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LAURA MELELLI (*) & ANDREA TARAMELLI (**)

CRITERIA FOR THE ELABORATION OF SUSCEPTIBILITY MAPS FOR DGSD PHENOMENA IN CENTRAL ITALY

ABSTRACT: MELELLI L. & TARAMELLI A., *Criteria for the elaboration of susceptibility maps for DGSD phenomena in Central Italy*. (IT ISSN 0391-9838, 2010).

In this research we analyze the overall requirement and use of parameters derived from geomorphic techniques for Deep-seated Gravitational Slope Deformation (DGSD) susceptibility assessment in the Central Apennine (Umbria-Marche area - Central Italy). The geometric parameters characterizing the topography affected by DGSD are investigated by remote sensing data. In particular, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) improved with Landsat ETM+ imageries are used to detect the topography signature representative of DGSD susceptibility. Landsat ETM+ data are processed with Spectral Mixing Analysis (SMA). The topographic DGSD signature is determined by different topographic parameters such as slope, relief, aspect and curvature which can be used as a DGSD index degree. To characterize important physical properties of the aforesaid signature, the linear mixing model between the dark surface endmember and both the substrate and vegetation endmembers was used. That model highlights the extent to which shadowing and non-reflective surfaces, combined with illuminated substrate and vegetation at sub-pixel scale, can modulate spectrally mixed ETM+ reflectances in a ridge topography within the DGSD signature. The final results indicate that when incorporated with optical SMA of the Landsat ETM+, the SRTM analysis should improve the capacity for mapping and identifying DGSD in specific landscapes.

KEY WORDS: DGSD, SRTM, ETM, Spectral Mixing Analysis, Central Italy.

RIASSUNTO: MELELLI L. & TARAMELLI A., *Elaborazione di una carta della suscettibilità da DGPV nell'Italia Centrale*. (IT ISSN 0391-9838, 2010).

Sono presentati i risultati di un metodo di valutazione della suscettibilità da Deformazione Gravitativa Profonda di Versante (DGPV) nell'Appennino centrale (settore Umbro-Marchigiano) attraverso la stima delle caratteristiche morfometriche e morfologiche che contraddistinguono un versante affetto da tali fenomeni. Il metodo si basa sull'analisi combinata di dati radar, in particolare un Modello Digitale di Elevazione (DEM) della Shuttle Radar Topography Mission (SRTM) e dati ottici con immagini Landsat ETM+. L'analisi del dato radar seleziona gli intervalli di valori caratteristici delle DGPV nell'area di studio per attributi topografici come energia di rilievo, pendenza, esposizione e curvatura. Come noto, il dato radar è affetto da «rumori» (effetto shadowing e layover) che ne diminuiscono precisione e validità.

Per migliorare la qualità del segnale sulle immagini Landsat ETM+ è stata effettuata una Spectral Mixing Analysis (SMA). Vengono così riconosciuti raggruppamenti (endmembers di topografia, vegetazione, substrato e specchi d'acqua) per un certo insieme di osservazioni (mixing space) al fine di isolare le firme spettrali necessarie alla correzione del dato radar. Le classi di attributi topografici relative alla presenza di aree affette da DGPV sono quindi identificate con maggiore precisione e accuratezza.

TERMINI CHIAVE: DGPV, SRTM, ETM, Spectral Mixing Analysis, Italia Centrale.

INTRODUCTION

Deep-seated Gravitational Slope Deformations (DGSD) are gravity-driven mass movements involving entire slopes, displacing huge rock volumes with width, length and depth on the order of several hundreds of meters. DGSD show key differences from landslides but clearly involving the gravity force in their start and ongoing control factors. Well known in scientific literature since 1940s (Dal Piaz, 1936; Stini, 1941; Jhan, 1964; Ter-Stepanian, 1966; Zischinsky, 1969; Beck, 1968; Nemcock, 1972) were recently defined as slope movements occurring on high relief-energy hillslopes, with size comparable to the whole slope and with displacements relatively small in comparison to the slope itself (Goudie, 2004; Kellerer-Pirklbauer & *alii*, 2010; Taramelli & *alii*, 2010).

The geomorphologic features were the first and best evidences used to understand and describe the phenomena, pointing out the differences from large landslides characterized by a rupture surface, not always evident (Zi-

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(*) *Dipartimento di Scienze della Terra, Università di Perugia, P.zza dell'Università 1 - 06100, Perugia* (lmelelli@unipg.it).

(**) *ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, Via Curtatone 3 - 00185, Roma.*

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schinsky, 1969; Radbruch-Hall, 1978; Savage & Varnes, 1987; Chigira, 1992). The deformation takes place in depth, along a zone characterized by micro-fractures alignment according to depth creep definition (Terzaghi, 1950) where, the high confining pressure, does not allow the developing of a slide surface. Due to this fact, well defined structural and lithologic parameters characterizing the rock mass are required for triggering and ongoing evolution. The main DGSD occurrence is on coherent lithotypes also jointed or stratified, supporting visco-plastic deformations in depth. Taking into account a finite slope affected by DGSD, peculiar landforms are recognizable from the top to the bottom: twin ridges, trenches, gulls, uphill facing scarps are diffused on the higher and middle part of the slope (Baron & *alii*, 2005). Sagging and a general radial convex shape, together with an increasing degree of surface landslides presence, characterize the lower slope portion (fig. 1).

In Italy, DGSD are investigated since the ’80s (Cavallin & *alii*, 1987; Crescenti & *alii*, 1994; Dramis & *alii*, 1995; Farabollini & *alii*, 1995; Melelli & *alii*, 2007). Most of the DGSD detected are located in the western and central Alps and in the central and southern Apennines. Large areas are present, both on eastern Alps and Apennines, with the same favourable geologic and geomorphologic conditions Apenines in which DGSD are almost completely lacking.

Due to the high volumes involved, and the geographical location in mountains areas with low values of vulnerability levels, geotechnical investigations are limited, so that topographic and geomorphologic analyses are the most suitable method to investigate the phenomenon. In order to better identify specific slopes with high susceptibility values that do not show DGSD, it is fundamental to define the morphometric and morphologic ranges that in similar geologic and geomorphologic conditions characterize the affected areas.

Indeed, despite the disastrous effects of DGSD on communities are well known (Kilburn & Petley, 2003), there is still a need to better understand the different mechanisms related to DGSD. Basic approach based on susceptibility model method has applied to DGSD assessment using topographic signature within DEM data (Roering & *alii*, 1996, 2005; Melelli & *alii*, 2007; Taramelli & Melelli, 2009; Taramelli & *alii*, 2010). The experience gained from the application, at various scales, of DEM-based models to DGSD topographic characterization, suggested some different levels of enquiry that has to be developed (Taramelli & Melelli, 2009).

The present research is applied within the central Apennines range (Italy), where a large number of DGSD is recognized. The very complex geologic and geomorphologic history of Apennine chain is the reason for the contemporary presence of factors favourable to DGSD spreading like a coherent bedrock composition, high values of energy relief, a drainage network characterized by a strong linear erosion and seismic events with high magnitude values. The paper shows the results of this

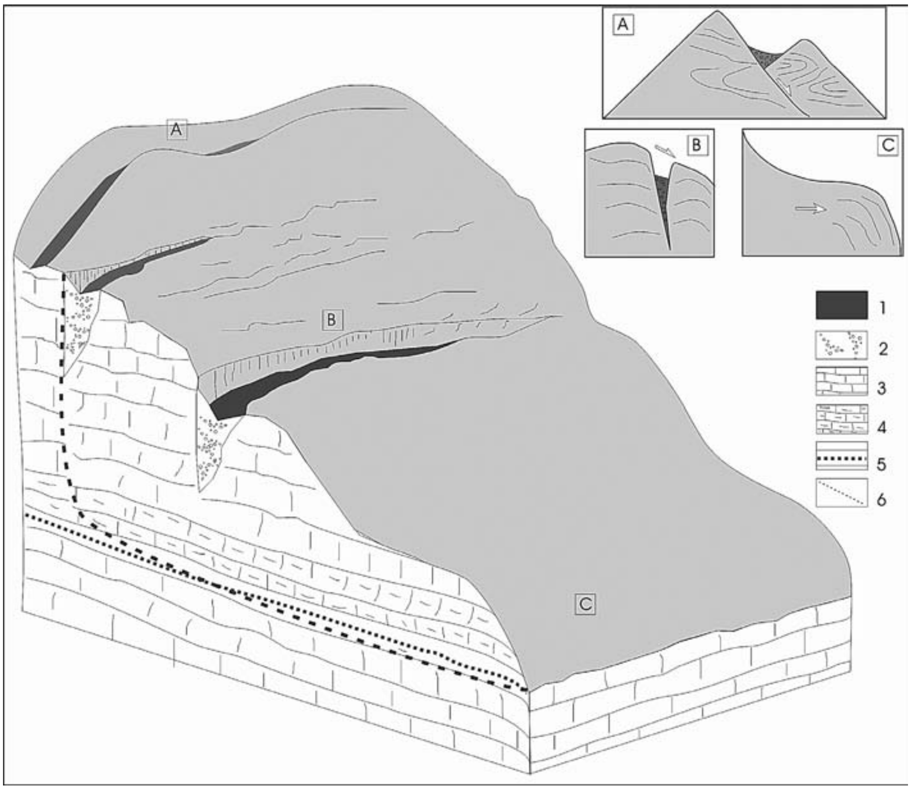

FIG. 1 - DSGSD sketches: a) Double ridges, b) Trenches, c) Sagging; 1) Trenches talus - top view, 2) Trenches talus - side view, 3) Prevalent coherent layer, 4) Weaker lithotype layer, 5) Layer boundaries or tectonic discontinuities, 6) Slide surface.

methodology on a dataset of 57 cases collected in the study area.

The key results of this research are:

1) the identification of previously undetected potential DGSD areas,
2) the division of the central Apennines in areas with an increasing DGSD degree value,
3) the correlation of the identified areas with geologic and geomorphometric parameters characteristic of the phenomena.

LANDFORMS IDENTIFICATION

In geomorphology, landforms can be defined by a semantic approach and a geometric one (Wood & Snell, 1960; Goudie, 2004; Taramelli & Melelli, 2008). The semantic approach defines a landform as the result of structural factors, past and present morphogenetic processes and climatic conditions. Due to the complexity of the landforms boundaries, the non-conservative lithotypes and different scales mapping, the features delimitation is affected by errors. A geometric approach selects the features on the basis of their shape, establishing linear and areal sizes (height, width, thickness, area) and relief measures (slope, radial and planar curvature). In the last decade, developing hazards models for DGSD impact using Geographical Information Systems (GIS) and remote sensed data have then become a major topic of research (Allievi & *alii*, 2003; Moro & *alii*, 2009; Taramelli & Melelli, 2009). Topographic parameters that characterized DGSD evidences can be highlighted by a combined approach using DEM analysis (Roering & *alii*, 1996, 2005; Burrough & McDonnell, 1998; Burrough, 2004; Melelli & *alii*, 2007; Taramelli & Melelli, 2009) while the superficial evidences such as landslides, sackung or rock-flow, lateral spreads and block slides, are detected from photogeological analysis (Stramondo & *alii*, 2005; Moro & *alii*, 2007). Here we show elevation and deep-seated terrain in the Apennine ridge where the distribution of β values (according to Roering & *alii*, 2005 and Taramelli & Melelli, 2009) quantifies the degree to which terrain exhibits the topographic signature of deep-seated movement.

THE STUDY AREA AND THE DATASET

The study area is located in the Central Apennines (Umbria and Marche regions) where the relief is the result of a very complex geologic and geomorphologic history (fig. 2).

The Central Apennines are a ridge with an high percentage of calcareous and marl limestone lithotypes with a coherent behaviour. The sequence is organized in a succession of anticlines and synclines of a NW-SE direction, eastward dipping resulting from a compressive tectonic phase (from Oligocene - Miocene to Pliocene, Bally & *alii,* 1986). An extensional tectonic phase, producing different sets of normal faulting (mainly oriented in Apennine and anti-Apennine directions, Malinverno & Ryan, 1986) has been active since the Upper Pliocene-Earlier Pleistocene (Calamita & Deiana, 1986); moreover, an isostatic uplift started in the Medium - Upper Pleistocene (Ambrosetti & *alii*, 1982, D'Agostino & *alii*, 2001) and is still active (Collettini & *alii*, 2000).

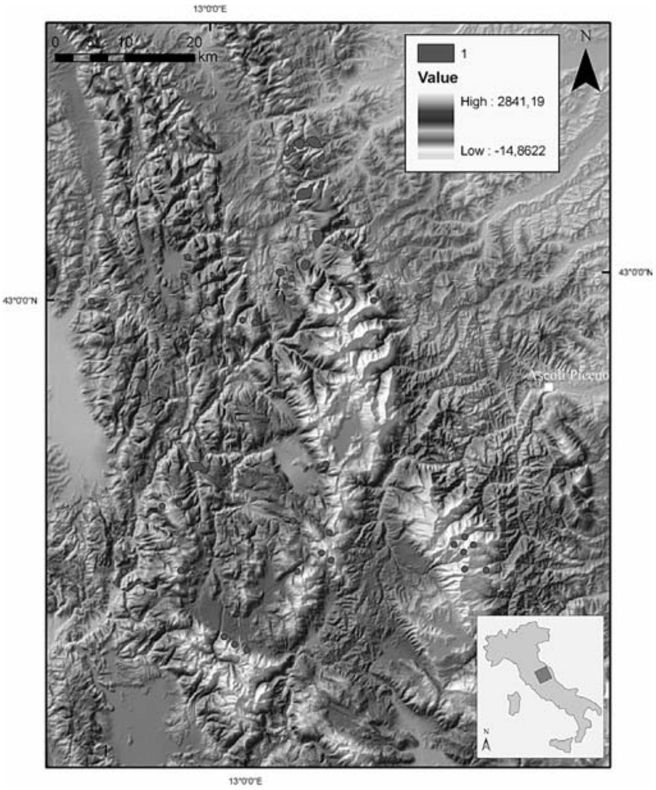

FIG. 2 - Location map of the study area with the DSGSD vector dataset (1).

Structural conditions are favourable for DGSD to occur (Dramis & Sorriso-Valvo 1994, Agliardi & *alii*, 2001, Saroli & *alii*, 2005): a topographic surface with high relief energy values and a drainage network characterized by high linear erosion rates. Moreover the slopes are affected by normal faults dipping with the same slope direction. The DGSD show a climax of their activity between the Pliocene and Pleistocene due to the extensional tectonic phase, the regional uplift and the strong climate variations (Coltorti & Dramis, 1995).

Data for this work were obtained from the Italian landslide inventory (IFFI, http://www.mais.sinanet.apat.it/cartanetiffi/) combined with a vector point data base of 403 DGSD collected from literature (Melelli, 2005).

In the study area 57 DGSD are present 27% of them previously unpublished, which were identified by field work combined with air-photo interpretation. Most of the DGSD identified were imported into a GIS environment as vector polygon data. Where the scale used was too small for the DGSD areas, the mass movements where imported as a point shapefile, located in the middle part of the slope involved.

All the movements identified are classified as sackung and deep-seated block slide. The first are found mainly along thrust fronts and the second on the western slopes of the anticlines. The depth creep surfaces are located mainly along the formations with high marl content, often intercalated between two calcareous formations.

All the study cases presented in literature show the same morphologic evidences as a result of Apennines tectonic and lithologic structure (Galadini, 2006; Moro & *alii*, 2007; 2009; Taramelli & *alii*, 2010). This leads to uncertainty for DGSD detection with traditional mapping techniques. DGSD show a similar topographic pattern regardless of the movements types, if they are present in the same lithologic complex and in the same macro area (past and present tectonic factors and climatic conditions). The main morphometric characteristics of each event are collected: length, width, altitude, height, slope (fig. 3).

Topographic attributes are referred to geometric slope properties. Moreover the correlation between topographic attributes and a specific landform is more evident when features show large dimensions and large evolution times whereas the scale factor minimizes the influence of boundary conditions.

TOPOGRAPHIC CHARACTERIZATION

To make more efficient the identification process, we formulated a quantitative method for the DGSD distribution of topography indicative of deep-seated slope.

To this end two datasets were used: Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) and Landsat ETM+ imageries. The SRTM DEM in its original format has a resolution of 3-arc-seconds, approximately 90m for the study area. The Landsat ETM+ (2000) has a resolution of 30m, technical details are available at: http://glcf.umiacs.umd.edu/data/guide/technical/landsat.shtml.

As first step DGSD locations were delocalized (location error) and spatial density calculated, with a radius of 450 m, yielded a gridded DGSD density map. A relief grid map was calculated with a 5 pixel circular diameter window (450 m scale). DGSD locations were overlaid on the relief grid and their spatial density calculated on a gridded DGSD density-relief map with 7 relief classes.

A grid for each topographic attribute, slope, aspect and curvature, was calculated and the mean angle was estimated using a 5 pixel diameter circular window (450 m scale) to derive the gridded relief map (fig. 4).

Thus mean slope, mean aspect and mean curvature are computed using the relief class (E_R) as grid mask. Statistical analysis of relief and DGSD frequency were carried out for each topographic parameter (slope, aspect and curvature).

Results show that a terrain prone to DGSD has:

- low curvature values: 0.0001 (47% E_R 100-300 m), 0.006 (32% E_R 300-400 m), 0.01 (16% E_R 400-500 m);
- high slope values: 39° (16% - E_R 100-200 m), 54°-55° (64% - E_R 200-400 m), 57° (16% - E_R 400-500 m);
- medium aspect value: 170°-180° N (90%).

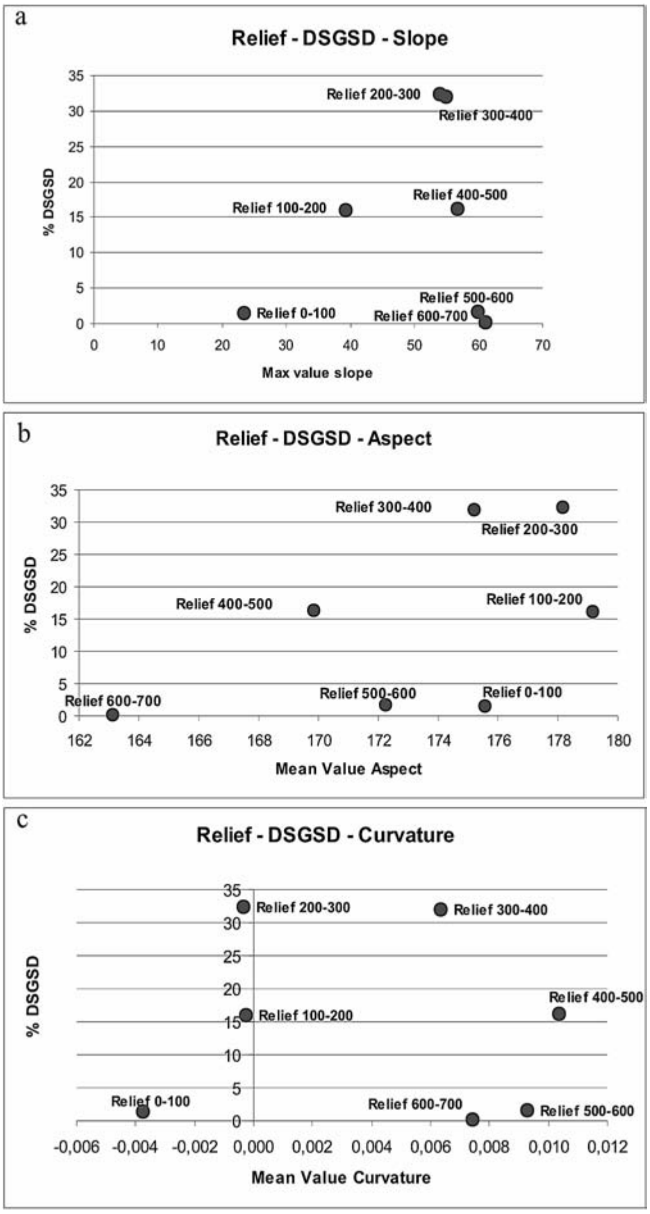

FIG. 3 - Charts with values of: a) slope, b) aspect, c) curvature, related to DSGSD relief classes.

Then, using the distribution of topographic relief and curvature using established algorithms (Zevenbergen & Thorne, 1987; Moore & *alii*, 1991) we calculate the DGSD topographic signature. Once we get the first susceptibility map we used the baseline imagery, circa 2000, acquired from the Global Land Cover Facility (GLCF) at the University of Maryland to calculated the topographic signature (ß) applying the SMA (fig. 5).

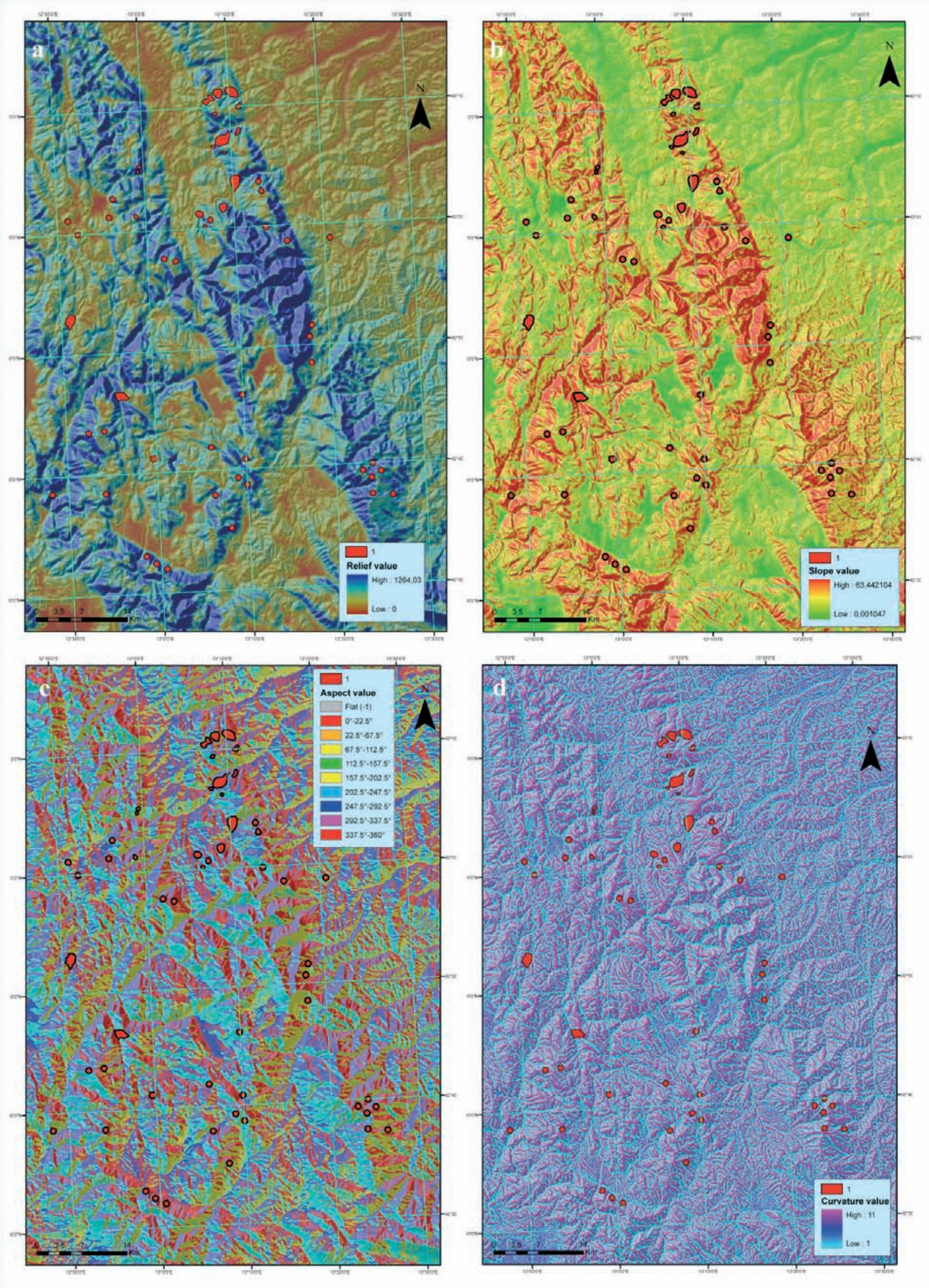

FIG. 4 - Grid derived from DEM SRTM with the DSGSD vector dataset (1): a) relief grid, b) slope grid, c) aspect grid, d) curvature grid.

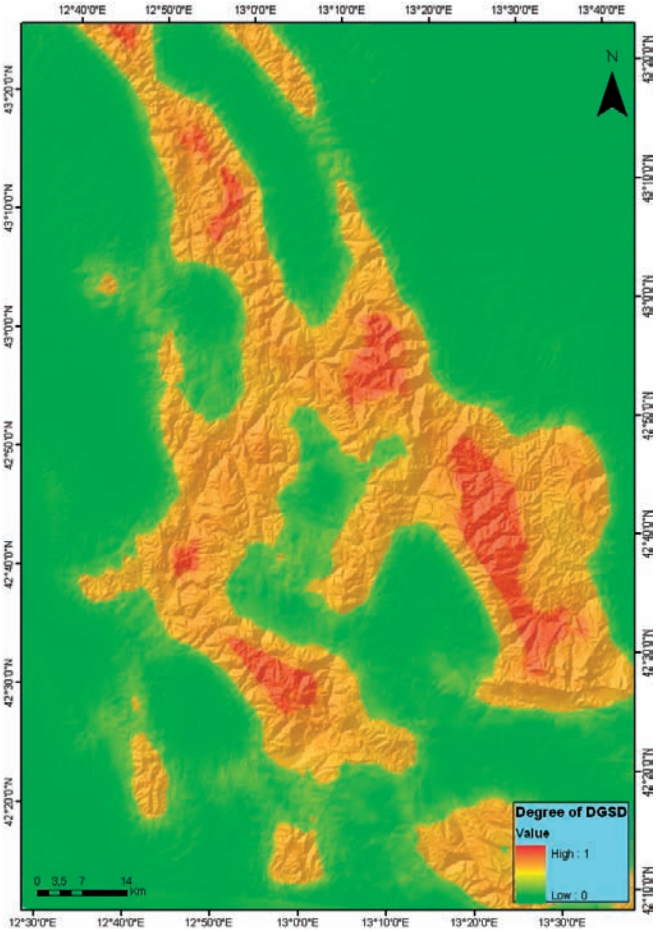

FIG. 5 - Map of DSGSD susceptibility derived from SRTM analysis corrected by Spectral Mixinig Analysis (a) High values of the signature are represented with warm color (red), low values with cool colours (yellow) and null values with light color (green).

Basically we recalculate the Substrate (S'), Dark (D') and Vegetation (V') fractions of the signature by partitioning the removed topographic shadow of the signature (~50%) among the Substrate (S), Dark (D) and Vegetation (V) in proportion to their respective contributions to the non-shadow fraction using a combination of three pure endmebers (Taramelli & Melelli, 2009; Taramelli & *alii*, 2010). Finally using the focalsum statistic we maximized the fraction of deep-seated data and minimized the fraction of valley floor and steep/dissected data that plot within the topographic signature.

Based on the above result β varies from 0 to 1; where 0 corresponds to steep and dissected terrain without indication of deep-seated movement and 1 represents terrain with morphology consistent with that generated by deep-seated movements. On the basis of literature data, field observations and air photo analysis, β = 0.43 (which corresponds to the transition from yellow to red) suitably discriminate DSGD susceptibility topographic signature. To calibrate the particular value of β that corresponds with the DSGD susceptible slopes, we examined the distribution of β values at numerous locations where we previously highlighted DSGD via aerial photos, field observations and literature (Farabollini & *alii*, 1995; Taramelli & Melelli, 2009). At these sites, β >0.43 served as an accurate benchmark for delineating the signature of DGSD. For a given grid point with β = 0.43, 43% of the surrounding patch of terrain has values of gradient and curvature that meet the topographic criteria.

CONCLUSIONS

In recognition of the DGSD research need of a considerable improvement of expertise in process studies and in mapping of precursor and antecedent conditions of natural phenomena, the role of remote sensing has increased both in the frequency of its use and in its influence upon the monitoring of these large events (Stramondo & *alii*, 2005). A growing number of studies have successfully utilized remote sensing to monitor earth process activity, and subsequently have concentrated on large scale investigations of hazard areas providing susceptibility maps. This paper has attempted a structured and integrated approach to DGSD assessment primarily from a quantitative perspective. The topographic approach employed to derive these insights is not intended for use in site-specific analyses of DGSD potential but instead identify slopes whose morphology is indicative of deep seated phenomena. Using a combined analysis, we were able to estimate the distribution of topography indicative of DGSD in the central Apennine ridge (calcareous fractions). We defined the range of slope, aspect and curvature values that best distinguishes the cluster of points associated with DGSD phenomena. Based on that, the results of the spectral mixture analysis in combination with the SRTM investigation indicate that the Central Apennine ridge is characterized by continuously varying DGSD signature. As a main results in the final susceptibility map we notice that negative values of curvature reflect concave terrains such as that associated with headscarps, whereas positive values represent convex forms such as sagging.

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