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The influence of slope instability processes in demographic dynamics of landslide-prone rural areas

L. Pisano
CNR-IRPI, Bari, Italy
Department of Biosciences and Territory, University of Molise, Pesche, Italy

V. Dragone
CNR-IRPI, Bari, Italy

C. Vennari
CNR-IRPI, Bari, Italy
Department of Earth, Environmental and Resources Science, University of Naples Federico II, Napoli, Italy

G. Vessia
CNR-IRPI, Bari, Italy
Department of Engineering and Geology, University of Chieti-Pescara, Chieti Scalo, Italy

M. Parise
CNR-IRPI, Bari, Italy

ABSTRACT: To assess the relationships existing between landslide evolution and economical development of a rural, highly prone to landslides, area in southern Italy, a demographic analysis covering the time span from 1861 to 2011 has been performed on about 30 municipalities. The work consisted in a detailed description of the demographic features of the studied area, aimed at analysing the growing/decreasing trend in the local populations, as a function of the main historical and hydrological events. The combined analysis of the above elements with data about landslide distribution and their temporal occurrence allowed to evaluate the influence played by slope instability processes in this sector of Apulia region.

1 INTRODUCTION

Landslide is one of the most significant natural hazards affecting society and its activities (Crozier, 1986; Guzzetti, 2000). In many countries worldwide, slope movements are the main causes of economic losses and casualties (Schuster & Fleming, 1986).

Landslides are caused by numerous and complex natural processes (e.g. heavy rainfall, earthquake, snow melting), to which others have to be added due to human activities, such as slope excavation, infrastructures construction, changes in land use, deforestation, etc. Their occurrence and frequency in a specific area depend on the interaction of the above processes (Malamud et al., 2004; Guzzetti et al., 2012; Peruccacci et al., 2012).

With respect to the Italian territory, landslides caused at least 1297 deaths, 15 people dispersed and 1731 injured from 1964 to 2013 (Salvati et al., 2010). In addition, in 2014 other 13 people died, 25 were injured and 3368 lost their houses (web source: http://polaris.irpi.cnr.it/). The casualties are distributed throughout the Italian territory, especially along the mountainous and hilly sectors, where a large variety of landslides is triggered, causing landscape change and rising issues of social concern. In fact, many rural communities located in geological and geomorphological complex areas, strongly affected by landslide occurrence, appear to be severely hit by development of slope movements, which results in significant parts of the population moving away, with particular regard to young people.

This is the case of the Daunia Apennines, located in the north-western sector of Apulia Region (southern Italy), where several small rural villages are located in highly landslide-prone areas. They are continuously hit by reactivations of slope movements during seasonal rainfalls, with earthquakes as a further possible trigger. Changes in land use have also to be invoked as a further cause of landslide onset (Parise & Wasowski, 2000; Lamanna et al., 2009).

In this study some considerations on the link between slope movements occurrence and demographic problems deriving from de-population are illustrated. They focus in particular on the relationship between the decreasing in population size and the occurrence of landslides caused by rainfall.

2 THE STUDY AREA

The Daunia Apennines include the 29 municipalities shown in Figure 1. This area is bordered by the Fortore River to the north and the Calaggio stream to the south, ranging in altitudes between 50 and 1,152 m a.s.l.

The geological system of Daunia is characterized by the Daunia and Fortore units (Dazzaro & Rapisardi, 1996; Patacca & Scandone, 2007), both consisting of flyschioid formations with different degree of tectonization and lithological composition, showing in general a high content in clay. These geological units have been affected by an intense and prolonged compressional activity with Adriatic vergence, chronologically occurred during the Tortonian, and continued until the lower Pleistocene (Doglioni et al., 1994; Menardi Noguera & Rea, 2000).

As a consequence of the tectonic stresses experienced by the rock masses, the Daunia Apennines, being characterized mainly by hilly and mountain areas, with predominantly clay deposits, are intensely affected by land instability. The main slope movements are complex (*sensu* Cruden & Varnes, 1996), starting typically as planar or rotational landslides, and often evolving as earthflows or debris flows (Parise, 2000, 2003; Cotecchia et al., 2006; Pellicani et al., 2014). Soil slips, typically involving the first 1–2 m of terrain, are extremely common, especially after heavy rainstorms (Figure 2).

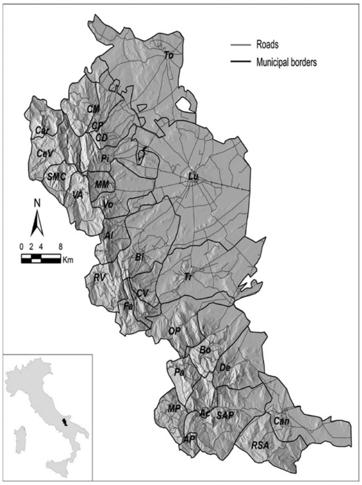

Figure 1. Location map, with indication of the Daunia municipalities: Accadia (Ac), Alberona (Al), Anzano di Puglia (AP), Biccari (Bi), Bovino (Bo), Candela (Can), Carlantino (Car), Casalnuovo Monterotaro (CM), Casalvecchio di Puglia (CP), Castelluccio Valmaggiore (CV), Castelnuovo della Daunia (CND), Celenza Valfortore (CeV), Celle di San Vito (CSV), Deliceto (De), Faeto (Fa), Lucera (Lu), Monteleone di Puglia (MP), Motta Montecorvino (MM), Orsara di Puglia (OP), Panni (Pa), Pietramontecorvino (Pi), Rocchetta Sant'Antonio (RSA), Roseto Valfortore (RV), San Marco la Catola (SMC), Sant'Agata di Puglia (SAP), Torremaggiore (To), Troia (Tr), Volturara Appula (VA), Volturino (Vo).

Figure 2. A typical example of slope movement (shallow soil slip) in the Daunia slopes.

In many cases the slope movements affect directly the built-up areas (typically located at the top of the hills, and bounded by landslides on many sides), or the main communication routes (generally developing along the watersheds, or at middle-slopes) (Zezza et al., 1994; Chiocchio et al., 1997; Parise et al., 2012). This latter situation is at the origin of frequent problems for movement of people and freights, with high rehabilitation costs for maintaining the road network in function (Vennari et al., 2013).

For the above reasons, namely the difficulties in living and working in an area severely hit by landslides, the Daunia sector shows a high rate of population decrease along the last 60 years (Dragone and Parise, 2014). This has also to be related to medium and long term socio-economical changes, but is likely fostered by the damages to roads and train by slope movements characterized by seasonal reactivations.

3 PRESENTATION AND DISCUSSION

3.1 *Environmental data*

The importance of historical research in the correct assessment of geological hazards is nowadays recognized as one of the first actions to be performed (Soeters & van Westen, 1996; Calcaterra & Parise, 2001; Glade, 2001; Glade et al., 2001), aimed at reaching the highest possible level of knowledge on the specific processes dealt with, in this case landslides.

The datasets used hereafter are mainly drawn from the archives of the AVI project (Vulnerable

Areas in Italy by landslides and floods; Guzzetti et al., 1994) and the inventory of landslide events collected by CNR-IRPI group with the purpose of reconstructing sub-regional empirical rainfall thresholds in the Daunia Apennines (Vennari et al., 2013; Brunetti et al., 2015; Pisano et al., 2015).

The information collected and used in this work cover a time span from 1950 to 2010. Two-hundred-eighty-three landslides and floods events mainly triggered by exceptional meteorological events were documented in Daunia.

In order to establish a connection between the rainfall and the landslide events, the cumulative rainfalls in the last decades have been calculated, using the data coming from the rain gauges indicated in figure 3. These rain gauges were selected on the basis of their locations and of the completeness of the rainfall series as well. The data are extracted from the hydrological records published annually by the Regional Center of the Apulia Civil Protection: http://www.protezionecivile.puglia.it/.

The landslide and flood frequency is in good agreement with the rainfall amount (Fig. 3): it increases and decreases as the rainfall regime, except than during the 1990–2000 decade. In this period, a reduction in rainfall corresponds to the highest landslide frequency. This apparent incongruence could be interpreted, in addition to changes in the main character of rainfall events, as a possible clue of human responsibility in landslide onset. In this same period, the population reduction (black bars in Figure 3) does not follow the peak observed in landslide and flood events. This result can be due to the time-shift of landslide effects on population reduction: if damages and road disruptions are not recovered in due time, they can generate indirect socio-economical effects in the long run, forcing people to move away in order to look for sites where to live and work, less exposed to hazard.

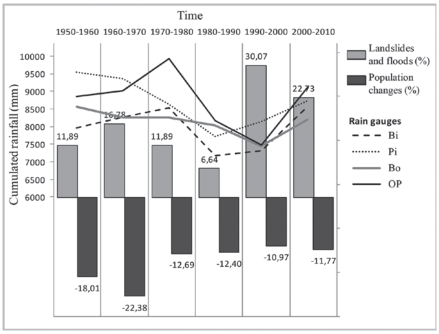

Figure 3. Graph relating the number of landslides and floods with the population changes per decade in the time span 1950-2010. The lines indicate the cumulate rainfall of the main rain gauges in the study area (labels as in Fig. 1).

Moreover, it can be noted that a lower general rainfall height in a decade could derive from a lower number of rainfall events, that, at the same time, may show extreme values of rainfall, being associated to intense rainstorms, thus possibly causing larger damages and higher economical losses.

Aimed at analyzing at a greater detail the population structure in Daunia, and its relationship with hydro-geological instability phenomena, we applied to this area the demographic malaise indicator (see section 3.2). This indicator enables to shed light on the structure of the population and its temporal dynamics. This latter, in turn, affects the variations in the social-economic conditions throughout the considered urban centers.

3.2 *Demographic malaise state (SMD indicator)*

In order to adequately represent the dynamics of the population, the Demographic Malaise State indicator (SMD) proposed by Bottazzi et al. (2006, 2012) is herein considered. It is defined by the following equation:

$$SMD = svnp_1 + ism \tag{1}$$

The indicator is the sum of two parameters: $svnp_1$ represents the weighted episodes of depopulation whilst *ism* is the amount (in terms of severity) of inhabitant loss. These episodes have been estimated for 6 censorial intervals considered within the two reference periods of 60 years that are compared in this study: from 1901 to 1961, and from 1951 to 2011. Each episode contributes to the final value of $svnp_1$ by an increasing weight (p_i): from 1 to 6. The highest (6) is given to the most recent episode (the nearest to 1961 and 2011) and the lowest (1) to the most ancient one. In addition, for each censual episode the value 1 is assigned if a population decrease has occurred; otherwise 0 is multiplied by the weight of the considered episode.

The first term of Eq. (1) is:

$$svnp_1 = \sum_{i=1}^{6} I \cdot p_i + (cg_{1,i} + cg_{2,i}) \tag{2}$$

where p_i are the weights of the 6 censorial intervals I, and cg_1 and cg_2 are coefficients that attribute the relevance index to the depopulation occurrence within each censorial interval. The magnitudes of these coefficients are reported in Tables 1 and 2.

The second term in Eq. (1) is calculated as the arithmetic mean of six parameters used to estimate the growth or the reduction of population in the first term of the same Eq. (1). These six indexes are listed in Table 3 and they refer to the period span 2001–2011.

These six parameters depict the population structure and its sustainable development. As a matter of fact, although if related to demographic aspects they can also be considered as the bases of the social-economic health of the investigated community. A thorough description of how to calculate the intermediate parameters that contribute to SMD indicator can be found in Bottazzi et al. (2006, 2012).

As for the Daunia case study, the calculated SMD values are reported in figure 4 divided into five ranges of population health: highly serious, serious, uncertain, moderate and good.

3.3 *Demographic data*

To highlight the socio-economical evolution of the Daunia territory along the past 50 years, the resident population index was used. The values were extracted from the national census of the population made by the National Institute of Statistics (ISTAT) starting from 1861 up to 2011 (ISTAT, 1963, 1965, 2012).

The demographic variation was firstly analyzed by means of a simple indicator of the percentage in population change: it consists in the percentage ratio between the net variation (increasing or decreasing) of the resident population in a fixed time interval and the number of the resident population at the beginning of this period. This index suggests that the population in the Daunia Apennine reduced 51% in the second half of the last century, at a rate higher than 1% per year. In 1951 the population in Daunia exceeded 41% of that located in Foggia (the main town in the area, counting at that time 97.386 inhabitants), but in 1981 it was only half than that in Foggia (Dragone & Parise, 2014).

Table 1. Values of cg_1 coefficients weighting depopulation episodes.

Depopulation amount D	cg1
D > 60%	5
45% < D < 60%	4
30% < D < 45%	3
15% < D < 30%	2
D < 5%	1
Population increase	0

Table 2. Values of cg_2 coefficients weighting depopulation episodes.

Depopulation amount D	cg_2
D > 20%	5
15% < D < 20%	4
10% < D < 15%	3
5% < D < 10%	2
D < 5%	1
Population increase	0

Table 3. Six indexes of depopulation used to calculate the SMD (after Bottazzi et al. 2006).

Variation of population between 2001 and 2011 (%)	$VP = \frac{P_{2011} - P_{2001}}{P_{2001}} \cdot 100$
Birth (N) over deaths (M) exceedance index referred to the period 2001–2011 (%)	$ESN = \frac{N - M}{N + M} \cdot 100$
Aging index: ratio between number of people older than 65 years and 100 inhabitants ranging between 0–14 years recorded up to 2001.	$IV = \frac{P_{65} - \Omega}{P_0 - 14} \cdot 100$
Elderly over children index: ratio between the number of people older than 65 years and children younger than 5 years, recorded up to 2001.	$AB = \frac{P_{65} - \Omega}{P_0 - 4}$
Dependency index: ratio between the sum of people younger than 15 years and older than 65, and people in the range 15–65 years.	$ID = \frac{P_{0-14} + P_{65} - \Omega}{P_{15-64}} \cdot 100$
Depopulation episodes in intercensorial times (2001–2011)	SSI

Figure 4 shows the spatial distribution of the SMD indicator in Daunia, calculated in two time intervals: 1901–1961 and 1951–2011. It is clear that after 1962 in the study area the population depletion ranges from serious to very serious. To provide with some examples, Table 4 reports examples of the values of the SMD indicator, calculated for the two considered time spans for 9 out of the 29 municipalities under study.

For a certain extent such a process can be related to a possible increase in landslides, although further indicators should be considered to definitely state a cause-effect relationship.

Finally, a recent study performed by Ferrara et al. (2015) suggests a novel perspective in the cause-effect chain established between depopulation and hydrogeological instability: causes and effects play in a circular way with social-environmental factors generating a spiral. Thus, although the rural society economical depletion can be induced by frequent soil failure causing temporal isolation of the community, it is also true that the abandonment of these territories might contribute to worsen their stability and drastically reducing their economical values.

In fact, the progressive depopulation in Daunia heavily affects the social-economic development of the territory. Since 1961 depopulation is highlighted in two main features of the population

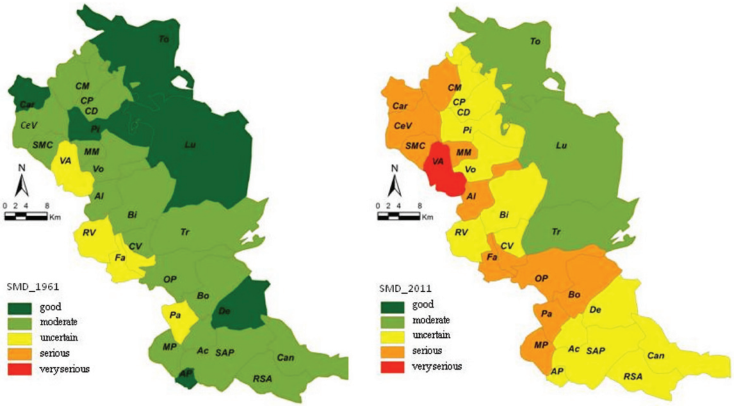

Figure 4. SMD changes in the Daunia municipalities occurred between 1961 and 2011.

Table 4. Values of the SMD indicator calculated at 9 municipalities for two time periods: before 1961 and up to 2011. The colors are as in Figure 4.

MUNICIPALITIES	SMD 1961	Range	SMD 2011	Range
ACCADIA	43,9	moderate	115,6	uncertain
ALBERONA	75,9	moderate	127,0	serious
ANZANO DI PUGLIA	38,6	good	120,9	uncertain
BICCARI	69,0	moderate	99,0	uncertain
BOVINO	64,1	moderate	124,8	serious
CANDELA	65,0	moderate	97,4	uncertain
CARLANTINO	23,7	good	125,3	serious
CASALNUOVO MONTEROTARO	56,8	moderate	127,1	serious
CASALVECCHIO DI PUGLIA	49,8	moderate	107,5	uncertain

structure: the prevalence of elderly people, and the decrease in population of the smaller centers.

These characters are related to the emigration of the active portion of people towards larger urban centers, with greater possibilities to find a job. This trend could be considered similar to other depopulation phenomena, if we ignore the "rural" nature of this community. Further analyses of economic indexes must be performed to point out the role of the hydrogeological instability in the depopulation trend associated to a general impoverishment of the community. Frequent interruption of lines service cannot be attractive for new investment in economic activities as tourism, farming, transformation industries etc. Thus, new demographic policies should be associated with an improved capacity of maintenance of these territories in order to start a new social-economic trend: the repopulation of this territory should contribute at establishing a rural economy that should be integrated with the safeguard of the cultivated land, aimed at producing a better quality of life.

4 CONCLUSIONS

This study is a contribution to improve the knowledge of the demographic effects of landslide occurrence in rural territories as the Daunia Apennines, in southern Italy. In this area the demographic structure is strictly related to the economic health and well-being, which are in turn affected by hydrogeological instability. The preliminary results drawn from the calculation of the SMD indicator enable to relate the progressive reduction of population to the increase of landslide events, as recorded in the decade 1990–2000. These events cannot be fully explained by the rainfall regime, due to the reduction in cumulated rainfall of this period. Further investigations are needed to understand whether the observed peak in landslides might be related, on the other hand, to the increase in number of extreme pluviometric events, with the rainfall concentrated in less, but intense, rainstorms.

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