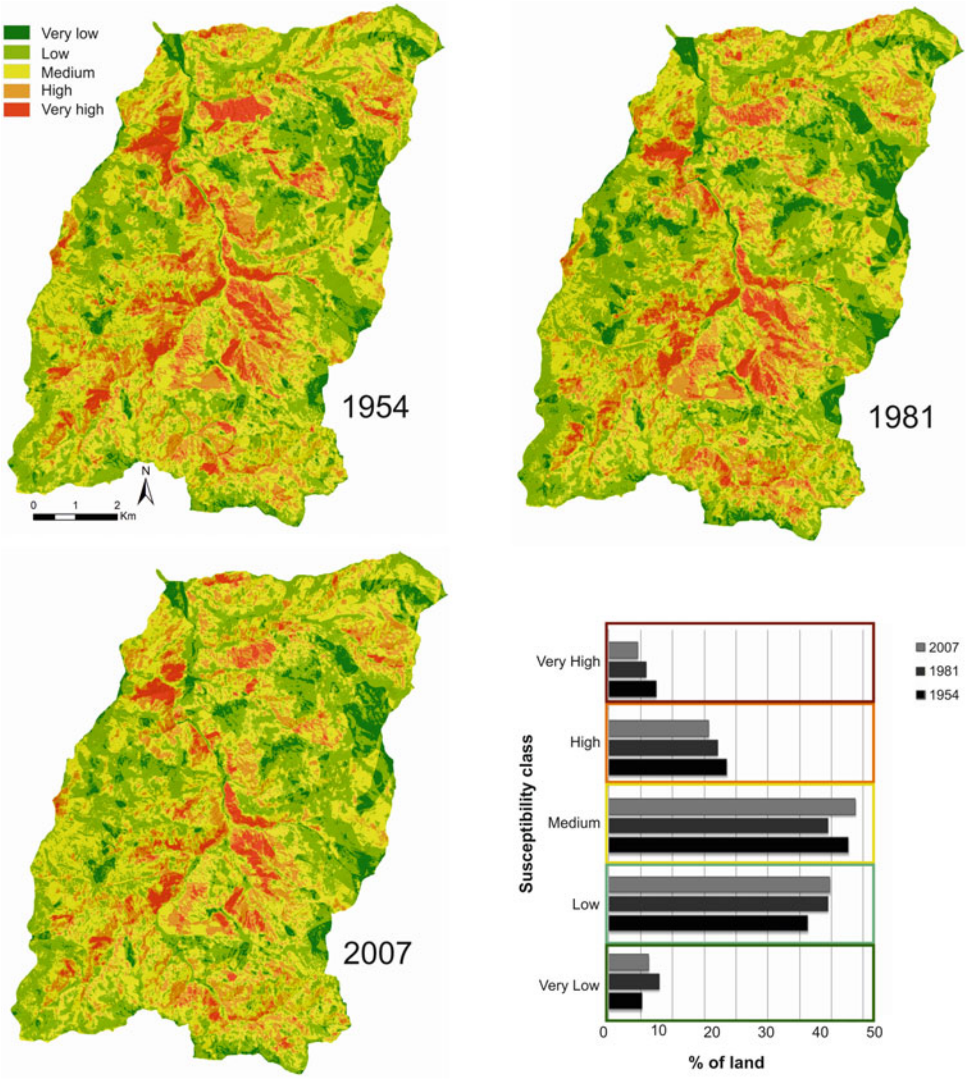

Fig. 3 Multi-temporal landslide susceptibility maps obtained for 1954, 1981, 2007. In the histogram the variation of the susceptibility class in each year

transition of land patches from one class to another that resulted in the above mentioned total changes, some interesting information emerged. In the first period (1954–1981), the most evident transitions were from grassland to cropland and from shrubland to forest land. From 1981 to 2007, major transitions occurred from shrubland to forest land, from grassland to cropland and from grassland to shrubland.

The areal extent of mapped landslides allowed us to determine that in 1954, 12.8% of the study area was covered by landslides, and this percentage reduced to 8.8% in 1981, and to 8.6% in 2007. For what concerns the relationship between landslide density and land cover typologies, the analysis showed that the highest landslide densities characterized the categories bare land (50%), grassland (25%) and shrubland (15%) for year 1954, with similar values for the other two years investigated, whilst the remaining land cover types were characterized by densities lower than 5%.

In the presented analysis the comparison of landslide inventories did not take into account the possible influence of rainfall on landslide distribution over time and space. This is due to the fact that the analysis of rainfall data for the time range analyzed at the Trivento weather station did not reveal any significant variations in annual rainfall of the antecedent years with respect to those analyzed, or during the wet season (October–March) before it.

Multi-Temporal Landslide Susceptibility Maps

The obtained susceptibility maps (1954, 1981, 2007) have been reclassified in five classes from very low to very high, using the following class limits: 0.35, 0.45, 0.55, 0.65, >0.65.

They show satisfying AUC ROC values, namely 0.78 for 1954, 0.83 for 1981 and 0.82 for 2007.

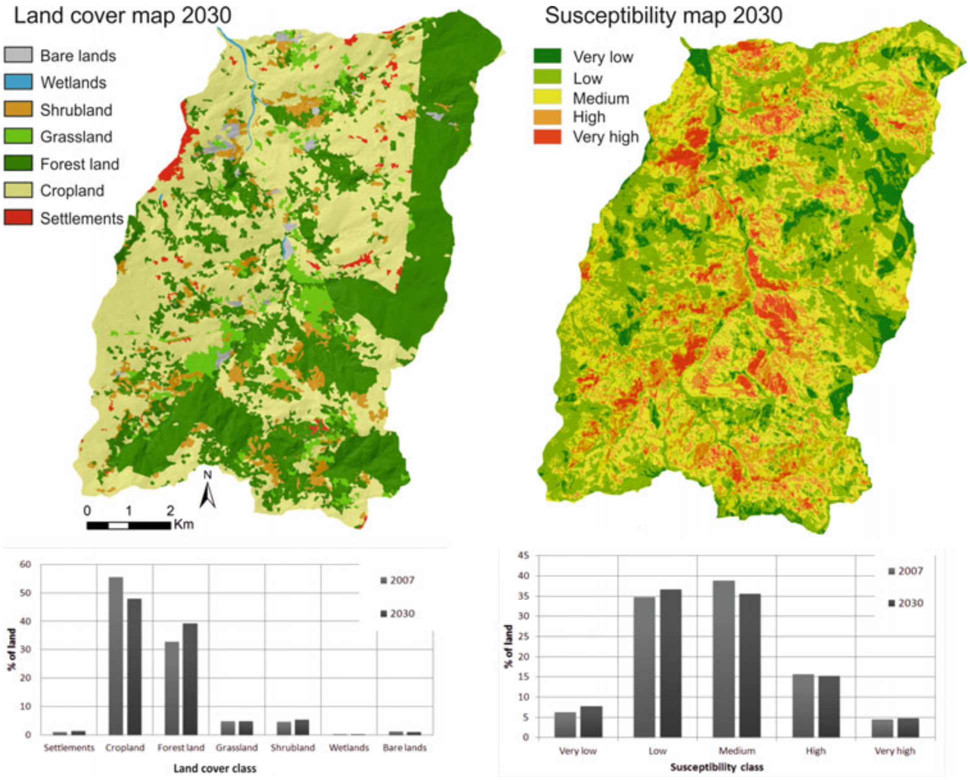

Fig. 4 Land cover and landslide susceptibility scenario for 2030. Histograms show the changes with respect to the correspondent map of 2007

The susceptibility maps (Fig. 3) show a decrease in the extension of the highest susceptibility classes (very high and high), and a correspondent increase of the lowest ones (very low and low). In fact, summing up the high and very high classes of each analyzed year, it is possible to appreciate a decrease of their extension with respect to the total area, from 25.9% in 1954 to 23.03% in 1981, and 20.19% in 2007.

In particular, between 1954 and 1981 the area that shows a decrease in susceptibility is 19.96%, whilst 7.62% shows an increase. Combining the susceptibility changes with the previously analyzed land cover transitions, the obtained information suggests for the first time interval (1954–1981) that the most outstanding decrease of susceptibility has occurred where the land cover changed from grassland to cropland (~5% of the total area).

Another important decrease occurred in correspondence of the transition from shrubland to forest land (~2%). Other changes close to 1% are recorded at the change from bare land to grassland or to shrubland. Conversely, an increment is mainly registered at the transition from cropland to grassland and from cropland to shrubland (respectively 2.7 and 1.3%).

For period 1981–2007, a decrease in the extension of the highest susceptibility classes of about 3% is registered. Most of the changes occurred in correspondence of the transition of grassland to cropland and of shrubland and grassland to forest land.

Land Cover and Landslide Susceptibility Scenario for 2030

The multi-temporal assessment of the influence of land cover on slope stability (addressed here as landslide susceptibility) was completed with a scenario projection for 2030.

The simulated land cover map for 2030 shows only minor changes. This is likely due to the short time period analyzed, but also to the fact that the developed scenario does not take into account any major changes in the study area due to land management or extreme natural events as forest fires. Despite this, it was possible to observe a decrease of cropland and an increase of forest land (Fig. 4).

The obtained land cover map was used as input data for the susceptibility analysis. The output map is indicating an increase of 3.5% in the low and very low classes which corresponds to decrements of 3.18% in the medium and high classes with respect to the entire study area. The main increases occurred where the scenario has modeled the transition from cropland to shrubland or to grassland. On the other hand, a decrease in susceptibility was registered where shrubland and cropland changed to forest land.

Discussion and Conclusion

We used multi-temporal information to investigate the effects of land cover changes on the spatial distribution of landslides in a small catchment in the southern Apennines of Italy. The analysis performed in the Rivo catchment covers a period of 53 years between 1954 and 2007; moreover, a possible land cover change scenario for 2030 was analyzed.

In this study, multi-temporal landslide susceptibility maps have been produced for 1954, 1981, 2007 and 2030 and investigated in order to highlight possible differences due to land cover changes. The comparison of the maps reveals a general decrease of the highest susceptibility classes for the past time interval, attributable primarily to the conversion of grassland and bare land respectively to cropland and to grassland and shrubland, and, secondly, to the change of shrubland to cropland and forest land. It is therefore possible to assume that the forest has a stabilization effect, together with the cropland; while the first one is well documented in literature (Schwarz et al. 2010; Caviezel et al. 2014) for cropland areas there might be some controversial issues. Despite the numerous previous studies sustaining the negative effects of cropland on slope stability (Begueria 2006; Wasowski et al. 2014), in our case the transition from land cover types that do not foresee any human action (or land abandonment), such as from bare land or grassland to cropland, is showing a positive effect on the spatial distribution and extent of landslides. In fact, for the analyzed catchment it is possible to state that the presence of cultivations requires a correct water control resulting in a much desired maintenance action of the land, possibly resulting in a reduction of slope instability. Increase in slope stability is confirmed even in a minor extent in the 2030 scenario where an increment of forest land is foreseen.

The performed study can be an explanatory example of what may also be observed in other sectors of the Italian Apennine with similar geo-environmental and rural structures. The information obtained can be helpful to lead toward improved land management if taken in consideration by stakeholders during land planning actions.

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