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Level-2 susceptibility zoning on seismic-induced landslides: An application to Sannio and Irpinia areas, Southern Italy

V. Paoletti [a,b,*], D. Tarallo [c], F. Matano [c], A. Rapolla [a,b,d]

[a] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, University Federico II of Naples, Italy
[b] Territorial Town Planning Laboratory, L.U.P.T., Naples, Italy
[c] Istituto per l'Ambiente Marino Costiero (I.A.M.C.), Consiglio Nazionale delle Ricerche (C.N.R.) Naples, Italy
[d] University Centre for Research on Major Hazards, C.U.G.RI., Salerno, Italy

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ABSTRACT

In this paper we recall a method for medium scale (level-2) zoning of seismic-induced landslide susceptibility and present its application to the Sannio–Irpinia area, Southern Italy. Previous small scale studies of the entire Campania Region identified this area as one of the most susceptible to earthquake-induced landslides in the region. The area's intense seismic and landslide activity and the characteristics of the deposits involved in landslides make this analysis an interesting case study for land planning, management and protection of an area characterized by high seismic and hydrogeological hazard. The result of the zoning shows good agreement between the distribution of the historical earthquake-triggered landslides and the areas defined by the method as the most susceptible ones. They also highlight the method's effectiveness in the presence of complex clayey deposits.

1. Introduction

Earthquake-induced landslides represent one of the major natural hazards in volcanic and seismic areas for population, properties, and environment. Seismic-induced landslide damage can be significant during and several weeks after a strong earthquake and in some cases may exceed the damage directly connected to the shaking (Jibson et al., 2000).

For instance, the 1805 Molise earthquake, Southern Italy (I = *X* MCS), triggered mainly rock falls and earth slides and flows. A big earth flow of about 5.5 km^2 occurred in San Giorgio La Molara (Benevento district) which severely damaged some buildings and dammed a river valley, producing a temporary lake with wide inundation of agricultural fields and farm buildings in the valley (Porfido et al., 2002).

The November 23rd, 1980 Irpinia earthquake, Southern Italy (I = *X* MSK), induced a widespread geological effects such as tectonic surface ruptures, soil cracks, landslides, deep-seated gravitational deformations and hydrological anomalies. Some of these phenomena had dramatic effects on infrastructures and urban settlements (Porfido et al., 2002), leading to the abandonment of the affected buildings or to significant restoration work. This earthquake triggered 200 documented landslides (Porfido et al., 2007), considering phenomena having volumes of several hundreds of cubic meters or more (Esposito et al., 1998), and it probably caused thousands of small slope failures which didn't damage houses or other infrastructure (Porfido et al., 2002). Some of the largest landslides damaged towns such as Andretta, Bisaccia, Buoninventre, Calitri, Caposele, Colliano, San Giorgio la Molara, Sant'Angelo dei Lombardi, Senerchia. etc. In terms of economic cost, the damages only caused by seismic-induced landslides during or after Irpinia 1980 earthquake required public financing for restoration work from 1981 to 1992 in the Campania and Basilicata regions of about 130 million euros, revalued to 2011 (Comm. Parl. Report, 1991).

Several methods have been developed for the evaluation of the susceptibility related to earthquake-triggered landslides (e.g., Keefer, 1984; Mora and Vahrson, 1994; Jibson et al., 2000; Parise and Jibson, 2000). These methods can be framed into three zoning levels depending on the scale of study, referred as zoning level-1 to -3 in ISSMGE-TC4 (1999). As recommended by Fell et al. (2008) for landslide susceptibility zoning for land use planning, level-1 is applicable to regional zoning (scale 1:250,000–1:25,000); level-2 to local zoning (scale 1:25,000–1:5,000), and level-3 to site-specific zoning (scale > 1:5,000).

Earthquake-induced landslide susceptibility is related to several, often interplaying, factors (such as lithologic, tectonic, morphologic, hydrogeologic and seismological aspects) that are normally accounted for in level-2 and level-3 studies and are not usually represented at a regional (level-1) scale.

Basic principles for level-1 were first stated by Keefer (1984) and then developed by other authors (e.g., Keefer and Wilson, 1989; Rodriguez et al., 1999). Keefer (1984) suggested a simple

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[*] Corresponding author at: Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, University Federico II of Naples, Italy. Tel.: +39 0812538149.
E-mail address: paoletti@unina.it (V. Paoletti).

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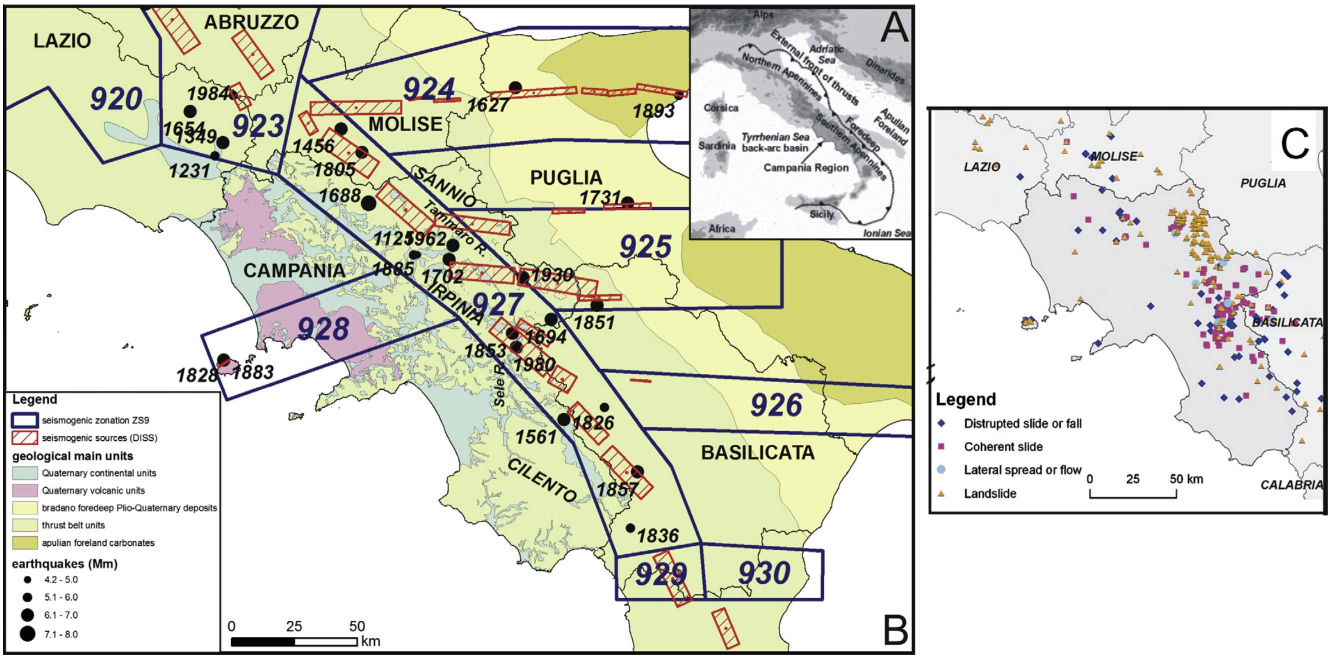

Fig. 1. (A) Location of the Sannio–Irpinia area and Campania Region within the Italian territory. (B) Geological sketch map of Campania and Seismological map of Southern Apennines, showing the epicenters of major earthquakes, the seismogenic sources (DISS W.G., 2009) and the seismogenic zonation ZS9 (INGV, 2004). (C) Location of the 374 seismic-induced landslides for the Campania territory and surrounding areas considered in this study (see text). Modified after Rapolla et al. (2012).

and effective method based on the seismic event Magnitude (or on the epicentral Intensity) and on the distance from the epicenter to evaluate a given region's susceptibility to seismic-induced landslides.

As regards level-2 susceptibility studies, different approaches usually based on geological, lithological, geotechnical, litho-seismical, morphological and seismological information can be found in literature. The most common ones include (Silvestri et al., 2005): (i) studies of local seismic hazard defined by deterministic scenarios (strongest historical earthquake or most recent earthquakes), and expressed in terms of peak ground acceleration, including local amplification effects; (ii) assessment of slope instability hazard by pseudo-static analyses based on limit equilibrium-infinite slope methods, by using a limited amount of information about seismic hazard, topographic data and geotechnical properties; (iii) preliminary estimations of geotechnical properties by assigning parameters, derived by scientific literature, to each lithological homogeneous unit mapped in 1:10,000–1:50,000 geological maps; (iv) determination of the groundwater conditions, i.e., water table lacking or outcropping at ground level; (v) compilation of maps of the ground displacements based on the Newmark's method (Newmark, 1965) and/or maps of correlations between ground displacement and seismic motion parameters (*Peak Ground Acceleration* or *Arias Intensity*). *Arias Intensity* is considered a good indicator to describe the shaking which can trigger landslides, whereas slope resistance to deformation may be effectively expressed by the *critical acceleration*: $a_c = (\mathrm{FS}-1)\sin\alpha$, where FS is the static safety factor and α is the slope angle. The expected cumulative displacements are function of the *critical acceleration* a_c and of the *Arias Intensity*, and their prediction can be obtained by applying different correlations available in literature (e.g., Jibson et al., 2000).

Among the level-2 zoning approaches available in literature, some methods, e.g., the three parametric methods suggested by ISSMGE-TC4 (1999), are based on heuristics analyses and combine thematic maps in which a weight is assigned to each input parameter. Other approaches make use of the mentioned *Arias Intensity* for the assessment of seismic input and of Newmark's analysis for the dislocation measurement and are based on statistical analyses. We mention the study of Luzi and Pergalani (1996), who evaluated the physical vulnerability to landslides in dynamic conditions using the Newmark's method and produced slope stability maps in terms of final displacements in an area of the Marche Region, Italy. Miles and Ho (1999) and Jibson et al. (2000) performed a seismic landslide hazard zoning also employing Newmark's analysis and applied it to different areas of California. Del Gaudio et al. (2003) made use of three parameters, i.e. *Arias Intensity*, *critical acceleration* and Newmark's displacement to represent, respectively, the level of seismic shaking, the slope resistance to deformation and the conditions for seismic triggering of landslides. Del Gaudio and Wasowski (2004) applied this method to evaluate seismically-induced landslide hazards in an area of Sannio–Irpinia, Southern Italy. Silvestri et al. (2005) carried out a similar approach for a zone near the town of Benevento, in the Sannio area. More recently, Saygili and Rathje (2008) presented an empirical model that reduces the uncertainty in the sliding displacement prediction by combining multiple ground motion parameters, i.e., peak ground acceleration, maximum velocity and *Arias Intensity*. The above mentioned methods, although effective, require knowledge of several parameters, and thus they may be costly and not always easily applicable. Instead, it would be proper to use the medium scale zoning method. Level-2 methods should in fact allow a significant improvement with respect to small scale analyses, but at the same time they should be relatively simple and cheap to apply, as suggested in Fell et al. (2008).

As regards level-3 studies, several authors (e.g., Wilson et al., 1979; Siyahi and Ansal, 1993; Ausilio et al., 2008) suggested different mathematical approaches. Because of the complexity of the methods and the number of parameters that need to be accounted for (e.g., Panzera et al., 2012), in some cases this led to the production of computer programs whose correct use requires accurate and complete laboratory and *in situ* data acquisition.

In this paper we shall describe a level-2 study carried out by the employment of a heuristic approach accounting only for geology, topography and seismic intensity (Rapolla et al., 2010) in the Sannio–Irpinia area, Campania Region, Southern Italy (Fig. 1A). The