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DONATELLO MAGALDI (*), ALESSANDRO LORÈ (**) & PATRIZIA PERONI (*)

# MAPPING SLOPE INSTABILITY GROUND FACTORS IN THE NATIONAL PARK OF GRAN SASSO - MONTI DELLA LAGA (ABRUZZO, CENTRAL ITALY): RESULTS AND PERSPECTIVES

**ABSTRACT**: MAGALDI D., LORÈ A. & PERONI P., *Mapping slope instability ground factors in the National Park of Gran Sasso - Monti della Laga (Abruzzo, Central Italy): results and perspectives*. (IT ISSN 1724-4757, 2007).

The National Park of Gran Sasso-Monti della Laga (Abruzzo, Central Italy) is representative of a mountainous Mediterranean environment, with a range of elevation from 800 to 2900 meters above sea level and commonly occurring landslides, particularly in the northern belt of the Park. Two main geological formation groups are predominant in the area: the oldest one (of the Trias to Miocene periods) consists of marine carbonate rock formations, which have been tectonically overthrusted by more recent siliciclastic formations during the last orogenetic phase of the Central Appennines (Upper Miocene - Lower Pliocene); these are formed mainly by sandstone and marlstone of the Miocene age and bear the name Flysch della Laga.

The research carried out on a pilot area of the Park was addressed to obtain a small scale mapping of both distribution and intensity of the slope instability factors. This was accomplished by considering the percentage occurrence of some instability factors, as the ratio of friction-angle to layering dip-angle less than 1, and the occurrence of morphological signs of instability as active talus. The resulting map (IFP) which could be interpreted as expression of potential susceptibility to slope instability, was not similar to a previous instability hazard map of the same area made by traditional parametric methodology. Instead the IFP map compared with actual distribution of instability phenomena (landslides, badlands, active scree deposits, etc.) over the same area resulted positively correlated at 0.99 probability level. The proposed method seems to be able for predicting the susceptibility to instability trend not only over whole territory but also in areas assumed after traditional methods to have homogeneously distributed hazard class.

KEY WORDS: Rockfall, Landslides, Scree Activity, Slope Instability Factors, Gran Sasso, Central Italy.

**RIASSUNTO**: MAGALDI D., LORÈ A. & PERONI P., *Cartografia dei fattori della instabilità dei versanti nel Parco Nazionale Gran Sasso - Monti della Laga: risultati e prospettive*. (IT ISSN 1724-4757, 2007).

Il Parco Nazionale del Gran Sasso-Monti della Laga in Abruzzo può a tutti gli effetti essere considerato rappresentativo di un ambiente mediterraneo di alta montagna. Il suo rilievo, che da una quota di 800 m s.l.m. si spinge fino a quasi 3000 m, è comunemente interessato da movimenti franosi, specialmente nella fascia più settentrionale. Due Gruppi di formazioni geologiche predominano nell'area: il più vecchio, di età compresa tra il Trias e il Miocene, è costituito da rocce calcaree e calcareo dolomitiche ed è sovrascorso sul più recente (Miocene Superiore - Pliocene) durante l'ultima orogenesi. Quest'ultimo è costituito da depositi flysciodi di arenarie, calcari marnosi, marne e argilliti (Flysch della Laga, principalmente).

L'indagine svolta è stata orientata alla ricerca di una metodologia semplice e relativamente veloce, capace di delimitare le zone potenzialmente a rischio di instabilità dei versanti in roccia, e si è basata sull'analisi della distribuzione percentuale sul territorio di alcuni parametri di instabilità quali il rapporto tra angolo di attrito della roccia ed angolo di inclinazione degli strati sedimentari e la presenza di indizi morfologici di instabilità quali falde di detrito attive.

Si è così ottenuta una carta ad isolinee di eguale frequenza dei fattori di instabilità che rappresenta l'andamento della suscettibilità potenziale all'instabilità di versante, la quale tuttavia risulta differente da una preesistente cartografia della pericolosità realizzata alcuni anni fa secondo un approccio parametrico.

Un successivo confronto della nuova Carta con l'attuale distribuzione dei fenomeni franosi entro l'area studiata rivela una significativa correlazione positiva (probabilità > 99%).

La metodologia proposta permette quindi di individuare l'andamento della suscettibilità potenziale all'instabilità secondo isolinee di frequenza relativa, non solo nell'intero territorio ma anche entro zone ritenute a rischio omogeneo sulla base dei metodi tradizionali di zonizzazione aprioristica.

TERMINI CHIAVE: Crolli in Roccia, Frane, Attività delle Falde Detritiche, Fattori di Instabilità del Pendio, Gran Sasso, Italia Centrale.

## INTRODUCTION

A fuller understanding of geologic conditions and geomorphologic processes influencing landscape dynamics in mediterranean areas is becoming ever more necessary for

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(*) *Dipartimento di Ingegneria delle Strutture, delle Acque e del Terreno (DISAT), University of L'Aquila, L'Aquila (Italy).*

(**) *Consultant Geologist, L'Aquila (Italy) - Corresponding Author: magaldi@ing.univaq.it; Fax: ++39 0862 434548.*

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land use planning purposes in areas reserved for nature reclamation and conservation. It is well known that the Mediterranean climate is characterised by extreme events of rainfall; according to Andah & Ubertini (1998), daily maximums of over 100 mm (which can represent some 30-40% of the annual average value) are possible. Due to such strong concentration of rainfall, as well as to some human influences, the Mediterranean environment appears very fragile and prone to periodic flooding and slope instability.

From a geomorphologic point of view, four general trends in landslide hazard methods are likely to occur worldwide: distribution analysis, qualitative analysis, statistical analysis, landslide frequency analysis.

According to Crescenti (1998), in Italy commonly available wide-spread instability maps are largely based on qualitative analysis (direct or semi-direct methods in which the mainly geomorphologic map is renumbered to a hazard map) and statistical ones (indirect methods in which statistical analysis are used to predict mass movements hazard from a number of parameter maps). More complex methods for hazard assessment, based on artificial neural networks, have recently been proposed (i.e. Bianchi & Catani, 2002), but these ones draw on large data sets and on powerful territorial information systems which may not always be available (ARPA, 2001).

The lack of adeguate data sets and the effects of global climatic change on rainfall trends, can render the relations linking rainfall characteristics to recurrence time of landslides somewhat unreliable. At least, common mapping based on hazard as expressed by frequency of phenomena is strongly conditioned by fast landscape dynamics; seismic, volcanic and fluctuating climatic conditions, all act on a number of instability factors which are likely to trigger the instability process.

These considerations lead to think that it is probably more useful for land use planning engineers to have at hand a cartography of the slope instability susceptibility which gather the following requirements:

1) to provide simple and easily workable GIS based documents, at regional scale, derived from published geological and geomorphologic maps, aerial photo interpretation and limited field control and investigation;
2) to accomplish a mapping in which the slope instability factors are characterised qualitatively in frequency ranges from low to high values, with class boundaries not fixed *a priori* but based on analysis of adeguate data sets.

Following on from a geomorphologic research programme on the Gran Sasso-Monti della Laga National Park (Abruzzo, Central Italy) this paper proposes a new method for mapping the slope instability susceptibility which takes into consideration previous findings related to identification of the rock slopes susceptibility to failure (Lorè & Magaldi, 2000; Magaldi & *alii*, 1997; Magaldi & *alii*, 2004; Magaldi & Tallini, 2002; Tallini & *alii*, 1997).

## GEOLOGICAL OUTLINES AND SLOPE INSTABILITY PHENOMENA

The study area (fig. 1) is part of the National Park of Gran Sasso-Monti della Laga, that is well known for its mountain rock fall phenomena (fig. 2), particularly in the northern belt of the Gran Sasso range (Buccolini & *alii*, 1994).

A small scale map (originally 1:100,000) of the slope instability hazard of a sample area of the Park was published by Magaldi & Tallini (2002). It is based on a parametric method proposed by Magaldi & *alii* (1997) and Borselli & *alii* (1998) and derived from Ambalagan (1992) with modifications. The method attributes three conventional scorings (0, 0.5, 1) to climatic, geomorphologic and geologic instability factors as well as to occurrence of past and present landslides for homogeneous pedo-geomorphologic land units in wich the study area was subdivided. Overall classification of hazard (very low, low medium, high) was obtained by the scorings products and empirically defined class boundaries (fig. 3).

Taking into account the close link between landslide type, lithology and geostructural setting (Guzzetti & *alii*, 1996) a subdivision of the study area was made on the basis of a recent, 1:100,000 scale, geologic map (Vezzani & Ghisetti, 1998).

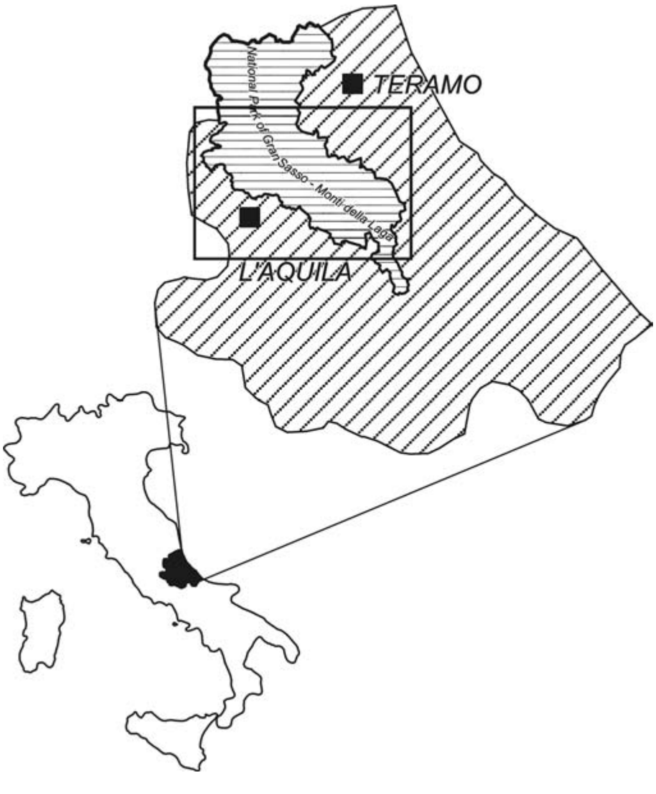


FIG. 1 - Location of the Gran Sasso-Monti della Laga National Park, Abruzzo, Central Italy.

FIG. 2 - The 08.22.2006 rockfall on the northern side of the Corno Grande Mt., Gran Sasso range. From the newspaper Il Centro, 08.23.2006.

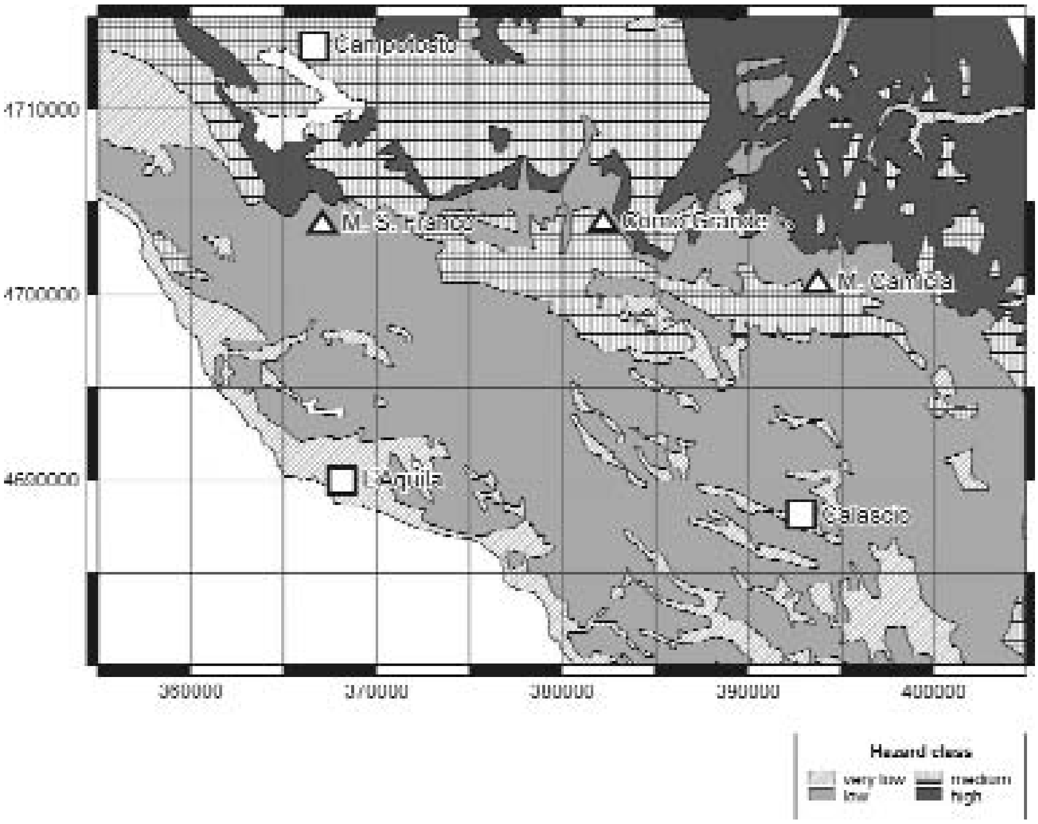


FIG. 3 - Slope Instability Hazard Map for the pilot area of Gran Sasso-Monti della Laga National Park, after Magaldi & Tallini, 2002.

Two main geological formation groups crop out over the area (fig. 4): the oldest formation group (Trias to Miocene) consists of marine carbonate rocks tectonically overthrusted by more recent silico-clastic formations (mainly sandstone and marlstone of the Miocene age) during the last orogenetic phase (Upper Miocene - Lower Pliocene).

Carbonate formation outcrops, mostly consisting of massive and karstified lithotypes, are strongly fractured by a variable number of joint sets. Rock falls from vertical or sub vertical cliffs represent the most common instability type, commonly producing diffuse talus at the foot of cliffs and steep hill slopes. On the basis of field observation, the rock falls appear to be strictly associated with carbonate cliffs, occurring over the landscape at relatively high elevations (1000 to 2900 m a.s.l.).

Large data sets from the northern European literature (Sjoberg, 2002) and some field experience (Lorè & Magaldi, 2000) are indicating carbonate cliffs of more than about 50 m in height to be more prone to instability by rockfall.

Other formations (Flysch della Laga) are characterised by plane wedge failure along fairly regular weakness planes but also by frequent fall of small blocks sharply modelled by joint systems. Most of the observed plane failure landslides occur along the contact between sandstone and marly-argillitic formations.

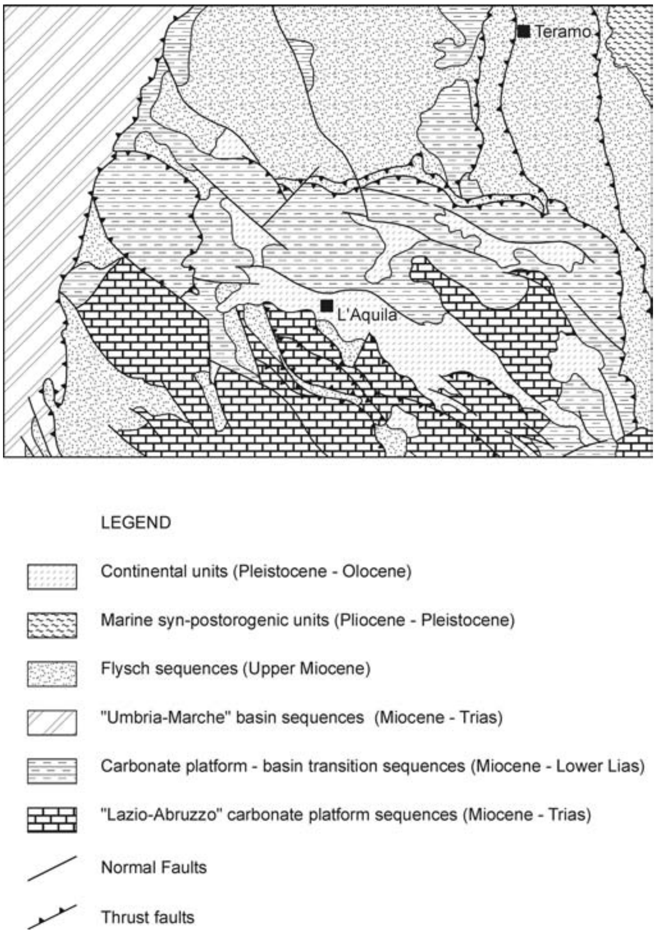


FIG. 4 - Sketch of the litho-geostructural conditions of the Park area (not at scale); axis measured in UTM metric coordinates.

## SLOPE INSTABILITY SUSCEPTIBILITY ASSESSMENT

Starting from previous information and some review of geomorphologic methods for slope failure assessment, after Cooke & Doornkamp (1990) a very simple cartographic approach was followed to determine locations where instability factors were more frequently to occur over studied area.

A GIS based map (originally 1:100,000) derived from a geological map at same scale (Vezzani & Ghisetti, 1998) was prepared to delineate the occurrence of the following instability factors:

- Sites where the ratio of bedrock friction angle (obtained, according to Hoek & Bray (2001), from field measures of discontinuity sets) to local dip bedding angle is less than 1 – so indicating the predisposition of a slope to slide. This ratio, that simplifies the classic infinite limit equilibrium method, is clearly indicative of likely failure assuming the cohesion along discontinuities to be zero. Mean calculated values of friction angle are 30° for carbonate rocks, 40° for sandstones.
- The occurrence over the area of rock cliffs (greater than 50 m and up to 600 m height) from field survey and photo-interpretation. Cliffs are commonly associated with scree slopes and can be expected to generate frequent rockfall and, on occasion, wedge slides, toppling and debris flows, over both carbonate and silico-clastic formations.
- The occurrence of «active» screes at the feet of carbonate rocks cliffs.

Assumming that vegetation cover above the scree is an indicator of its activity, an Instability Index (INIX) was defined as the percentage ratio of non-vegetated to total scree surface (a rating reduction of 50% was attributed to discontinuous shrub vegetation). A value of 100% indicates a barren scree while a value of 0% indicates a fully vegetated one.

Direct assessment in the study area evidences that active screes are associated with general instability conditions of the cliffs above them (rockfalls, frost shattering, etc.). Then, we can assume that INIX is directly representative of the susceptibility to slope instability of the cliffs above screes. The hypothesis is that «active» screes refer to deposit of small to medium sized blocks which have fallen from the overlying cliff, mainly due to both frost weathering and latent tension release; whereas «inactive» screes are likely to testify to the stability of the related cliffs.

Evaluation of scree «activity» was made from direct assessment and 1:10,000 photo interpretation.

A statistical analysis on some geostructural and morphological data collected from the cliffs of the Gran Sasso Range led to find INIX to be well correlated for all cliff aspect values to cliff foot elevation (fig. 5) by an empirical equation:

$$INIX = a^{*}Q - b,$$

where:

Q = elevation of cliff foot from topographic surface (m a.s.l.),
a, b = numerical coefficients depending on local conditions.

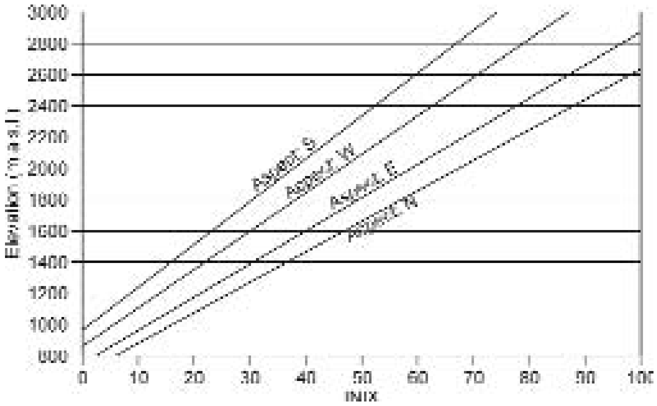


FIG. 5 - Cliff instability index (INIX) as expressed by an empirical function ($r^2 = 0.66$) in relation to main values of cliff exposure.

The numerical coefficients a and b are supposed to be representative of the local climatic conditions (mean annual temperature, weathering, frost shattering, etc.) and of the rock response to them.

The distribution map of instability factors was successively transformed into a contour map of «percentage of instability factors» (IFP Map) according to the following precedure.

Taking account the scale of the GIS model (1:100,000), the geomorphologic map was subdivided into 60 grid cells with a grid size of 6,4 x 6,4 km.

Secondly, the «instability factors percentage» for each cell was roughly estimated by means of visual tables. The percentage values were geo-statistically elaborated by kriging method (Surfer 8, Golden software, 2002) in order to produce an instability factors contour map of the study area (IFP map, fig. 6).

For comparison, the same procedure was applied to Magaldi & Tallini (2002) slope instability hazard map (fig. 3), for the same area. Original hazard classes of the map were transformed into a contour map assuming the following scheme:

- very low hazard class = 0 to 10% instability factors
- low hazard class = 11 to 20% instability factors
- medium hazard class = 21 to 30% instability factors
- high hazard class = 31 to 40% instability factors

The limit of 40% was choosen because the maximum percentage of surface affected by instability phenomena (referring to the same grid used for the IFP map), result-

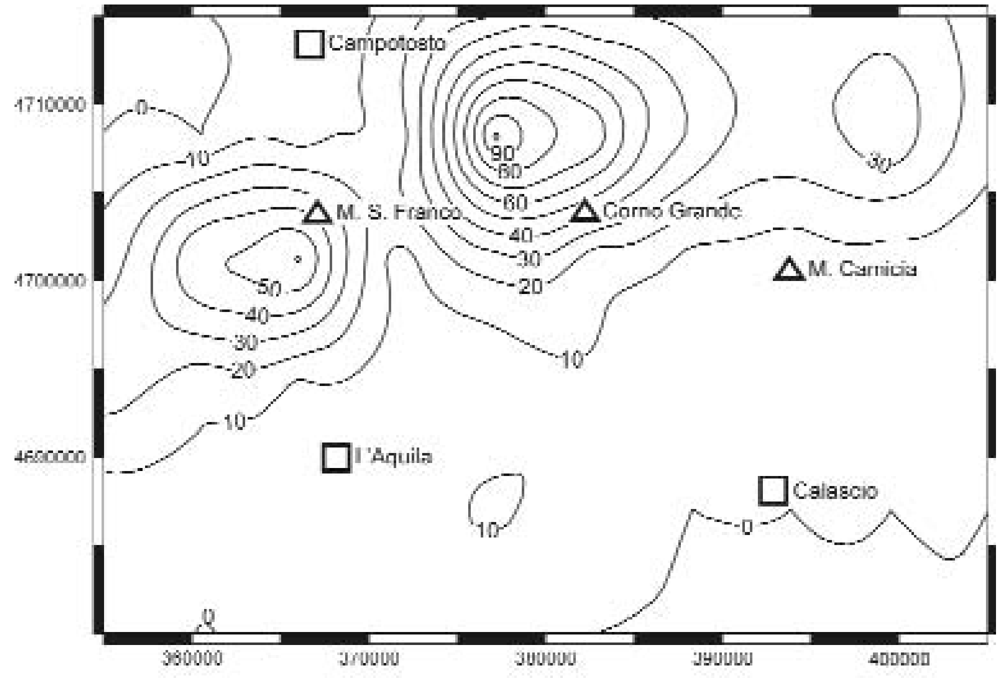


FIG. 6 - Contour map of the pilot area showing the distribution of percentage of instability factors over the land (IFP map).

ing by an instability affected areas map (fig. 7), resulted about 40%. Fig. 8 shows resulting map (SIH Map), normalized to 100%.

## DISCUSSION

A comparison between IFP and SIH maps using Wilcoxon rank sum test (in Lewis, 1977) shows they appear to be very different.

This is not surprising because basic assumptions for maps construction are conceptually different. The SIH map is based on classic qualitative and subjective approach to hazard assessment (Ko Ko & *alii*, 2004), whereas IFP map on distribution frequency of instability factors over study area.

IFP Map is qualitatively similar to the topographic map of the area being the instability factors increasing with relief energy.

What is the true meaning of the IFP map? A comparison with the map of actually occurring instability phenomena (landslides, badlands, active scree deposits, etc.), which takes no account of presumed unstable rock slopes, was carried out by transforming the instability affected areas map (fig. 7) into a contour map following the previously described procedure (OIP map, fig. 9).

In spite of the basic difference between numeric series relating to IFP map and observed instability phenomena map (OIP), a significant, even if not good, correlation ($n = 60$, $p < 0.01$, $r^2 = 0{,}38$) however resulted for both maps (fig. 10a). For comparison, the correlation between SIH and OIP maps appears to be very weak ($r^2 = 0{,}17$) (fig. 10b). Then IFP appears to be representative of the slope potential susceptibility to failure.

## CONCLUDING REMARKS

To propose a simple methodology for the low scale instability susceptibility assessment was the main purpose of this research. It is noticed instead that SIH and IFP are different. This is because the new method does not pro-

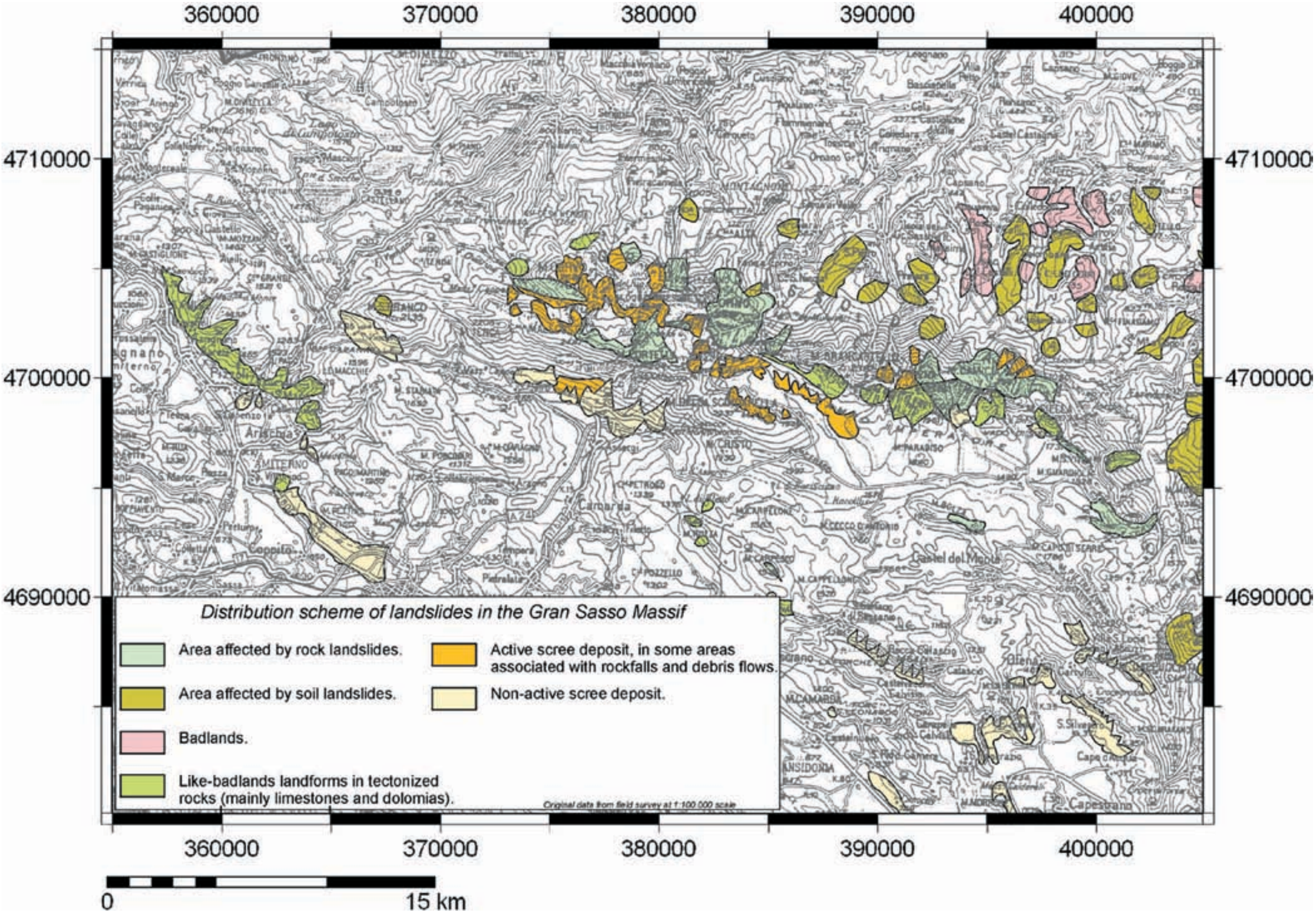
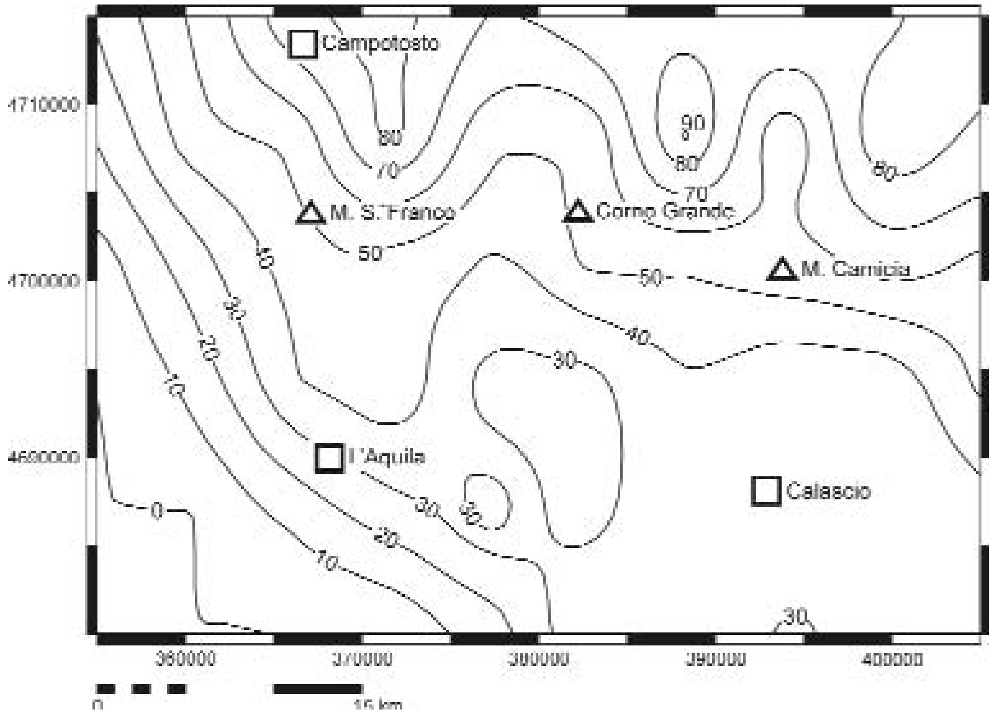


FIG. 7 - Occurrence of instability phenomena in the pilot area after field survey and aerial photographs interpretation.

FIG. 8 - Contour map of the pilot area derived from the Slope Instability Hazard Map by Magaldi & Tallini, 2002 (SIH map).



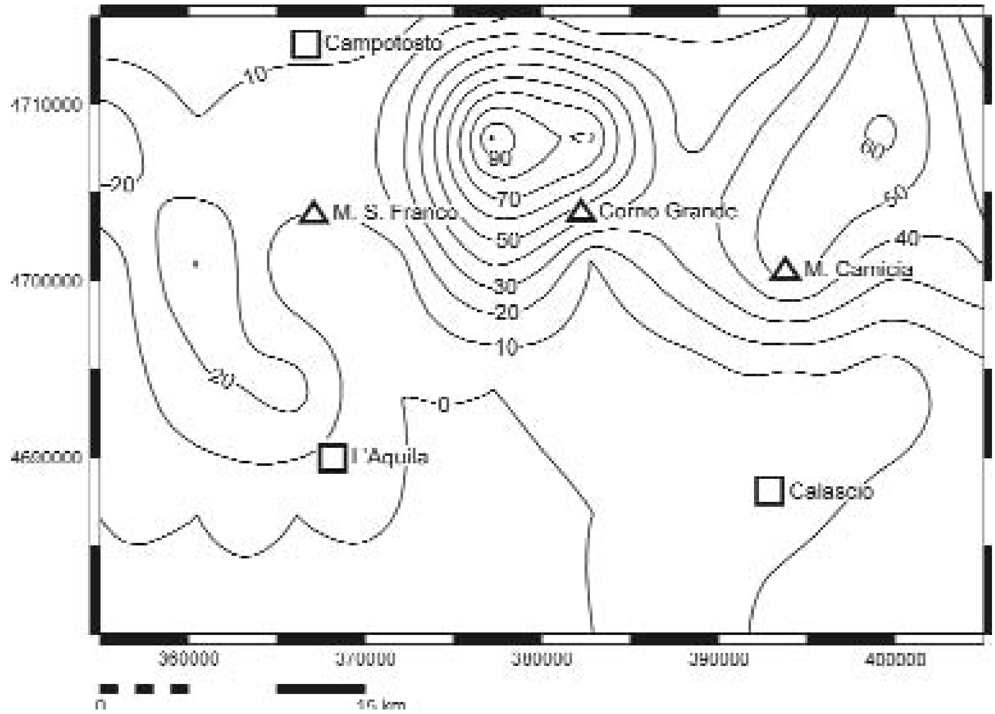


FIG. 9 - Contour map of the pilot area showing the percent distribution of actual instability phenomena (OIP map).

duce homogeneous areas as the traditional ones, but isolines relating to values of landscape dynamics were the obtained results.

This could be an advantage for applied purposes, mainly for land management. In fact, traditional methods produce mapping units where susceptibility degree is assumed to be homogenously distributed, the new one is able to show inside each unit the distribution of potential susceptibility in relation to general trend of whole mapped area.

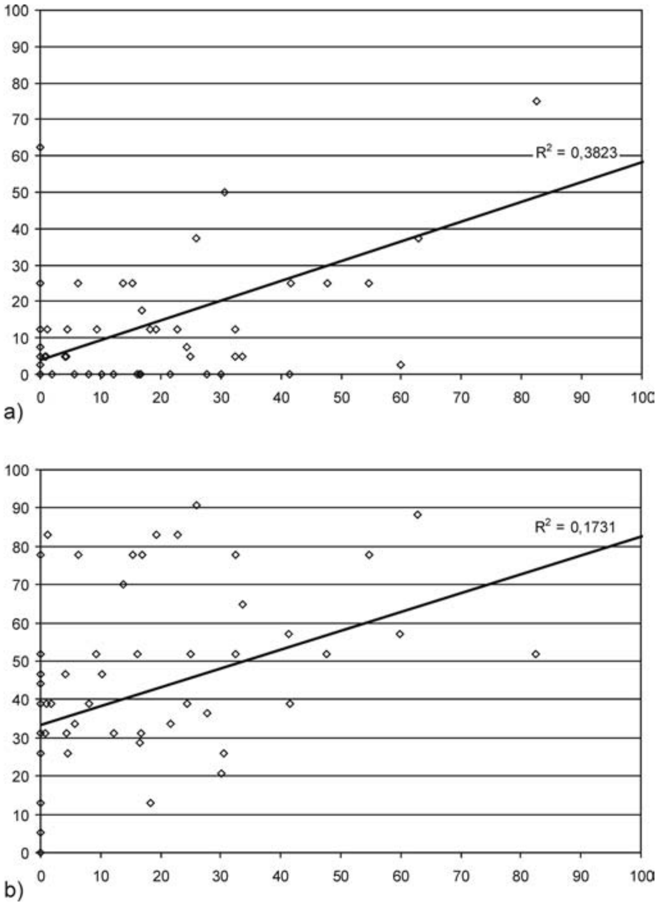


FIG. 10 - Linear correlation between numeric series relating to: a) IFP and OIP maps; b) SIH and OIP maps.

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