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Brief communication
"The assessment of damage caused by historical landslide events"

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Abstract. The paper presents a methodology for relative damage assessment for historical landslide events, i.e. periods during which damage caused by rainfall-triggered landslides affected wide areas. The approach requires a minimum amount of data, and it is based on the assessment of direct, indirect and intangible damage indices at municipal and regional scale. An application to major events which occurred in Calabria (Italy) highlighted roads as the most vulnerable element, even representing the source of intangible damage for people forced to use alternative roads for their daily activities. Indirect costs seem mainly tied to displacement of people even for short periods.

1 Introduction

The assessment of the overall damage caused by a natural disaster supplies crucial information that can be useful in the implementation of both prevention and response measures, and can help in decision support (UNEP-ECLAC, 2000). However, this assessment is difficult to obtain: a univocal evaluation procedure is far to be established because of the multifaceted nature of the induced damage (Petrucci and Llasat, 2013). The problem is still more complicated when the focus is on old events: while for current cases data availability is problematic, for older events it can represent an insurmountable obstacle. This may be particularly true for the *economic* damage assessment. Documentary data describing damage are widely available, while, on the contrary, exact figures of the economic costs are rare, often unreliable and made of a multitude of estimates, which can be different according to the scale upon which data were collected (Hallegatte and Przyluski, 2010). The costs of a disaster can only be assessed "a posteriori"; nevertheless, there is no certainty that all the costs – spanning from disaster occurrence and the time of damage assessment – have been taken into account. A suitable example in this sense can be represented by expert advice that I gave in December 2012 for Calabria Regional authority of public works (Regione Calabria, Dipartimento No. 9, Prot. No. 409094, 10 December 2012) in order to assess the exceptionality of a flood event that occurred in Reggio Calabria town (southern Italy) on 16 November 1987: the owners of a damaged apartment block are still waiting for damage reimbursement. Thus, 25 yr later, the assessed cost of that event, even if available, is still not complete and then underestimated.

Therefore, in the case of past events, it is necessary to individuate a semi-quantitative damage assessment approach, taking into account both the quality and the quantity of data available for past events. Methodological approaches to assess damage caused either by single landslides (Petrucci and Gullà, 2009, 2010) or by complex damaging hydrogeological events, during which damage is caused by both landslides and floods (Petrucci and Polemio, 2003; Petrucci and Pasqua, 2008, 2009; Petrucci et al., 2009a), have already been published.

In this paper, a customised version of this approach has been outlined to assess damage caused by the historical series of severe landslide events (defined in the following) which occurred in a region of southern Italy between 1960 and 1999.

2 The methodological approach

A landslide event (LE) is defined as the *occurrence of numerous rainfall-triggered landslides which damage wide areas*

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throughout an almost continuous sequence of days. Every year, both single landslides and landslide events cause huge losses in terms of both economic damage and casualties, and, due to the anthropogenic expansion towards unstable hilly areas, these losses are expected to increase. Then, assessing the damage of historical events can be useful in the reconstruction of damage trend and to improve urban planning. Moreover, it can be a track in the reimbursement procedures for future events, because the typical damage scenario of an area supplies an overview of the most vulnerable elements, even helping in emergency management planning.

To individuate a consistent series of LEs which affected a study region, it is necessary to realise specific historical research or to get damage data from historical databases that, where available, are generally compiled using different types of data sources and especially newspapers. Limitations of historical data regarding the uncertainty affecting the localisation in both time and space of damage, the number of people involved, and reliability of sources have been widely described in literature and critically reviewed in recent papers (Petrucci, 2012). To select LEs which caused severe damage, the database must be filtered in order to extract landslide damage that occurred almost continuously (or separated by a few days), and affected an area that must have a conventionally defined minimum size. Then, assuming that the extent of the involved area can be considered such as an indicator of the magnitude of LEs, the *index of damaged area* (IDA) is introduced. IDA (1) roughly represents the size of the area damaged: for an administrative region, it is the sum of the areas of damaged municipalities (S) divided by the area of the administrative region (R), and multiplied by 100:

$$\mathrm{IDA} = \frac{S}{R} \times 100. \tag{1}$$

S is greater than the area truly affected, but this simplification allows by-passing the unavailability of detailed maps of damaged areas, generally not included in historical data sources. For each LE, IDA thus represents the percentage of regional area affected.

Besides this simple geometrical index, based on the textual descriptions of what occurred, the procedure supplies an assessment of three entities (Swiss Re, 1998):

– *direct damage,* including the whole of physical effects such as destruction and reduced functionality of structures and buildings, damages to people, and clean-up costs;

– *indirect damage,* affecting an area that can be larger than the landslide zone itself, and encompassing the actions aiming to restore pre-landslide situation; and

– *intangible damage,* defined as the psychological effects and emotional consequences of either temporary evacuation or permanent house loss.

In the following, the assessment of the abovementioned entities is described.

2.1 Direct damage assessment

Direct damage is expressed referring to administrative boundaries (regional and municipal) as described in the following.

$\mathrm{DIR_{Di}}$ is an appraisal of direct damage caused by each of the n landslides which occurred in a municipality (Eq. 2). Assuming damage as the product of the value of an element and the level of loss that it suffered (Varnes and IAEG, 1984), $\mathrm{DIR_{Di}}$ is assessed by multiplying the relative value V of each damaged element (Table 1) for the suffered level of loss L (*low:* $L = 0.25$, *medium:* $L = 0.5$, *high:* $L = 0.75$, and *very high:* $L = 1$).

$$\mathrm{DIR_{Di}} = V_i \times L_i \tag{2}$$

$\mathrm{DIR_{DMun}}$, the *municipal damage index* (Eq. 3), is the sum of all direct damages caused in a municipality by the n landslides that occurred there:

$$\mathrm{DIR_{DMun}} = \sum\nolimits_{i=1}^{i=n} \mathrm{DIR_{DMun}}. \tag{3}$$

$\mathrm{DIR_{DReg}}$, the *regional damage index* (Eq. 4), is obtained by adding the $\mathrm{DIR_{DMun}}$ values obtained for all the damaged municipalities.

$$\mathrm{DIR_{DReg}} = \sum \mathrm{DIR_{DMun}} \tag{4}$$

2.2 Indirect damage assessment

For old events, data allowing the assessment of indirect damage are not so frequent. Here, based on the actual data availability, two groups of actions have been individuated to represent indirect damage, and the damage related to each action can assume one of four increasing values: 0.25, 0.50, 0.75, or 1.

For the first group of actions (Table 2), dealing with *people accommodation*, the relative damage increases according to the number of people for which the action was undertaken.

Even the actions of the second block, dealing with *restoring pre-landslide conditions*, can assume four values, according to their supposed economic burden.

For each municipality affected, a form such as Table 2 (section INDIRECT DAMAGE ASSESSMENT) has to be filled out to obtain an *indirect damage index* at municipal scale ($\mathrm{IND_{DMun}}$); the sum of all the damage indices at municipal scale supplies the *indirect damage index at regional scale* ($\mathrm{IND_{DReg}}$).

2.3 Intangible damage assessment

Data availability allowed us to individuate the following circumstances, which indicate the occurrence of intangible damage: loss of a family member; injury of a family member;

Table 1. Form to fill out to assess direct damage at municipal scale. The D_{Mun} index is the sum of all the products *Levels of loss* × *element value*. In other words, if the damage indicated by bold text occurred, then $D_{\mathrm{Mun}} = 2.58$.

DIRECT DAMAGE ASSESSMENT						
Level of loss				Elements Value		
	Public buildings	*City Hall* *1*	*Barrack* *1*	*Hospital* *1*	*School* *0.75*	*Church* *0.75*
1	Collapsed	1	1	1	0.75	0.75
0.75	Unusable: structural damage	0.75	0.75	0.75	0.56	0.56
0.50	Unusable: loss of functionality	0.50	0.50	0.50	**0.38**	0.38
0.25	Habitable	0.25	0.25	0.25	0.19	0.19
	Private houses			*>10 houses* *1*	*2–10 houses* *0.75*	*1 house* *0.50*
1	Collapsed			1	0.75	0.50
0.75	Unusable: structural damage			**0.75**	0.56	0.38
0.50	Unusable: loss of functionality			0.50	0.38	0.25
0.25	Habitable			0.25	0.19	0.13
	Roads	*Railway* *1*	*Highway* *1*	*State road* *0.75*	*County road* *0.75*	*Municipal road* *0.50*
1	Break (months)	1	1	0.75	0.75	0.50
0.75	Break (days)	0.75	0.75	0.56	0.56	0.38
0.50	Break (hours)	**0.50**	0.50	0.38	0.38	0.25
0.25	No break	0.25	0.25	0.19	0.19	0.13
	Services	*Gas pipeline* *1*	*Electric line* *1*	*Aqueduct* *0.75*	*Telephone line* *0.50*	*Drainage* *0.50*
1	Break (months)	1	1	0.75	0.50	0.50
0.75	Break (days)	0.75	0.75	0.56	0.38	0.38
0.50	Break (hours)	0.50	0.50	0.38	0.25	0.25
0.25	No break	0.25	0.25	**0.19**	0.13	0.13
	Productive activities	*Industry* *1*	*Commerce* *0.75*	*Handicraft* *0.50*	*Tourism* *0.50*	*Farming* *0.25*
1	Interruption of production and loss of productive system	1	0.75	0.50	0.50	0.25
0.75	Interruption of production and loss of products	0.75	0.56	0.38	0.38	0.19
0.50	Loss of products	0.50	**0.38**	0.25	0.25	0.13
0.25	Light damage without loss of products	0.25	0.19	0.13	0.13	0.06
	People		*>50 people* *1*	*30–50 people* *0.75*	*10–30 people* *0.50*	*<10 people* *0.25*
1	Victims		1	0.75	0.50	0.25
0.75	Severe injuries		0.75	0.56	0.38	0.19
0.50	Minor injuries		0.50	**0.38**	0.25	0.13
0.25	Shock		0.25	0.19	0.13	0.06

prolonged condition of displaced people; temporary condition of displaced people; loss of personal belongings; use of alternative roads; public service inefficiency; and temporary traffic delay (Table 3).

Even in this case the value of damage is assessed according to the number of involved people (less than 10 people: 0.25; 10–30 people: 0.50; 30–50 people 0.75; and more than 50 people: 1). Information on intangible damage can be gathered almost exclusively by newspapers; nevertheless in some cases the number of people involved is a definite value, but often it is supplied in terms of either "*tens of people*" or "*families evacuated*".

For each municipality affected, a form such as in Table 2 (section INTANGIBLE DAMAGE ASSESSMENT) has to

Table 2. Forms to fill out to assess indirect and intangible damage.

INDIRECT DAMAGE ASSESSMENT					
Level of loss		*People involved*			
	People accommodation	*>50 people*	*30–50 people*	*10–30 people*	*<10 people*
		1	*0.75*	*0.50*	*0.25*
1	Lodging for prolonged periods (>10 days)	1	0.75	0.50	0.25
0.75	Lodging for short periods (<10 days)	0.75	0.56	0.38	0.19
		Relative economic burden			
	Restoring pre-landslide conditions	*Very high*	*High*	*Medium*	*Low*
		1	*0.75*	*0.50*	*0.25*
1	Construction of new houses	1	0.75	0.50	0.25
1	Building renovations	1	0.75	0.50	0.25
0.75	Retaining walls building	0.75	0.56	0.38	0.19
0.75	Opening of by-pass roads	0.75	0.56	0.38	0.19
0.50	Economic loss due to the decrease of traffic	0.50	0.38	0.25	0.13
0.25	Cleaning of roads	0.25	0.19	0.13	0.06

INTANGIBLE DAMAGE ASSESSMENT					
Level of loss		People involved			
	Psychological effects due to:	*>50 people*	*30–50 people*	*10–30 people*	*<10 people*
		1	*0.75*	*0.50*	*0.25*
1	Loss of a family member	1	0.75	0.50	0.25
1	Injury of a family member	1	0.75	0.50	0.25
1	Prolonged condition of displaced people	1	0.75	0.50	0.25
0.50	Temporary condition of displaced people	0.50	0.38	0.25	0.13
0.50	Loss of personal belongings	0.50	0.38	0.25	0.13
0.50	Use of alternative roads	0.50	0.38	0.25	0.13
0.50	Public services inefficiency	0.50	0.38	0.25	0.13
0.25	Temporary traffic delay	0.25	0.19	0.13	0.06

be filled out to obtain an *intangible damage index at municipal scale* (INT_{DMun}), and finally the sum of all INT_{DMun} represents the *intangible damage index at regional scale* (INT_{DReg}).

3 The case study

The study region is Calabria, the southernmost Italian peninsular region (15 230 km^2), having a mean altitude of 418 m, and a maximum one of 2266 m. Crystalline rocks (Palaeozoic–Jurassic), piled during the middle Miocene over carbonate massifs, form the geological structure of the region, with Neogene flysch filling tectonic depressions. The region has been subjected to still-active uplift since the beginning of Quaternary. Its morphology is hilly or mountainous, with only 10 % of territory made of coastal and fluvial plains. The climate is Mediterranean, with dry summers and wet winters and a mean regional annual rainfall (1151 mm) that is higher than the national value (970 mm). Because of the predominant west-to-east movement of perturbations, the west side is the rainiest area, even if the eastern sector is frequently hit by intense storms (Petrucci and Polemio, 2009). Climate and tectonic stresses weaken rocks and predispose slopes to landslides and erosion. Administratively, the region is made of five provinces, further divided into 409 municipalities.

Starting from a database on historical landslides and floods which occurred in Calabria during the past centuries and containing more than 11 000 records (Petrucci et al., 1996; Petrucci and Versace, 2005, 2007; Petrucci et al., 2009b; Palmieri et al., 2011), we selected a 40-yr study period for which data entry can be considered homogenous even if not finished, as it could happen that further data contained in currently inaccessible archives may be available in the future. For the study period, spanning between 1960 and 1999, our historical database contains 4786 records of rainfall-triggered landslides: in order to select severe events, we

A

N.	YY	MM	DD	D	IDA	DIR_{DReg}	IND_{DReg}	INT_{DReg}
1	1960	Jan	8	19	4.38	11.125	2.375	4.500
2	1960	Oct	12	11	6.12	11.188	1.250	3.250
3	1971	Oct	1	4	7.43	16.313	0.750	9.875
4	1972	Dec	15	29	36.33	141.375	24.625	47.938
5	1973	Jan	23	12	9.41	20.438	0.875	10.500
6	1973	Mar	26	11	18.27	29.938	4.500	11.875
7	1976	Nov	17	8	13.76	30.625	1.813	14.750
8	1985	Jan	9	15	10.85	26.250	2.375	9.375
9	1988	Mar	4	8	17.24	34.188	3.250	14.625
10	1990	Dec	12	17	8.74	12.625	2.063	4.750
11	1996	Jan	12	17	12.93	19.375	1.438	4.625
12	1996	Oct	3	6	21.62	50.813	3.438	9.000

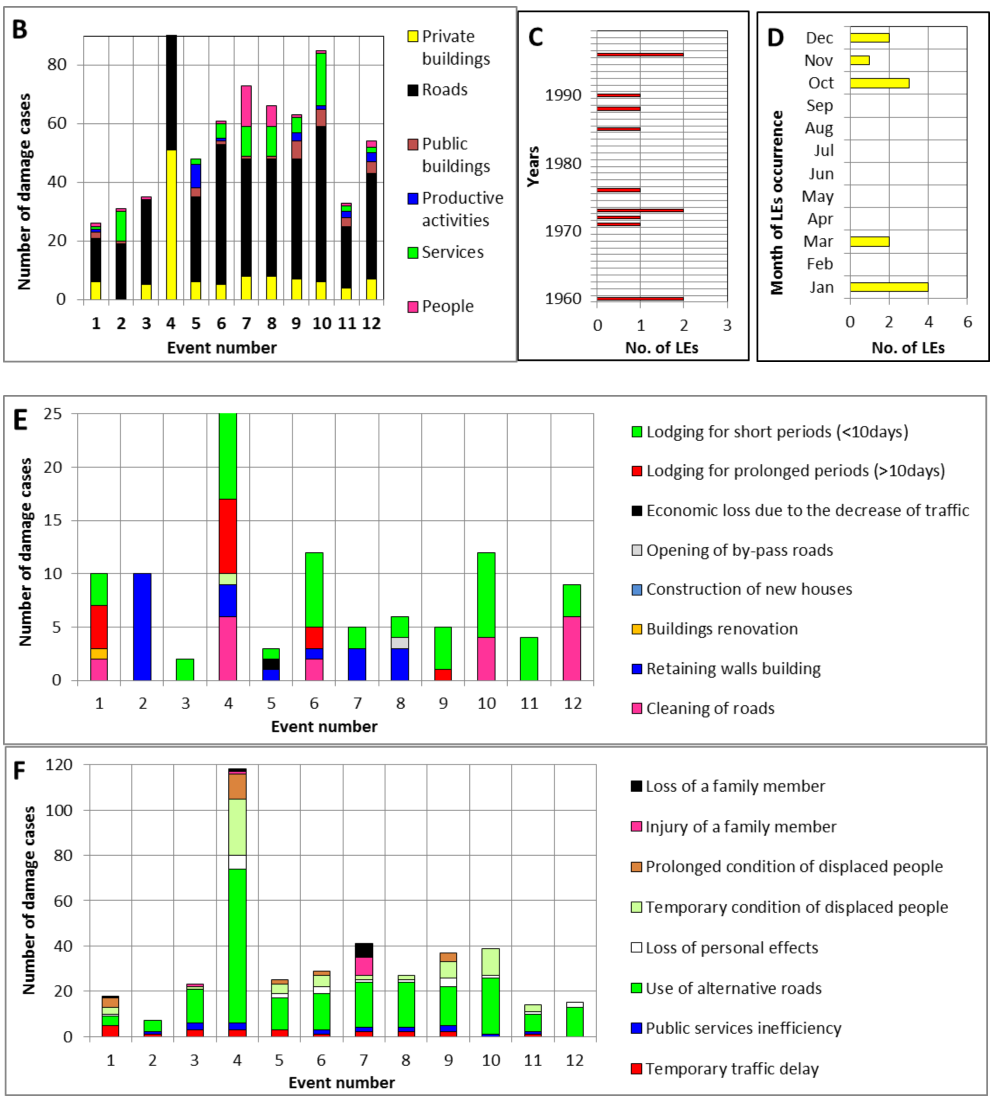

Fig. 1. (A): The analysed LEs. For each event, the beginning of damage occurrence (year: YY; month: MM; and day: DD), the index of damaged area (IDA) and direct (DIR_{DReg}), indirect (IND_{DReg}) and intangible damage (INT_{DReg}) assessment at regional scale are reported. In **(C)** and **(D)**: annual and monthly frequency of LEs. **(B)**, **(E)** and **(F)** present the number of data concurring to the determination of direct, indirect and intangible damage, respectively.

chose the LEs for which IDA is greater than 4. This means that affected area is almost 600 km^2, or 4 % of regional area. Using this criterion a series of 12 LEs has been extracted.

For each LE, the available historical records were analysed in order to individuate the damaged elements and damage indices at both municipal and regional scales, as described in Sect. 2. The results are summarised in Fig. 1a, where each LE is represented by a line containing the following: the beginning of damage occurrence (year: YY; month: MM; and day: DD), the index of damaged area (IDA) and direct (DIR_{DReg}), indirect (IND_{DReg}) and intangible damage (INT_{DReg}) assessed at regional scale.

The yearly and monthly frequencies of LEs (Fig. 1c and d) show a concentration of LEs in the 1970s and, according to the climate of the region, during winter months. Among the 12 events exceeding the conventional threshold of IDA > 4, the severest case of the analysed period is the LE No. 4, which occurred in December 1972, showing the highest values of IDA, and direct, indirect and intangible damage indices. In terms of both direct damage and IDA value, the second LE is No. 12, which occurred in 1996. Going into detail of damaged elements (Fig. 1b), LE No. 4 mainly affected roads and private buildings with consequently high indirect damage related to the numerous families evacuated for long time. A common feature of all the events is that the element most frequently damaged is the road network, while the other elements are shown to be differently affected from one event to another. The highest number of people affected (6 victims and 8 injured) pertains to the event No. 7, also characterised by the second value of intangible damage, mainly related to both loss of and injured family members.

In terms of indirect damage (Fig. 1e), lodging for short periods is the most consistent source of post-event expenses; on the contrary, a few data concerning building renovations have been gathered. It is probably due to the long time for reimbursement procedures: the renovations do not usually start immediately after the event, and thus it can be difficult, if not explicitly mentioned in historical documents, to put in relation a LE with a renovation. In practice, it is easy to find the reimbursement requests, which are sent to the competent authorities in the days or months after each event, but it is not expected to find documents confirming that funds were actually supplied to the owners of damaged houses.

Finally, in terms of intangible damage (Fig. 1f), the most frequent cause of psychological effects is due to the inconvenience of the use of alternative roads because of road breakages caused by landslides, as emerged in direct damage assessment (Petrucci and Pasqua, 2013). This problem is particularly heavy in a region such as Calabria, characterised by a rugged morphology, where some villages located on the mountains are connected to the regional road network by means of a single road: when this road in unavailable because of landslide damage, people living in those villages are forced to drive on tortuous tracks. Thus their way home becomes longer and more expensive in terms of fuel costs.

4 Conclusions

The paper presents a methodological approach for the assessment of damage caused by landslide events, i.e. periods during which rainfall-triggered landslides affected a wide percentage of a study region. The result is a set of three indices expressing direct, indirect and intangible damage, thus allowing the comparison of damage induced by different landslide events, even if they occurred both at different times and in different regional sectors.

The application performed on major landslide events that occurred between 1960 and 1999 in a region of southern Italy highlighted the road network as the most vulnerable physical element, even representing the source of huge intangible damage for people forced to use alternative and longer roads for their daily activities. In terms of indirect costs, it seems that the frequent displacement of people, even if for short periods and sometimes as precautionary measure, influences the costs of LEs. Future development, especially in terms of improvement in definition of actions contributing to indirect damage, will be undertaken as soon as the historical data available for the period between 2000 and 2012 are validated. Further improvements to the approach should be introduced in order to add a supplementary damage weight to the cases in which there were victims, being human life the most complex element for which damage assessment has to be done.

The approaches can be used to perform relative assessments based on a minimum amount of information which usually characterises historical events. The simplicity of the approach allows the time-consuming data gathering procedure to be committed to non-specialists who should simply be trained on what kind of data must be mined from historical documents.

The relative damage assessments that can be obtained show a reliability which strictly depends on the quality of historical data employed: for this reason, a careful cross-check of different historical data sources (newspapers, reimbursement requests to municipal and regional offices, scientific reports, etc.) should be performed, in order to be sure that all available data have been considered.

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