International Conference
Analysis and Management of Changing Risks for Natural Hazards
18-19 November 2014 l Padua, Italy

Abstract Code: AP8

Landslide hazard zonation using GIS environment: an example from Calore river basin (southern Italy)

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Keywords:
Risk Maps, Landslides Hazard, GIS environment, Indicator Model, Rainfall.

Abstract
This study aims at deriving an indicator mapping that analyses landslide hazard studying past precipitations. The proposed method takes into account the daily critical storms and the normalized antecedent cumulate precipitation related to a landslide density index. The result is a simple model workable on a relative large scale (50-100 km). To test the model, we used three landslide records available on the study area (Benevento province, southern Italy) triggered by rainfall events in 1997 (AVI Project), 2003 and 2005 (Guadagno et al., 2006). The rain gauges used were different for the three years due to the availability of data, but they evenly covered the study area. The critical threshold applied was rearranged from De Paola and Diodato (1999) on the basis of events that occurred in the autumn-winter season. The results were plotted at a grid resolution of 1 x 1 km. The related hazard index suggested five hazard classes: no hazard, low hazard, medium hazard, high hazard and very high hazard. Among the rainstorm events, the one occurred in 1997 results as being the most damaging, having the high and very high hazard classes . This is evident by the presence of the hazard classes that were slightly spread out. In the remaining two events, 2003 and 2005, there was greater competition between the classes. On the 1997 map, the high and low hazard areas were well distributed along the whole SW-NE direction. Conversely, the 2003 and 2005 maps show the high and very high hazard classes that are spreaded in an almost homogenous way on the north-east sector of the province. From a hydrological point of view, the 1997 events occurred in late autumn, producing intense phenomena with widespread storms and associated shallow landslides. The 2003 and 2005 landslides are similar events because they occurred at the end of winter. Currently there is an on-going evaluation in relation to return periods and critical rain changes over time for some locations where a long series of rainfall data is available.

Introduction

Landslide hazard is very high in Italy due to the fact that much of its hilly and mountainous areas are or could be affected by different types and sizes of landslides (Guzzetti et al. 2000). These landslides cause different damage to people, as well as to the environment (Glade, 1998). Therefore, landslide hazard and risk maps are essential in spatial planning to minimize social impact (Martha et al., 2013). In addition, rainfall represents the most common triggering factor (Martelloni G. et al., 2012). In regions where landslide records are available,

it is possible to look for relations between landsliding and rainfall (Corominas and Moya, 1999), reaching to obtain landslide hazard zonation maps to be used for landslide forecasting. The conceptual approach comprises variable space and time-scales of system evolution and external system control (Jaiswal and Westen, 2009). Moreover, landslide hazard zonation techniques can be generally subdivided into direct and indirect methods (Papathanassiou et al., 2012).
Benevento Province area is prone-area to landslides due to several factors such as, geologic, and geomorphologic but there are two important factors that contribute to the landslides triggering as the rains and earthquakes so, feedbacks become even more complex (Armbruster 2002). In this area, the rainfall represents the most common triggering factor (Martelloni et al., 2011).
Here we used GIS environment for indirect mapping in which rainfall factors are combined with a landslide conditioning factors, because it is very suitable for this type mapping (Bonham-Carter 1994; Chung et al. 1995; van Westen et al. 2003).The goal of this study is to split the territory in different landslide hazard areas, from those less to very likely landslides affected. Here we were derived a Shallow Landslide Indicator Mapping (SLHIM) model. This is an indicator for predicting of the landslides that have occurred in the past after rainfall event, considering both daily critical storm, normalized antecedent cumulate precipitation and a landslide index, a simple model workable on large scale.

Characteristics of the study area

The Benevento Province, which extends for about 2,000 kmq, is in one of the most geologically complex areas of the Southern Apennines. Marine successions from the Cretaceous to the Pliocene and continental deposits of Pleistocene age outcrop in the area. The morphology is strongly influenced by the structural setting. The western portion of the province is characterized by the presence of calcareous mountains, while the eastern sector has a hilly morphology. In contrast, the central area is a depression where marine and continental clastic deposits of Pleistocene age outcrop and through which the main rivers flow (Revellino et al., 2010). The erodibility of the rock types, related to lithology and rising gradients of slopes, contributes to the identification of large areas characterized by the presence of erosions (Diodato, 2006), and disseminated superficial landslides mainly due to the action of the surface layer as creep and gullies, set mainly on clayey-marly flysch and Red Clays Varicolori, with weak slope (<10%) (Guadagno et al., 2006).
The landsliding processes are the result of the complex geological setting and evolution of the region, so a large part of the area can be considered one of high risk (Guadagno et al. 2005; Revellino et al. 2008). Landslides were inventoried by Guadagno et al. (2006) resulting in about 18% of the whole surface affected by slope instability, which are predominantly shallow.

Methods and Data sources

We have developed a model for the assessment of the landslide hazard using: i) a static component, the landslide index, and ii) a dynamic component, that is rainfall. We used landslides records available for the study area and related to 1997 (AVI Project, http://wwwdb.gndci.cnr.it/), 2003 and 2005 (Guadagno et al., 2006) rainfall events. This choice derived for the fact that are landslides data available and for the particular conditions of rain occurred (Fiorillo and Guadagno 2007). In the figure 1 are the rain gauges used are different for the three years based on the data availability but evenly covering the study area. The precipitation threshold was estimated by events that occurred in the autumn winter season and jointly identifies the 59 days of antecedent cumulate rainfall and the critical rainfall that occur in the neighborhood area just before of the event (De Paola and Diodato, 1999) and rearranged for our model.

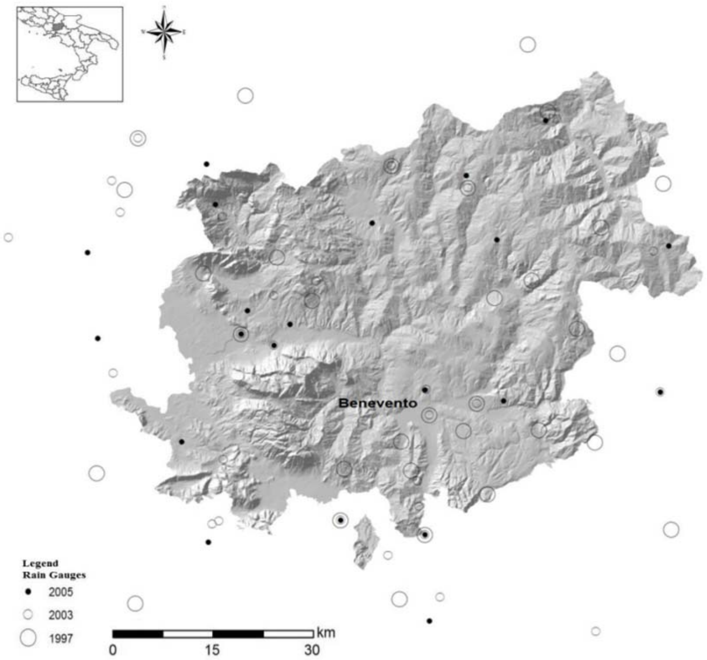

Fig. 1 - Distribution of rain gauge for three different events considered (1997, 2003, 2005) across Benevento Province.

This flow-process shows the steps of this work as boxes of various kinds and their order by connecting them with arrows (fig. 2). This to represent in a schematic and synthetic solution adopted to achieve the objective of this work. In order to help visualize what is going on. Firstly was the collection of historical data; as regards the space component data considered were inventory landslide and the parameter maps in digital format, a database that is need to know the features of landslide. We have been used and georeferenced in the system geographic coordinate WGS84 the shape files data for the inventory landslides and reclassified raster files for the maps parameters. Through an empirical way we assessed the SLHIM model with both antecedent rain data, daily rain in neighbour of the event and landslide density index (LI_r) reclassified from Revellino et al., 2010. The rainfall data obtained were interpolated on the threshold graph, and then reported in environment GIS trough tabular format to raster with the same cells of LI_r. The critical rainfall maps obtained were downscaled through Geostatistical Analysis with Inverse Distance Weighting tool. Map calculator multiplying the dynamic and static factors tool estimated the spatial probability per each cells (1x1 km) grid and subsequently hazard scenarios validated to several years were obtained. It was assumed that the occurrence landslides are conditioned by rainy periods of N days and when the precipitation on antecedent days exceeds certain threshold values. To determine the N value were reconstructed the curves cumulating backlinks daily rains that anticipated the landslide from the days associated with the highest number of events areas.

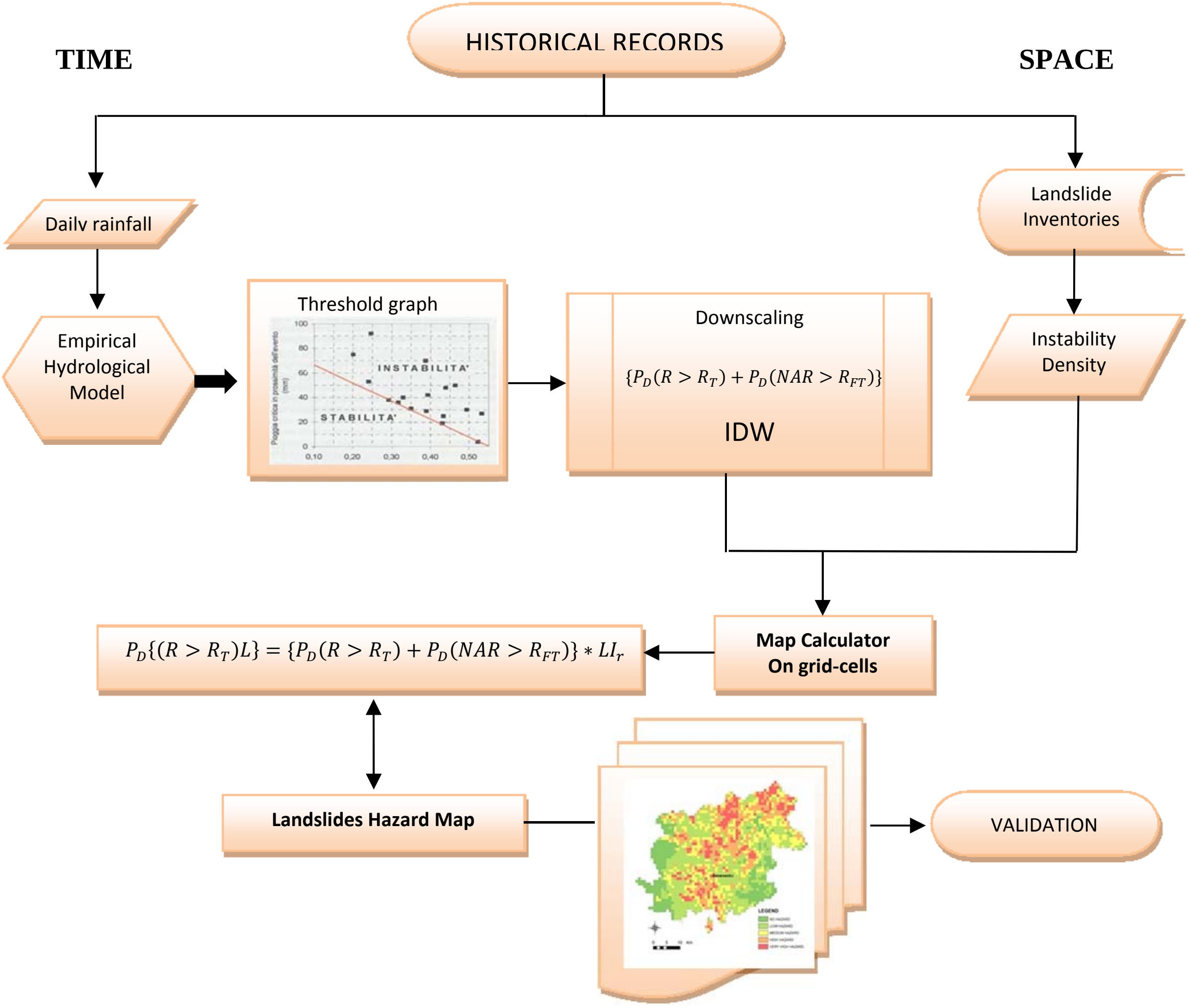

Fig. 2- Flow chart adopted for qualitative assessment of landslides hazard in Benevento Province.

Results

The first result obtained by transferring the data point (Hydrological Predictability Indicator) in the DBF format in a GIS environment to get a spatial result using the Inverse distance weighting, multiplying the critical rain index with LI_r (fig. 3a), is the SLHIM (shallow landslides hazard indicator mapping) showing five hazard classes from nothing to very high. As expected, the very high hazard areas are spread where landslides density is higher. Initiation or reactivation of landslides generally occur after periods of rain of two months, with antecedent precipitation included between 150-600 mm and rainfall triggering between 20-70 mm (De Paola and Diodato, 1999). As the antecedent precipitation is greater, a lower value of rainfall threshold is necessary for the reactivation of the landslide. Fast kinematic phenomena involve, however, on limited areas, although anthropization of places and change in technical agricultural can induce significant increases in danger as a function of local predisposing conditions.
The result is a landslide scenario characterized by a morphological evolution conditioned by processes particularly active. In fact, in the past more or less large areas of the Benevento

Province have been affected by events differentiated by type and intensity, although, given the prevailing clay formation of large sectors, dominated by slow moving phenomena.

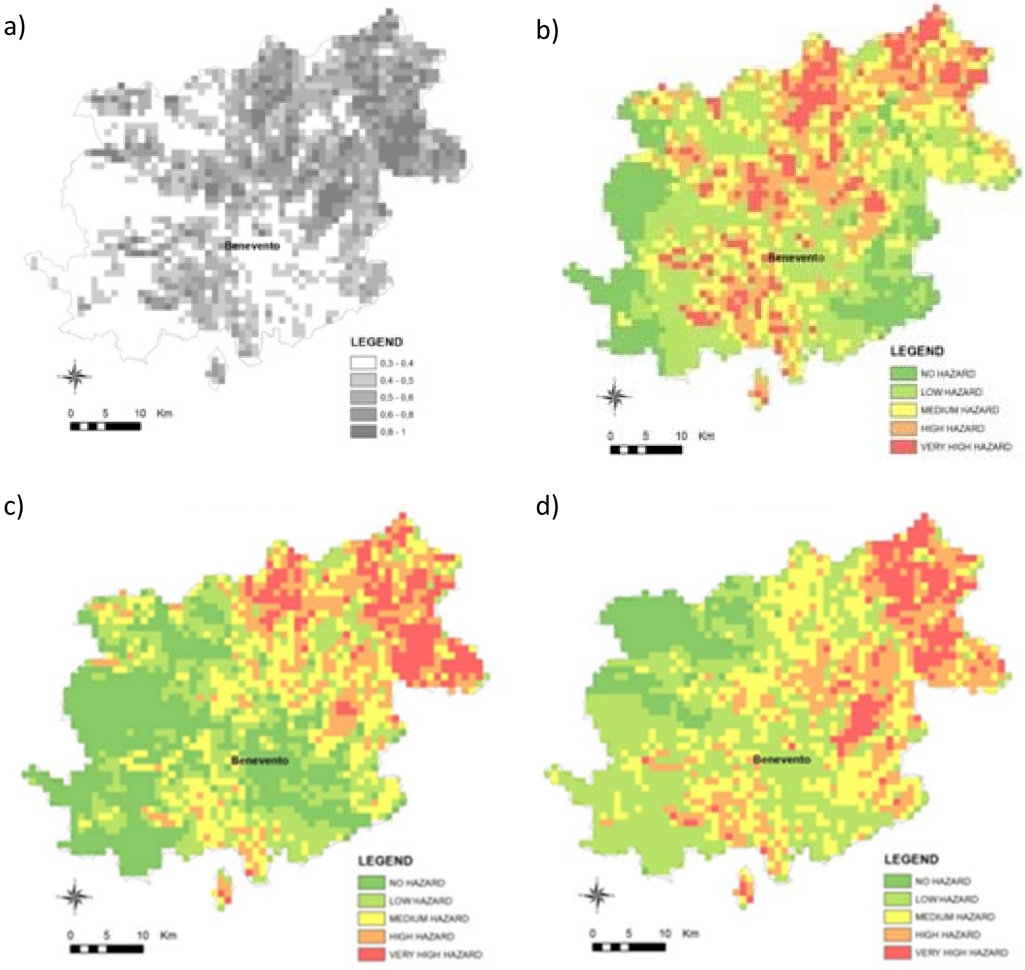

Fig. 3 - a) Benevento Province: Map of LIr = reclassified landslide index a); Shallow landslides hazard indicator mapping to three events: 1997 b), 2003 c), and 2005 d), where there are 5 zonation hazard classes: no hazard, low hazard, medium hazard, high hazard, very high hazard.

These, on the one hand be considered a low impact for human life, can be significantly risky events for the involvement of towns and infrastructure. Other factors, in particular, having a marked influence on the large-scale behaviour of the land flysch respect to roads are swelling and decompression, observed along the faces of cutting and in deep trenches dug during the course of the numerous road construction (Budetta et al., 2005; Guadagno et al., 2005; Revellino et al., 2010).
The related hazard index suggested five zonation hazard classes: no hazard, low hazard, medium hazard, high hazard and very high hazard. Among the events considered, the 1997 (fig. 3b) event results as being the most damaging. This is evident by the presence of the hazard classes that were slightly spread out, so high and low hazard areas were well distinguishable. The first class prevailed along the SW-NE direction within the middle Calore River area, high Fortore, Tammaro and high Telese Valley. In the remaining two events, 2003 (fig. 3c) and 2005 (fig. 3d), there was greater competition between the classes. It was distributed in an almost homogenous way; the high and very high hazard classes were

mainly in northern sectors; on the 2005 map, these classes, include the middle Calore River area and also the Titerno area that remained free in the 1997 and 2003 maps.

Conclusion

Simulation models represent one of the main tool used by scientists and analysts to investigate the dynamics of a system. Understanding the time-space behavior of environmental processes and state variables at large scales involves the use of many different types of data, obtained from field measurement, remote sensing, digital terrain models, and numerical simulation. In such a context, the support of GIS data processing functions can be particularly valuable for the modeler. As discussed previously, landslides are found to be associated with certain rainfall intensity that is rainfall climate foregoing to the event and the critical rainfall that occurred in the nearby of the event and it represented a dynamic factor. Meteorological data and a determination algorithm were developed and integrated into the final model obtaining a shallow landslides indicator mapping. The applied methodology was also tested and compared with previous data. In this way it was possible to identify those areas of different proneness to landslides.

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