DOI: 10.4408/IJEGE.2017-01.S-08

THE INFLUENCE OF CLIMATE VARIABILITY AND LAND USE VARIATIONS ON THE OCCURRENCE OF LANDSLIDE EVENTS (SUBAPPENNINO DAUNO, SOUTHERN ITALY)

Teresa LONIGRO[(*)], Francesco GENTILE[(**)] & Maurizio POLEMIO[(*)]

[(*)] CNR IRPI - Via G. Amendola 122/I - 70126 Bari, Italy
[(**)] University of Bari "A. Moro" - Bari, Italy
Corresponding author: m.polemio@ba.irpi.cnr.it

EXTENDED ABSTRACT

L'obiettivo del seguente lavoro è quello di descrivere l'applicazione di una metodologia di studio che utilizzi diversi tipi di dati: climatici, di occorrenza degli eventi di dissesto idrogeologico e di uso del suolo, col fine ultimo di mettere in evidenza e descrivere le relazioni esistenti tra variabilità climatica e variazioni di uso del suolo sull'occorrenza di eventi di dissesto idrogeologico, nel caso specifico di frane che abbiano causato danni alle persone o alle cose.

La metodologia presentata è basata sull'analisi di serie storiche temporali e sull'analisi geospaziale di dati climatici a registrazione mensile (pioggia, numero di giorni piovosi, intensità di pioggia e temperatura) e dati inerenti i massimi annui delle piogge di breve durata (da 1 ora a 5 giorni). Unitamente ai dati di tipo climatico sono stati analizzati anche dati storici relativi alle modificazioni dell'uso del suolo.

Per quanto riguarda lo studio delle relazioni tra le variazioni climatiche e gli eventi di frana, la metodologia prevede l'uso delle seguenti analisi comparate tra le serie dei dati storici relativi alle frane e le serie di dati climatici: correlazione, correlazione incrociata e individuazione dei trend. Il problema dell'elaborazione di un gran numero di dati di diversa natura, sia temporale che spaziale, è stato semplificato attraverso l'introduzione e l'utilizzo di alcuni indici, che hanno permesso di ridurre notevolmente le elaborazioni da effettuare.

La metodologia descritta nel seguente lavoro è stata applicata all'unica area del territorio pugliese a franosità diffusa: il Subappennino Dauno.

L'analisi climatica è stata effettuata utilizzando dati climatici mensili (pioggia, numero di giorni piovosi, intensità di pioggia e temperatura atmosferica) a partire dal 1877 e relativi a 16 stazioni pluviometriche, di cui 10 anche termometriche. I dati relativi ai massimi annui delle piogge di breve durata (da 1 ora a 5 giorni, per 10 durate diverse), disponibili a partire dal 1921, sono relativi, invece, a 37 stazioni.

I dati degli eventi franosi occorsi nell'area di studio coprono un intervallo temporale compreso tra il 1928 e il 2007, durante il quale sono state individuate ben 176 frane.

L'analisi delle serie mensili dei dati climatici ha evidenziato il ruolo prevalente delle precipitazioni nel giustificare la variabilità dell'occorrenza delle frane. Tuttavia i risultati derivanti dall'analisi dei trend evidenziano che le variazioni climatiche tendenziali non giustificano il trend crescente dell'occorrenza dei fenomeni franosi registrati nell'area di studio.

L'analisi dei trend ha messo in evidenza una tendenza alla diminuzione per quanto riguarda le precipitazioni e l'intensità di pioggia, mentre una tendenza all'aumento è stata registrata per i giorni di pioggia, per la temperatura e per le frane. L'analisi effettuata sui dati relativi ai massimi annui delle piogge di breve durata (da 1 ora a 5 giorni) ha messo in evidenza una prevalente tendenza alla diminuzione anche per questo tipo di aspetto idrologico, spesso determinante nell'innesco delle frane.

I risultati quindi inducono ad escludere la locale modificazione del clima quale fattore chiave per giustificare la tendenza crescente dell'occorrenza delle frane.

L'analisi relativa alle variazioni di uso del suolo è stata effettuata utilizzando e confrontando diversi dati di uso del suolo:

- carta forestale del Regno d'Italia del 1936;
- carta dell'utilizzazione del suolo d'Italia del CNR-TCI relativa al 1959;
- i tre livelli temporali del Corine Land Cover (1990, 1999, 2006).

Per effettuare le elaborazioni è stato necessario rendere confrontabili in qualche modo i dati a disposizione, dal momento che, mentre i primi due livelli informativi (Carta forestale del Regno d'Italia del 1936 e Carta dell'utilizzazione del suolo d'Italia del CNR-TCI relativa al 1959) sono stati recuperati su base cartacea, i livelli informativi del Progetto Corine sono rappresentati da shapefile. Solo dopo una conversione del formato cartaceo in formato digitale e successiva digitalizzazione si è potuto procedere con il confronto e con le analisi relative alle variazioni di uso del suolo. Nell'area del Subappennino Dauno l'analisi è stata condotta basandosi sul confronto tra la serie storica delle frane e l'evoluzione temporale dell'uso del suolo. L'intero periodo investigato (1928-2008) è stato suddiviso in decadi e l'analisi ha evidenziato, in corrispondenza della decade caratterizzata dal maggior numero di eventi, la contemporanea diminuzione dei boschi e il netto incremento delle aree urbanizzate, mettendo in evidenza quanto la componente antropica incida sull'occorrenza di frane.

ABSTRACT

The aim of the paper is to describe the results of the application of a methodology based both on the use of time series analyses and of geospatial analyses of monthly climatic data (rainfall, wet days, rainfall intensity, and temperature), annual maximum of short-duration rainfall (from 1 hour to 5 days), and historical modification of land use in order to characterise the effects of these variables on the occurrence of landslide events. The methodology was applied in the Subappennino Dauno area, located on the eastern margin of the Southern Apennines thrust belt (Southern Italy).

Despite the decreasing trend of rainfall and rainfall intensity and the increasing trend of temperatures and wet days, there is an increasing trend of landslide occurrence, highlighting the negative effect of anthropogenic modifications and the mismanagement of landslide-prone areas.

This hypothesis was confirmed by comparing the distribution of landslides with the land use variations data (especially urban areas and wooded areas) collected from 1930 to 2006.

***Keywords**: Apulia, climate change, landslides, land use, Subappennino Dauno*

INTRODUCTION

Historical data about landslide events on a specific area are very important for the comprehension of the evolution of the area and represent an important tool for a more conscientious land management and for the estimation of hazard scenarios as a basis for Civil Protection purposes (Petrucci *et alii*, 2010).

The variation in time of the number of landslides in a given territory can be due to the variation of one or more factors that regulate their occurrence.

The role of climate (and its variations) and land use variations on the occurrence of landslides can be considered main landslide occurrence factors on long periods (decades).

Recent international research has underlined the evidence of climate change throughout the world, which is evident in the gradual, but constant, rise of temperatures and in the variation in the distribution of rainfall (EEA, 2008). Among the consequences of these climate conditions there is the increase in the frequency and magnitude of natural disasters, such as droughts, windstorms, heat waves, floods and secondary floods (i.e. rapid accumulation or pounding of surface water with very low flow velocity), and landslides (Petrucci & Polemio, 2002).

It is estimated that in Italy about 10% of the territory (about 30,000 km^2) is characterised by high hydrogeological risk (landslide and/or floods risk) and that more than 80% of Italian municipalities fall within these areas, involving about 10% of the population (just under 5.8 million people). The landslide events cover an area of about 17,000 km^2 (representing 58% of the Italian areas subjected to highly critical hydrogeological risk) (Guzzetti & Tonelli, 2004; Gisotti & Masciocco, 2013).

The situation described represents a serious problem in Italy which be worsened by deep land use modifications observed after the Second World War.

The aim of the present study is to describe the application of a methodology that uses different types of data: climate data, land use data and data on the landslide occurrences. It is based on time series analysis and geospatial analysis of climatic data (rainfall, number of rainy days, rainfall intensity and temperature), data relating to the annual maximum of short-duration rainfall (from 1 hour to 5 days), historical data on landslide occurrences, and data on land use variations, in order to characterise the effects of these variables on the occurrence of landslide events within the territory of the Subappennino Dauno (Southern Italy).

THE STUDY AREA

The Subappennino Dauno is situated in the north-west of Apulia region, southern Italy. It has an area of approximately 1900 Km^2 and it includes 28 municipalities.

This area is characterised by moderate relief only locally exceeding 1000 m a.s.l., e.g. Monte Cornacchia (1152 m a.s.l.), the highest relief of the entire Apulia region.

The climate is Mediterranean sub-humid (according to De Martonne aridity index) and it is characterised by hot and dry summers, while the rainfalls are concentrated between autumn and winter. The mean value of rainfall is approximately equal to 700 mm, while the mean temperature registered in this area is of 14°C.

From a geological point of view this area represents the eastern margin of the Southern Apennines thrust belt. Flysch and marly clay, mainly constituted by clayey marls, clays and silty-clays, dominate in the study area. Due to the intense strain history, these successions are found to be from stratified to deeply fractured, up to be disrupted and floating as blocks in a clayey matrix. In turn, the clay units are laminated to intensely fissured and characterised by very poor mechanical properties (Santaloia *et alii*, 2001; Santaloia *et alii*, 2012), characterising the Subappennino Dauno as the landslide-prone Apulian sub-zone (Fig. 1).

For this characteristic the area of Subappennino Dauno is largely studied from different points of view. Some works highlight the risk existing in this area, making a list of all (or the more dangerous or fatal) events recorded in the study area while other works describe the distribution on the territory of the events, using thematic maps (Almagià, 1910; Catenacci, 1992; Iovine *et alii*; 1996). Some works relate to the individuation of the relationships between land use and/or climate modifications and landslide occurrences on limited areas, such as catchments or municipalities particularly affected by landslide events (Melidoro, 1971; Wasowski *et alii*, 2010 and 2012). Some authors analyse the landslide risk in the area of Subappennino Dauno considering the

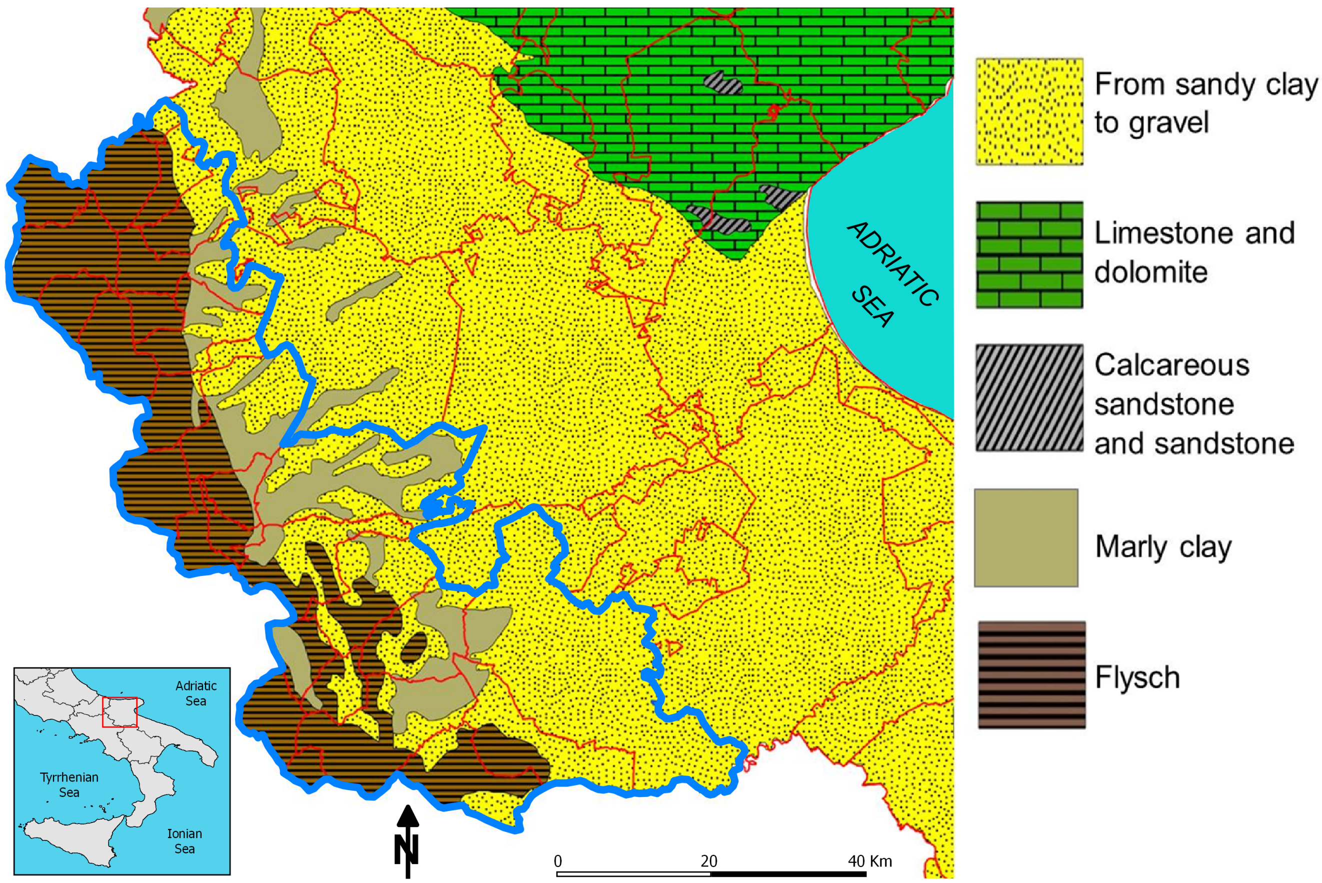

Fig. 1 - Subappennino Dauno geological-technical map. Blue line bounds the Subappennino Dauno area; red line indicates municipality border

conditions of stability of the municipalities more often damaged by landslides (or considering the damage caused by landslides on the main roads (Cotecchia, 1963; Zezza *et alii*, 1994).

Taking into account the geotechnical characteristics of the successions involved in the landslide movements, the area of Subappennino Dauno is characterised by slow or very slow movements in marly-clay or flysch soils, intensely disturbed or tectonised and characterised by poor geotechnical properties (Cruden & Varnes, 1996; Santaloia *et alii*, 2012). Flows in clay slopes and complex landslides represent the principal mechanisms of landslides in the study area. The complex landslides present characteristics of rotational slides in the upper area of the landslide body and characteristics of flowing in the lower part (Zezza *et alii*, 1994; Cruden & Varnes, 1996).

The landslide events occurring in the area of Subappennino Dauno often represent the reactivation of old/past events; the principal reactivation mechanisms are complex sliding and mud flows (with a variable depth, but often from a medium to a high depth). The reactivation movements are always characterised by low to very low speeds (Cotecchia *et alii*, 2009 and 2011).

THE CLIMATE DATABASE

The climate database is used to define the assessment of the effects of climate variability on the trends of landslide occurrences and it includes two sections: monthly climate data and the annual maximum of short-duration rainfall.

The annual maximum of short-duration rainfall is used to characterise the variability and trend of peak rainfall intensity, by considering durations that are both short and relevant for landslide occurrences. For the present work annual maximum rainfall observed from 1 hour up to 5 days are used.

The integrated use of monthly climatic data and the annual maximum of short-duration rainfall is proposed as an equilibrated solution to characterise the climatic variability spanning all antecedent conditions and triggering conditions of the considered phenomena (Polemio & Lonigro, 2015).

The monthly climate section of the database was realised by collecting monthly data on rainfall R, wet days WD (days in which precipitation is equal to or greater than 1 mm), and temperature T from the Annali Idrologici (annual publication of the national hydrological service), published from 1919 to 1996

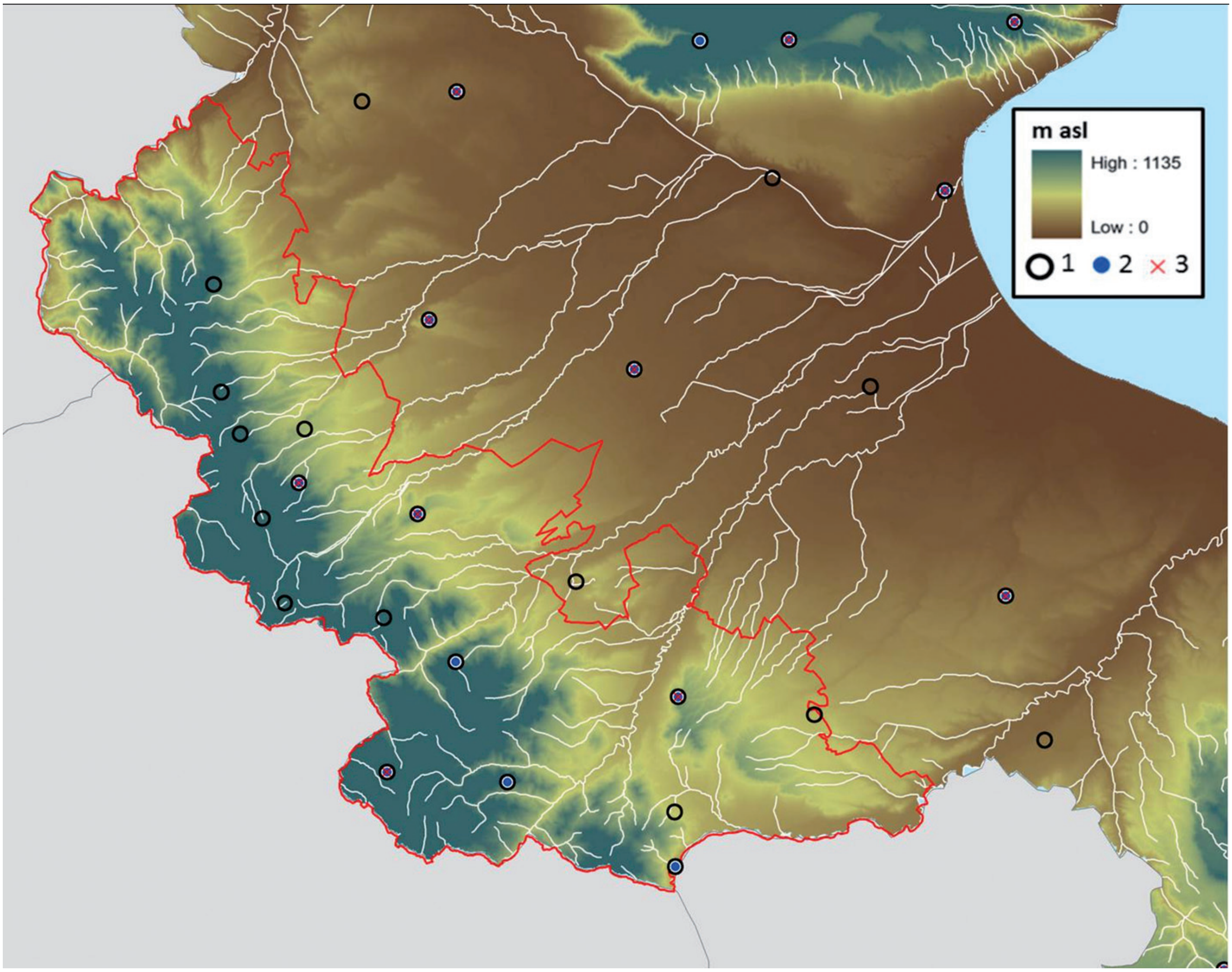

Fig. 2 - Subappennino Dauno main drainage network and altimetric map (m a.s.l.). Gauge locations: (1) short duration rainfall; (2) monthly rainfall; and (3) monthly temperature

(SIMN, 1919-1996). This database has been integrated with historical data from 1877; the most recent data (until 2008) were provided by the Centre of Functional Service of Civil Protection of Regione Puglia.

For each month and rain gauge, the monthly-mean rainfall intensity of wet days (following rainfall intensity or I) was calculated as the ratio between the monthly rainfall R and the monthly number of wet days WD. The following text always refers to the hydrological year, which runs from September to August.

Sixteen rainfall gauges/time series, ten of which were also thermometric, were selected inside and in the vicinity of the study area for the climate analysis. The selection was optimised by maximising the time series length, minimising time series gaps, and pursuing a sufficient gauge density and spatial continuity for each climate variable (Fig. 2).

The section of the annual maximum of short-duration rainfall was realised by collecting rainfall data from 1 hour up to 5 days of duration. The available data included in this section are of two types: the former type, available from 1929 to 2005, included peaks measured in a mobile window of duration of 1, 3, 6, 12, and 24 hours. The latter type, available from 1921 to 2005, included the annual rainfall maximum from 1 to 5 days and was obtained as the total of daily values (each day as 24-hour total observed at 9.00). There were 37 time series selected for the annual maximum of short-duration rainfall for the Subappennino Dauno.

Some monthly indices of rainfall, wet days, rainfall intensity, and temperature were introduced to simplify the analysis of parameters, characterised by spatial and temporal variability (Polemio & Petrucci, 2010).

THE LAND USE VARIATIONS DATA

The main data about land use variations were collected from the "Corine Land Cover" programme for the years 2006, 1999 and 1990.

As the topic of the work concerns the historical data research, in the case of land use the following sources of data were found and analysed:

- 1:250,000 "Land use Map" edited by CNR-TCI, relative to the land use of the 1959, which was acquired in digital format and digitalised;
- 1:100,000 "Carta forestale" edited by "Milizia militare italiana", during the thirties. This map is useful for the study of the evolution of wooded areas, because this map was realised considering not all the types of land use, but only the areas voted to woods. As in the previous case, the maps were acquired and digitalised.

In order to better compare the data coming from the abovementioned maps, a shared map legend was realised. It represented the following land uses:

- urban areas;
- cultivated areas;
- wooded areas;
- meadows and pastures;
- unproductive areas;
- reservoirs ad rivers (Fig. 3).

Taking into account the land use variations from 1959 to 2006 (from 1936 for wooded areas), the Subappennino Dauno represents the area of Apulia region with the lower increase of the urban areas; in fact this kind of land use increases from 8 km^2 recorded in the 1959 to about 10 km^2 recorded in the 2006.

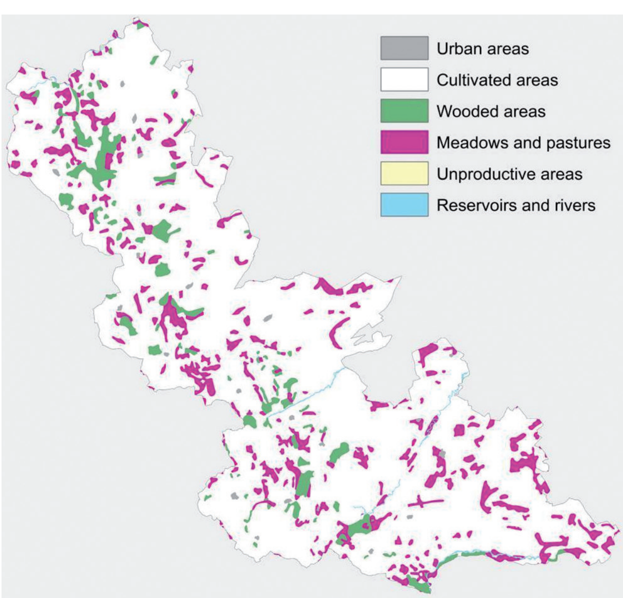

Fig. 3 - Subappennino Dauno «Land use map» for the year 1959

The cultivated areas present an almost stable trend from 1959 (when 1556 km^2 of cultivated areas was recorded) to 2006 (when 1562 km^2 was recorded). During 1990 was recorded the maximum extension of cultivated areas, even if the value is slightly greater than the previously listed values (1653 km^2).

The meadow and pasture areas undergo the greater modifications of all the land use categories considered in the present study. In fact while in 1959 were recorded 203 km^2 of meadows and pastures, in 1990 (that represent the time level immediately subsequent to 1959) were recorded only 42 km^2; in 2006 were recorded 53 km^2 of meadows and pastures.

In 1936 the wooded areas occupied a surface of 118 km^2 (with a prevalence of oak and english oak and only a turkey oak forest between the municipalities of Pietramontecorvino, Celenza Valfortore e Motta Montecorvino), while in 1959 were recorded 94 km^2. There was an increase in wooded area until 1999, when the maximum value was reached (262 km^2) and a successive decrease of about 16 km^2 in the period 1999-2006.

THE LANDSLIDE EVENTS DATABASE

As concerns the landslide events, they were collected from 1928 to 2007. The main source of these records is the AVI database (CNR-GNDCI, 1999), an existing Italian database that collects data about damaging floods and landslides from 1918 to 1996.

This dataset was integrated up to 2007 by consulting newspapers, scientific publications and technical reports, written by the researchers of the CNR-IRPI for the Civil Protection, and also documents belonging to a research project (Polemio & Lonigro, 2015).

From 1928 to 2007, 176 landslides were recognised in the study area. On average, 2 landslides occurred each year.

Landslides monthly time series were defined both for each municipality and for the entire study area; the annual time series could be extracted by simply adding monthly values.

As with the climate data, synthetic indices were calculated for 1 to 12 months and for hydrological years (Ly).

Considering the annual landslides time series, the maximum number of landslides events was 57, recorded in January 2003, when 11 of the Subappennino Dauno municipalities have been affected by landslides. Rocchetta Sant'Antonio was the municipality with the highest number of landslides (8) recorded in that month.

Another year characterised by a great number of landslides (29) was 1963. During the month of December 1963 were recorded 27 events, affecting 18 of the 28 municipalities of the study area. Alberona, San Marco la Catola e Sant'Agata di Puglia were the municipalities that recorded the highest number of landslides (3 events recorded in December 1963).

The data about landslides were sorted by municipality to obtain a spatial distribution of occurrences for the entire territory;

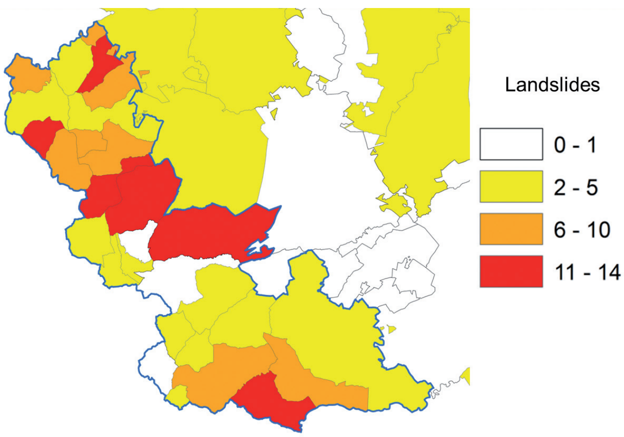

Fig. 4 - Occurrence landslides municipality map. Blu line bounds the Subappennino Dauno area

the database was analysed in a GIS environment (Fig. 4).

The municipalities with the higher number of landslides recorded from 1928 to 2007 were Alberona (14 landslides), Rocchetta Sant'Antonio (13 landslides), Casalvecchio di Puglia (12 landslides), Biccari, San Marco la Catola (11 landslides), and Candela and Sant'Agata di Puglia (10 landslides). The other municipalities recorded values of less than ten landslides in the same period.

ANALISYS AND DISCUSSION

The mean monthly values of R, WD, I, and T (as mean values of gauges) and the monthly mean values of L (as total values) were used to achieve the regime diagram (Fig. 5). Considering the main hydrological year, rainfall increases from September until the maximum in November and then decreases; the minimum value is recorded in July. WD shows the same trend as R, with the maximum value in December; I shows a low variability and a fluctuating trend, with the maximum value in November. With regard to temperature, T presents a trend opposite that of R; in fact T decreases from September to January, when the minimum value is reached, and then increases to the maximum value, which is reached in August. The landslide regime has two peaks. The main peak is in January, two months after the peak rainfall, and the second one is in March, probably due to the effect of melting of snow, accumulated on ground surfaces in previous two months. Eighty-four per cent of the total number of landslides occurs from December to March (Fig. 5).

The correlation analysis was performed between annual indices. A positive and direct correlation existed between the landslides from a side and the rainfall, wet days, and temperature from the other side (the highest correlation coefficient was observed for temperature). The correlation between landslides and rainfall intensity is almost negligible. These results highlight that landslides are much more related to the whole rainfall amount and the duration of rainfall than rainfall intensity.

The trend analyses showed that the landslide occurrence was increased with the time, despite of the rainfall and temperature data are not prone to landsliding. As a matter of fact, the trend of both the monthly rainfall and the rainfall intensity decreases, and the temperature and the wet days show a positive trend during the period of reference. The trend of the short-duration rainfall results generally decreasing.

In order to better compare landslide occurrences and land use variations (especially urban areas and wooded areas), the landslide database was analysed by decades (starting from 1928) (Fig. 6).

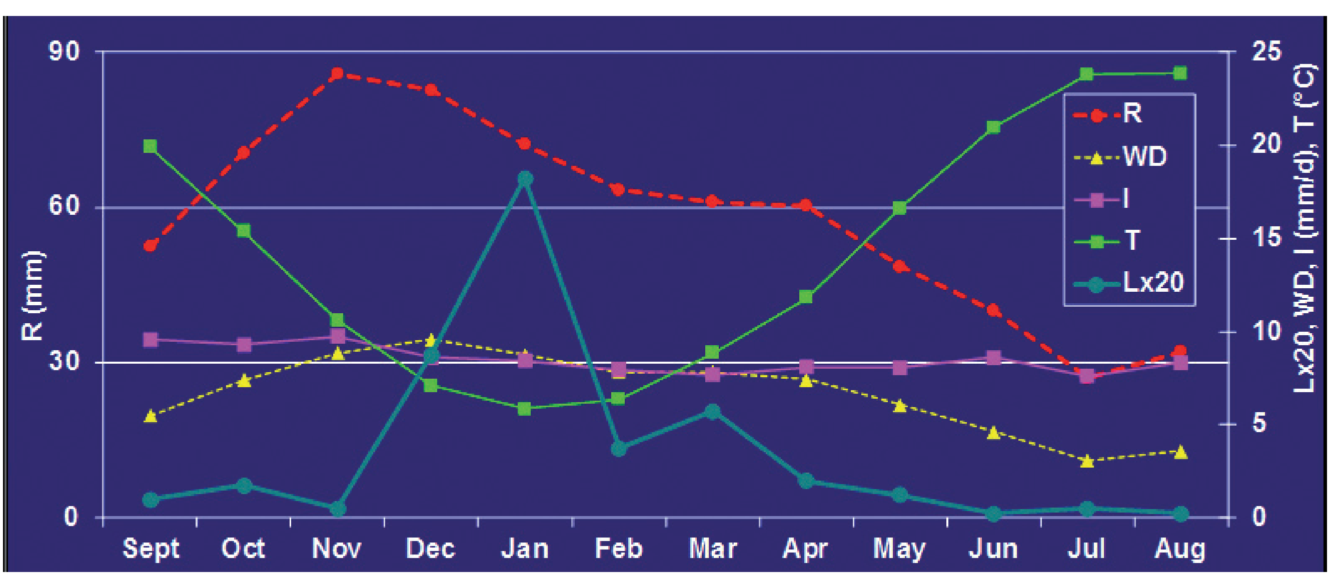

Fig. 5 - Subappennino Dauno regime (mean monthly values) of rainfall (R), wet days (WD), rainfall intensity (I), temperature (T), number of landslides (L)

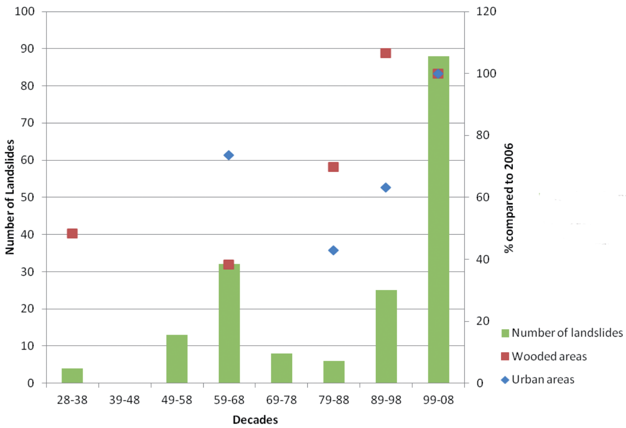

Fig. 6 - Relationship between number of landslides, wooded and urban areas

According with this distribution, the first decade (starting from 1928, the first year in which there was a recorded landslide event, to 1938) recorded only 4 events; in the second decade (1939-1948) no events were recorded, maybe because this decade represented the period of the II World War, in which recordings were often not carried out. Starting from the 1949 to 1968 there was an increase in the number of events; in the decade 1959-1968 there was a first peak (32 landslides) in the occurrence of landslide events. From 1969 to 1988 there was a decrease in the number of landslides. A second phase of increasing landsliding was recorded from 1989 to 2008; the decade 1999-2008 represented the highest value of landslide occurrences recorded (88 landslides).

With regard to the land use variations, a preliminary analysis of land use from 1959 to 2006 showed a significant increase of urban areas, and a decrease in the meadows and pastures. With regard to wooded areas, having the additional data coming from the map of thirties, it could be noticed a decrease in this kind of land use from 1930. From 1959 there was an increase of the wooded areas, till the maximum value of 1999. There was a slight reduction of wooded areas from 1999 to 2006.

To better compare the land use data with the landslide occurrence data, the following assumptions were done:

- data of Carta Forestale of thirties were associated to the decade 1928-1938;
- data of Land use map of 1959 were associated to the decade 1959-1968;
- data of the three temporal levels of Corine land cover project (1990, 1999, and 2006) were associated respectively to the decades 1979-1988, 1989-1998; 1999-2008 (Fig. 6).

The elaboration was possible considering the value of the extension (km^2) of wooded areas in 2006 equal to 100 and calculating the value of the extension of wooded areas of the previous years in relation to that of 2006, in order to emphasise some trends, that otherwise would not be appreciable.

The results of this kind of elaboration are the following:

- There is an increasing trend in the landslide events during the considered period (1928-2008);
- There is an increase in the wooded areas from 1959 to 1999 and a slight decrease from 1999 to 2006;
- There is a decreasing trend in the urban areas from 1959 to 1990; starting from 1990 there is an intense increase in the urban areas. The apparent inconsistency in the decreasing of urban areas from 1959 to 1990, could be related to the different source of land use data utilised for the analyses, each one with a different scale of detail.

The comparison between the abovementioned data showed a direct relationship between landslide occurrences and urbanisation. In fact with the increasing in the number of landslide events corresponded an increasing of urban areas (starting from the decade 1979-1988 to the decade 1999-2008) and vice versa (from the decade 1959-1968 to the decade 1979-1988).

Landslides are influenced by wooded areas too, although the relationship between them is less evident.

In fact it can be noted that an increase of the wooded areas, corresponded a decrease in the number of landslides (from 1959-1968 to 1989-1998) and vice versa (as for the decades 1939-1948 to 1959-1968).

With the decrease of wooded areas starting from the decade 1928-1938 to the decade 1959-1968, there was a simultaneous increase in the number of landslide occurrences in the study area.

The subsequent increase of wooded areas brought an improvement in the stability conditions of the study area and consequently there was a decrease in the number of landslide occurrences up to the decade 1979-1988.

When the maximum value of the areas occupied by woods was reached (in the 1999), there was a simultaneous further increase of landslides events.

During the decade 1989-1998 were recorded a high number of landslide events and a simultaneous decrease in wooded areas, associated with an increase of urban areas.

The highest number of landslides was recorded during the decade 1999-2008, when an increase in the urban areas and a decrease in the wooded areas were recorded.

CONCLUSIONS

The study shows that the increasing number of landslide events on the Subappennino Dauno does not seem due to climate variability; in fact the analyses conducted on the climate parameters show the decreasing trend of rainfall and rainfall intensity and the increasing trend of temperatures and wet days.

Better results come from the comparison between landslide events and land use variations, highlighting the negative effect of anthropogenic modifications and the mismanagement of landslide-prone areas.

REFERENCES

Almagià R. (1910) - *Studi geografici sulle frane in Italia.* Memorie della Società Geografica Italiana, **14** (2).

Catenacci V. (1992) - *Il dissesto geologico e geoambientale in Italia dal dopoguerra al 1990.* Memorie descrittive della Carta Geologica d'Italia, **47**: 301 pp.

CNR-GNDCI (1999) - *Database AVI degli eventi alluvionali occorsi su tutto il territorio nazionale dal 1930 al 1999.*

Cotecchia V. (1963) - *I dissesti franosi del Subappennino Dauno con riguardo alle strade provinciali*. La Capitanata, **1**: 5-6.

Cotecchia F., Santaloia F., Lollino P., Mitaritonna G. & Elia G. (2009) - *Meccanismi di frana in pendii in argille dell'Italia Meridionale ed effetti delle precipitazioni meteoriche*. Proc. 1st Italian Workshop on Landslides, Napoli, June 2009, **2**: 31-44.

Cotecchia F., Santaloia F. & Lollino P (2011) - *Slow landsliding as effect of hydro-mechanical coupled processes: examples of resulting damages and mitigation strategies.* Proc. 2nd Italian Workshop on Landslide, Napoli, 28-29 September 2011: 71-79.

Cruden D.M. & Varnes D.J. (1996) - *Landslide types and processes.* In: Turner A.K. & Schuster R.L. (eds) - *Landslides. Investigation and mitigation.* Transportation Research Board, Special Report 247, Washington D.C.: 36-75.

EEA (2008) - *Impacts of Europe's changing climate - An indicator-based assessment.* European Environment Agency Report 4. http://www.eea.europa.eu/publications/eea_report_2008_4/

Gisotti G. & Masciocco L. (2013) - *Il ruolo economico del riassetto idrogeologico in Italia*. Valutazione ambientale, **23**.

Guzzetti F. & Tonelli G. (2004) - *Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards.* Nat. Hazards Earth Syst. Sci., **4**: 213-232.

Iovine G., Parise M. & Crescenti E. (1996) - *Analisi della franosità nel settore centrale dell'Appennino Dauno.* Memorie Società Geologica Italiana, **51**: 633-641.

Melidoro G. (1971) - *Movimenti franosi e zonizzazione del bacino del Fiume Fortore*. Geologia Applicata e Idrogeologia, **6**: 17-39.

Petrucci O. & Polemio M. (2002) - *Hydrogeological multiple hazard: a characterisation based on the use of historical data.* In: Rybar J., Stemberk J. & Wagner P. (eds). *Landslides*. 269-274.

Petrucci O., Polemio M & Pasqua A.A. (2010) - *Flash floods risk variation of steep drainage basins in Calabria (Italy) and the role of rainfall and anthropogenic modifications since 1800.* In: Servat E., Demuth S., Dezetter A., Daniell T, Ferrari E., Ijjaali M., Jabrane R., van Lanen H. & Huang Y. (eds.). *Global change: facing risks and threats to water resources.* IAHS Publication N° 340: 103-110, IAHS Press, Wallingford.

Polemio M. & Lonigro T (2015) - *Trends in climate, short-duration rainfall, and damaging hydrogeological events (Apulia, Southern Italy).* Nat. Hazards, **75** (1): 515-540.

Polemio M. & Petrucci O. (2010) - *Occurrence of landslide events and the role of climate in the twentieth century in Calabria, southern Italy.* Q.J. Eng. Geol.Hydrogeol., **43**: 1-14.

Santaloia F., Cotecchia F. & Polemio M. (2001) - *Mechanics of a tectonized soil slope: influence of boundary conditions and rainfall.* Q.J. Eng. Geol. Hydrogeol., **34**: 165-185.

Santaloia F., Cotecchia F. & Vitone C. (2012) - *Applicazione dei metodi avanzati al fronte appenninico apulo-lucano: analisi di I livello.* In: Cascini L. (ed). *Criteri di zonazione della suscettibilità e della pericolosità da frane innescate da eventi estremi (piogge e sisma).* 130-140. Composervice s.r.l., Padova.

SIMN (1919-1996) - *Annali Idrologici - Parte I. Sezione di Bari.* Ministero dei Lavori Pubblici, Roma.

Wasovski J., Lamanna C. & Casarano D. (2010) - I*nfluence of land-use change and precipitation patterns on landslide activity in the Daunia Appennines, Italy.* Quarterly Journal of Engeneering Geology and Hydrogeology, **43**: 387-401.

Wasovski J., Lamanna C., Gigante G. & Casarano D. (2012) - *High resolution satellite imagery analysis for interferring surface-subsurface water relationships in unstable slopes.* Remote Sensing of Environment, **124**: 135-148.

Zezza F., Merenda L., Bruno G., Crescenti E. & Iovine G. (1994) - *Condizioni di instabilità e rischio da frana nei comuni dell'Appennino Dauno Pugliese.* Geologia Applicata e Idrogeologia, **29**: 77-141.

Received February 2016 - Accepted May 2016