



Land-Use Change and Shallow Landsliding: A Case History from the Apennine Mountains, Italy

Janusz Wasowski, Marina Dipalma Lagreca, and Caterina Lamanna

Abstract

We investigate temporal variations in land use and landsliding in a small catchment characterized by the predominance of clay-rich materials and known to be prone to shallow slope failures. The results demonstrate a pronounced change from land use dominated by grassland pasture (~53 % in 1955) to wheat-based agriculture (~74 % in 2011). The temporal series of landslide inventories also indicate significant variations in landslide activity in the same period. In particular, the highest susceptibility to landsliding has been registered in recent years on the sown fields which had initially (1955) been used for pasture and grazing. The data also reveal that with time the steeper and apparently more landslide-prone slopes with grassland-pasture have been given over to new wheat cultivation. The introduction of ploughing for the new wheat cultivation on the often steep slopes that had originally been covered by grass is considered to be a significant factor in the increased susceptibility to landsliding. The negative impact on slope stability can be related to the decrease in effective strengths of soil resulting from modification of the existing cover from grass that is present all year to wheat characterized by a few month growth period per year, which implies increase in groundwater levels, and mechanical disturbance of soil caused by tillage. Finally, for the studied period (1955–2011) the local precipitation data indicated high inter-annual variability without the presence of any statistically significant trends.

Keywords

Land use change • Wheat cultivation • Landslide activity • Apennines • Italy

Introduction

This work follows up our earlier studies on the relative impacts of land-use change and climate on landslide activity in the municipality of Rocchetta Sant'Antonio (the

Apennine Mountains) in the period 1976–2006 (Wasowski et al. 2007, 2010; Lamanna et al. 2009). Here, we focus on a small catchment (15.6 km²) and extend the observation period of land-use changes and variations in landslide activity by examining historical air photos from 1955 and recent (2011) orthophotos. Furthermore, with respect to the previous studies, the investigation of land-use change is more detailed, thanks to the inclusion of an additional class, i.e. grassland-pasture. For the entire period (1955–2011) precipitation data from a local weather station are also used to assess rainfall temporal variability and identify possible long-term trends.

The main objective of this work is to draw attention to anthropogenic pressures that can have considerable influence

J. Wasowski (✉) • C. Lamanna
CNR – IRPI, National Research Council, Institute of Geo-Hydrological Protection, Bari 70126, Italy
e-mail: j.wasowski@ba.irpi.cnr.it; cate.lama@tiscali.it

M.D. Lagreca
Department of Earth and Geo-Environmental Sciences, University of Bari, Bari 70125, Italy
e-mail: marina.dipalmalagreca@uniba.it

on local slope stability (e.g. DeGraff and Canuti 1988; Sidle and Ochiai 2006). By using the example of this study we argue that a detailed assessment of historical to recent land-use changes is needed to avoid potentially misleading interpretations and conclusions regarding impacts of climate change and variability on landslide activity.

Environmental Setting of the Study Area

General

The study catchment is in the southern part of the Apennine Mountains, often called the Daunia Apennines. The area studied is characterized by moderate relief topography, with elevations below 800 m above sea level and modest slope inclinations ($\sim 10^\circ$ on average).

Today the land use and vegetation cover is dominated by agricultural activity (mainly cereals). Grassland-pasture and trees are only locally significant. Barren land is very limited, corresponding to flysch, limestone and clay outcrops. Similarly, developed land (e.g. rural settlements, roads) accounts for a small portion of the territory.

The area is characterized by a Mediterranean sub-humid (sub-Apennine) climate, with annual rainfall values that show large variations, from about 400 to nearly 1,000 mm (Fig. 1). Fall and winter months have similar precipitation, which together on average accounts for about 60 % of the annual total. The winter season is relatively mild, with a modest amount of snow precipitation. Summers are typically dry and hot.

Geology

The geologic units cropping out in the study area belong to tectonically deformed flysch successions of Late Cretaceous-Miocene age. They can be divided into three main categories, each dominated by one specific lithology. These include: clays-clay shales (76.5 % of the overall area), sandstones (18 %) and limestones (5.5 %). The predominance of sheared, scaly clays (Fig. 2) with weak geotechnical properties (Φ'_r varying from 6.9° to 16.5°) and the presence of poorly drained slopes are considered the underlying causes of landsliding (Wasowski et al. 2010, 2012).

Landslides

The Daunia Apennines are well known for recurrent landslide problems (e.g. Zezza et al. 1994; Magliulo et al. 2008). In a study of the area (132 km^2) neighbouring to the north-west of the territory of Rocchetta Sant'Antonio, Mossa et al. (2005) reported a frequency of landslides exceeding 20 %.

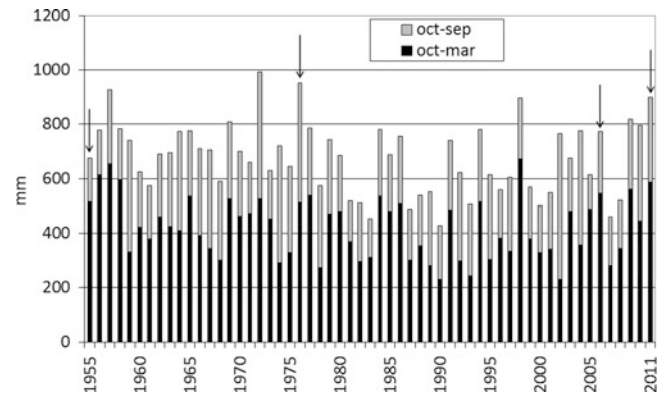


Fig. 1 Time series of hydrological year (October–September) and 6 month groundwater recharge period (October–March) precipitation registered in Rocchetta Sant'Antonio; note the large inter-annual variability. Arrows indicate the 4 years for which land use maps and landslide inventories were compiled

They also showed that the landslide frequency is the highest in the $10\text{--}15^\circ$ slope class, followed by the $5\text{--}10$ and $15\text{--}20$ slope classes.

For the municipal territory of Rocchetta Sant'Antonio (72 km^2), the landslide inventories compiled by Lamanna et al. (2009) revealed the impact of slope failures, with areal frequency of active landslides amounting to 2.0 % and 5.2 %, respectively in 1976 and 2006. Most of these landslides were relatively small, with resulting densities (number per km^2) ranging from about 6 (in 1976) to 34 (in 2006).

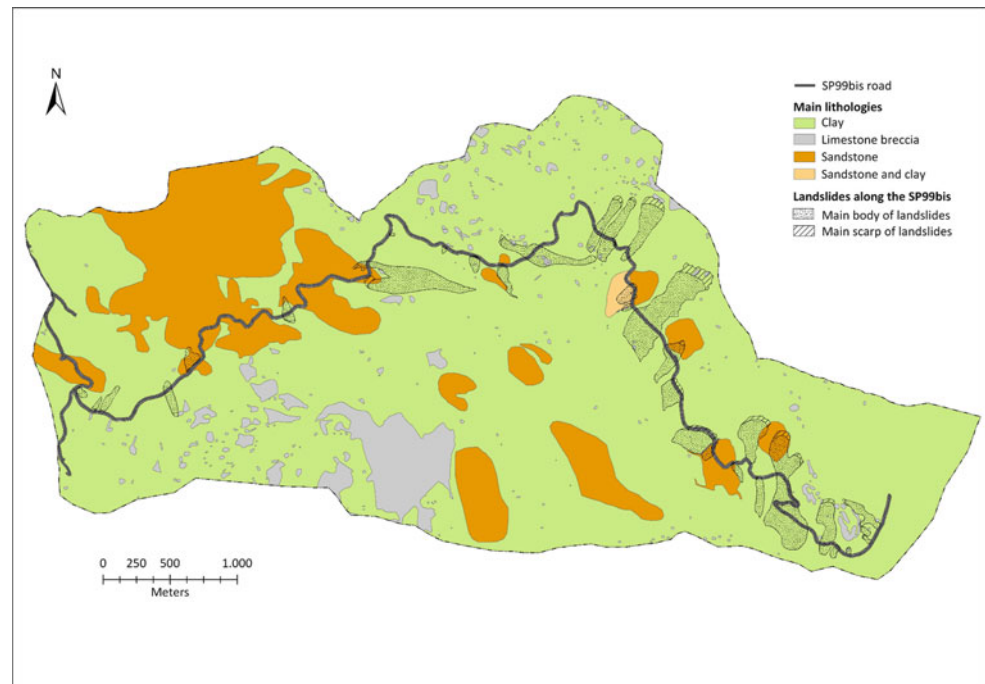
Subsequent studies within the municipality of Rocchetta Sant'Antonio focused on the 15.6 km^2 catchment traversed by SP99bis road. The road was damaged by series of landslides in the period 2003–2005 (Fig. 2) and this prompted detailed subsurface geotechnical investigation, as well as piezometer and inclinometer borehole monitoring. The outcomes of the investigation demonstrated the link between the presence of high piezometric levels in winter and early spring months and the occurrence of predominantly shallow slope failures (Wasowski et al. 2010, 2012).

Data and Methods

The information and datasets used in this work included:

- Topographic base map at 1:5,000 scale, from 2002, and the derived digital elevation model (DEM);
- Slope map obtained from the DEM;
- Inventory map of 30 landslides that damaged the road in the catchment in the period 2003–2005 (from Wasowski et al. 2010);
- Inventory maps of active landslides derived from 1976 black and white air photos (1:25,000 scale) and high resolution (1 m panchromatic) 2006 IKONOS-2 multispectral imagery (from Wasowski et al. 2010);

Fig. 2 Distribution of main lithologic units in the study area and locations of 30 landslides, mapped in 2005, which damaged different portions of the SP99bis road



- Inventory maps of active landslides derived from 1955 black and white air photos (1:33,000 scale) and 2011 multispectral orthophotos (0.5 m resolution);
- Land-use maps derived from the same 1976 air photos and 2006 orthophotos (updated after Wasowski et al. 2010);
- Land-use maps derived from the same 1955 air photos and 2011 orthophotos;
- Daily rainfall data (1955–2011) from the pluviometric station in Rocchetta Sant’Antonio.

This work also relied on frequent in situ inspections conducted in the study area since 2005. All the datasets were collated and analyzed using commercial Geographic Information Systems (GIS) and remote sensing software.

Landslide Inventories

To assess the differences between historical (1955, 1976) and recent (2006, 2011) landsliding, four temporally distinct landslide activity maps were considered. In this effort we closely followed our earlier work and the generally accepted landslide mapping criteria (cf. Wasowski et al. 2010).

In addition to the already available 1976 and 2006 datasets, a historical landslide inventory was obtained through a stereoscopic interpretation of 1955 air photos. Furthermore, a recent landslide inventory was produced from high resolution multispectral orthophotos acquired in late winter of 2011.

Land-Use Maps

To estimate the differences between historical (1955, 1976) and recent (2006, 2011) land use, four temporally distinct maps were compiled from the same air photos and multispectral imagery used for landslide mapping. Only two of them (for 1955 and 2011) are shown here (Fig. 3).

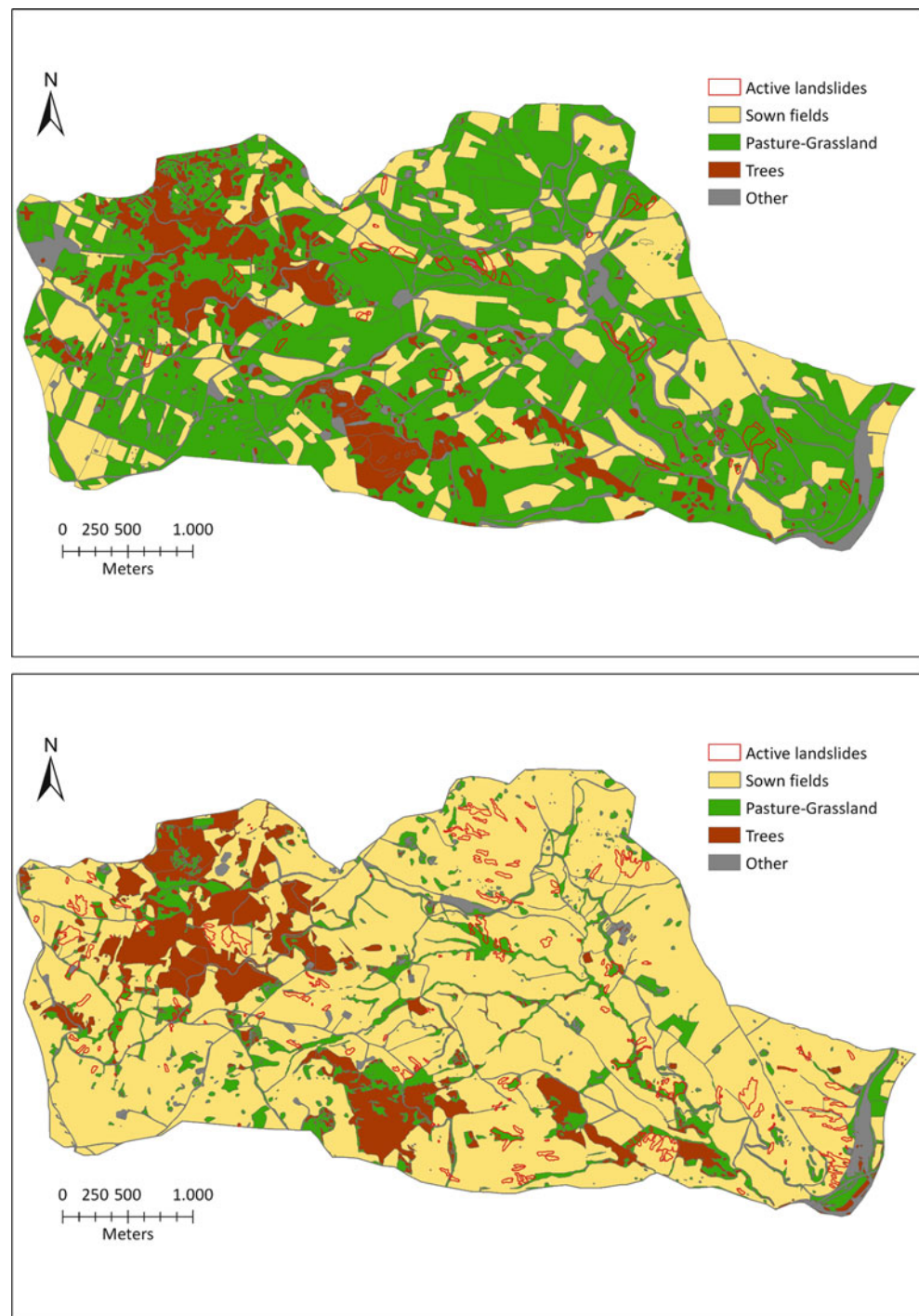
We followed the approach described in our earlier work (Wasowski et al. 2010, 2012). In particular, through image interpretation four major land-use classes were distinguished: (i) agricultural land (sown fields with mainly cereal cultivation); (ii) grassland-pasture; (iii) trees, including dense shrub; (iv) other (including uncultivated and barren land and man-made structures). We will show that these four classes of land cover and land use can have different impacts on the susceptibility of slopes to shallow landsliding.

Results

Variation in Landslide Activity

Table 1 shows a summary of landslide statistics for the four inventories: 1955, 1976, 2006 and 2011. The results, presented in terms of areal frequency of landslides (in percent of total land area) and their density (number per km²), reveal the presence of substantial variations over time.

Fig. 3 Land use and distribution of active landslides in 1955 (*upper*) and in 2011 (*lower*). A comparison of the two maps reveals pronounced change from grass-pasture land use to sown field-based agriculture. There are more active landslides in 2011 and they involve mainly the sown fields. See Fig. 4 for land-use statistics for 1955 and 2011, as well as for the intermediate years 1976 and 2006



In particular, there is an increase over time in areal frequency, from about 1.5 % in 1955 (2.49 % in 1976), to 5.6 % in 2006 (2.73 % in 2011). The lower frequency of landslides in 2011 could be in part due to the early acquisition date of the orthophotos with respect to the imagery used to produce the other three inventories (respectively before and after the spring seasons).

Historical and Recent Land Use Versus Landslide Activity

The land-use maps in Fig. 3 illustrate the changes that occurred between 1955 and 2011. Whereas in 1955 the major part of the land has been used as pasture and grass, by 2011 sown fields are predominant.

Table 1 Variation of landslide activity with time in terms of areal frequency (%) and density per km²

| Year | Active landslides | |
|------|-------------------|---------------------------|
| | Area (%) | Number (km ²) |
| 1955 | 1.5 | 3.3 |
| 1976 | 2.5 | 6.3 |
| 2006 | 5.6 | 60.3 |
| 2011 | 2.7 | 12.7 |

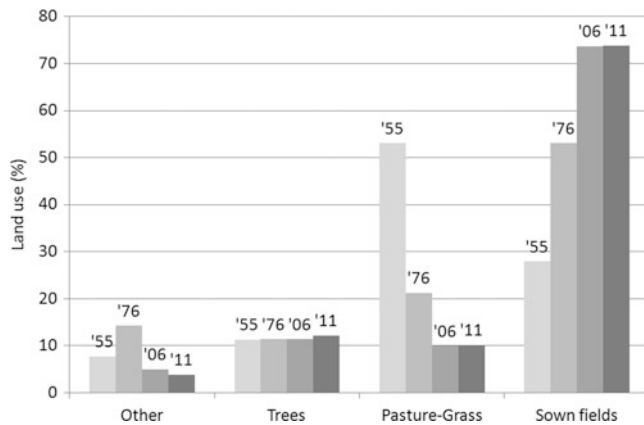


Fig. 4 Statistics of lands use in 1955, 1976, 2006 and 2011. Note the remarkable change from the grassland-pasture in 1955 (53 % of the total area) to agriculture with the predominance of the sown fields (74 %)

The temporal variations in land use are further detailed in Fig. 4 in terms of areal frequency of the four land-use classes: sown fields, grass-pasture, trees and other. This quantification reveals that the increase in sown fields from 28 % in 1955 to 74 % in 2011 originated from the concomitant reduction of the land used for pasture and grazing (from 53 % to 10 %).

Furthermore, already by 1976 the portion of the land used as sown fields had nearly doubled with respect to 1955, exceeding 50 %. During the entire period considered the remaining two land-use classes have undergone relatively minor changes (Fig. 4).

The influence of land-use changes on slope instability appears evident when considering the distributions of active landslides in 1955 and 2011 versus land cover in the same years (Fig. 3). The maps indicate that the portions of the grassland-pasture that have been changed to sown fields agriculture are today (2011) most prone to failure. This is consistent with the findings of Wasowski et al. (2010), who compared land use and landslide activity in 1976 and 2006.

Further details on the influence of land-use changes on slope instability, and in particular on the role of conversions to sown fields are presented in Fig. 5. It is shown that the areas with sown fields, which in 1955 had been used for pasture and grazing, today (2011) exhibit the highest frequency of active landslides (nearly 4 %). Indeed, before the conversion

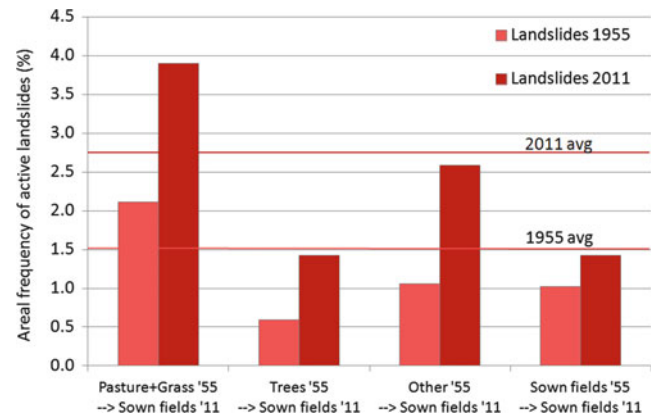


Fig. 5 Areal frequency of active landslides in 1955 and 2011 for fields that have already been sown in 1955 (“old” sown), and for the remaining three land-use classes (grass-pasture, trees and other) that have become sown after 1955. The two lines mark the average areal frequency of landslides in 1955 and 2011. At present (2011), the highest frequency to landsliding is observed on the sown fields which had initially (1955) been used for pasture and grazing

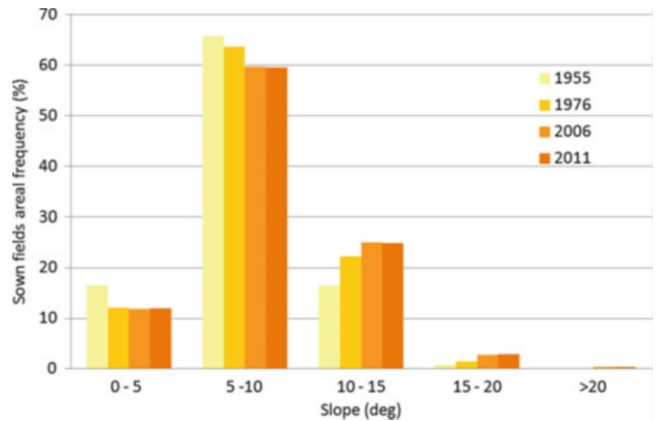


Fig. 6 Areal frequency of fields sown in 1955, 1976, 2006 and 2011 for different slope classes. Note the trend over time towards cultivation of steeper slopes

this land-use class had already been the most landslide-prone. Figure 5 also indicates that the conversion to sown fields resulted in an additional increase in susceptibility to slope failure.

The increased susceptibility to landsliding is further investigated by considering variations of slope inclinations of the sown fields. Figure 6 shows that during the entire period (1955–2011) the majority of the sown fields were within the same slope interval of 5–10°. Nevertheless, the data revealed also a clear trend towards the cultivation of steeper slopes. In particular, in the periods 1955–1976 and 1976–2006 the percentage of sown fields significantly increased for the slope classes 10–15° and 15–20°. It is likely that the expansion of cultivation onto steeper and presumably less stable slopes also contributed to the observed increases in frequency of active landslides.

Discussion and Conclusion

Even though the comparison of the historical (1955, 1976) and recent (2006, 2011) inventories demonstrated a significant increase over time in landslide activity in the investigated catchment, the data available for the same period from the local weather station did not reveal any clear temporal trends in precipitation. In fact, the climatic data indicated significant variations in the annual rainfall, which are even more marked if the October–March (groundwater recharge periods) are considered (Wasowski et al. 2010).

Instead, the recent increases in the frequency of active landsliding coincided with significant change in land use over time. In particular, the areal extent of sown fields (used mainly for wheat cultivation) grew from about 28 % (of the total catchment area) in 1955 to about 74 % in 2011. Furthermore, a comparative analysis of the land-use maps and landslide inventories demonstrated that the highest areal frequency of failures is recently being registered on the slopes which had initially been used for pasture and grazing. The negative impact of the conversion to wheat cultivation on slope stability can be related to the decrease in effective strengths of soil resulting from (i) modification of the existing cover from grass that is present all year to wheat characterized by a few month growth period per year, which implies increase in groundwater levels and (ii) mechanical disturbance of soil caused by tillage.

Acknowledgments We thank the Prefettura di Foggia, Rocchetta Sant'Antonio administration and Eng. G. Amoruso (Regione Puglia) for their support. This work benefited from the review by Jerome DeGraff.

References

- DeGraff JV, Canuti P (1988) Using isopleths mapping to evaluate landslide activity in relation to agricultural practices. *Bull Int Assoc Eng Geol* 38:61–71
- Lamanna C, Casarano D, Wasowski J (2009) Cambiamenti dell'uso del suolo e aumento dell'attività franosa nel territorio di Rocchetta Sant'Antonio (Appennino dauno) Il quaternario. *Ital J Quat Sci* 22 (2):139–156
- Magliulo P, Di Lisio A, Russo F, Zelano A (2008) Geomorphology and landslide susceptibility assessment using GIS and bivariate statistics: a case study in southern Italy. *Nat Hazards* 47:411–435
- Mossa S, Capolongo D, Pennetta L, Wasowski J (2005) A GIS-based assessment of landsliding in the Daunia Apennines, southern Italy. In: *Proceedings of the international conference "Mass movement hazard in various environments"* 20–21 October 2005, Cracow, Poland, pp 86–91
- Sidle RC, Ochiai H, (2006), *Landslides: processes, prediction and land use*. American Geophysical Union, Water Resources Monograph 18
- Wasowski J, Casarano D, Lamanna C (2007) Is the current landslide activity in the Daunia region (Italy) controlled by climate or land use change? In: *Proceedings of the international conference on landslides and climate change*, Ventor, Isle of Wight, UK, 21–24 May 2007, pp 41–49
- Wasowski J, Lamanna C, Casarano D (2010) Influence of land-use change and precipitation patterns on landslide activity in the Daunia Apennines Italy. *Quart J Eng Geol Hydrogeol* 43: 1–17
- Wasowski J, Lamanna C, Gigante G, Casarano D (2012) High resolution satellite imagery analysis for inferring surface-subsurface water relationships in unstable slopes. *Remote Sens Environ* 124:135–148
- Zeza F, Merenda L, Bruno G, Crescenzi E, Iovine G (1994) Condizioni di instabilità e rischio da frana nei comuni dell'Appennino Dauno Pugliese. *Geologia Applicata e Idrogeologia* 29:77–141