Evaluating landslide hazard through geomorphologic, hydrologic and historical analyses in North-Eastern Calabria (Southern Italy)

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ABSTRACT

An integrated analysis of geomorphologic, hydrologic and historical data has been carried out in the NE Calabrian sector named *Alto Jonio* (AJ). The principal *hydrogeologic events* (*i.e.* events of damage to urbanised sectors and roads, caused by floods or rainfall-triggered landslides), which occurred in AJ in the present century, have been recognised through historical data collection and analyses. Slope movements, either located in the surroundings of the villages or affecting the roads, have been mapped. The daily rainfall series, recorded at rain gauges located in the study area, have also been analysed. Comparing the results of the three "independent" phases of our study (geomorphologic, hydrologic and historical), different "types" of damaging event, characterised by distinct meteoric and geomorphic features (in terms of both spatial and temporal patterns), can be recognised. Recurrence intervals, as evaluated for the main triggering events, combined with typological classification of damaging events, can be helpful in defining scenarios and strategies for risk management.

1 INTRODUCTION

Evaluating rainfall thresholds for landslide activation represents a major task in the risk reduction and management process (Keefer *et al.* 1987; Wieczorek, 1996). In areas characterised by meteoric triggering of landslide phenomena, like the Calabrian *Alto Jonio* (AJ), combining rainfall-threshold and susceptibility analyses can provide useful information for hazard assessment. Historical data of damage caused by *hydrogeologic events* (*i.e.* events of damage to villages, roads and facilities, caused by landslides, river floods or urban flooding) can allow a better understanding of both spatial pattern and average temporal occurrence of damaging phenomena.

With the aim of evaluating landslide hazard in AJ, an integrated study of geomorphologic, hydrologic and historical data has been recently carried out (Ferrari *et al*., 1998). In this paper, the four main historical events of damage, which occurred in the study area during the present century, are examined and some preliminary considerations of hazard are given.

2 GEOLOGIC AND GEOMORPHOLOGIC SETTING

In AJ, flyschoid terrains of Cainozoic age mainly crop out (Fig. 1). These belong to the Southern Apennine Chain, a NE vergence thrust belt originated in Miocene-Pleistocene time. By the coast, terraced Quaternary sediments (clay, sand and conglomerate) are to be found up to several hundreds of meters *a.s.l.* In the south-westernmost sector of the study area, limestone of Mesozoic age also crop out (Ogniben, 1969; Bonardi *et al.*, 1988).

AJ is severely affected by slope movements and erosion processes (Carrara *et al.*, 1977; Merenda, 1983; Iovine & Merenda, 1996; Iovine & Petrucci, 1998). Through interpretation of air-photos and field surveying, slope movements affecting the urban environment were mapped and classified according to Varnes' 1978 scheme. Landslide types are mainly slow earth-flows and slump-flows; soil slips are also recognisable on hillslopes; rock falls and topples affect the steepest sectors of the area, where coherent terrains (conglomerate, limestone and arenite) crop out. Evidence of Deep-Seated Gravitational Slope Deformations is to be found along most of the mountain ridges (Iovine *et al*., 1996).

3 HISTORICAL DATA OF DAMAGE: COLLECTION AND ANALYSES

The study area is sparsely populated: inhabitants per square kilometre range from 16 (Castroregio municipal territory) to 328 (Trebisacce). The highest density of population characterises the coastal sector where, in the last 30 years, villages developed along the State road (SS106) and the railway. Villages located in the upper reaches of the basins are reachable only thanks to a network of secondary roads.

The urban setting of the area directly affects the availability of historical data. In fact, damage is possible only where there are either property or people to hit. Nevertheless, for a damage event to be historically "registered", we need also an interest in recording it (*e.g.* claim for damage). Moreover, several minor cases passed unnoticed when major hydrogeologic events occurred elsewhere in the region.

Historical data of damage caused to the urban environment by slope movements, river floods and *urban flooding* (*i.e.* rain accumulation over waterproof surfaces), as recorded in documents available in national and local archives, were collected and critically analysed. This effort was funded by the CNR - "Area della Ricerca" of Cosenza, in agreement with the local branch of the "Archivio di Stato". Data were also gathered from the press and scientific publications (Caloiero & Mercuri, 1980; CNR-GNDCI, 1995; Petrucci *et al.*, 1996). Available information was recorded into a digital data base: when feasible, validation of data contained into independent sources was also performed through cross-checking.

The series of the principal damaging events, occurred in AJ in this century, was in this way reconstructed. Obviously, it is only a sub-sample of the "complete" series of damage actually suffered in the area. Information is not homogeneous in the considered temporal window, becoming "detailed" only in the second part of the century. Nevertheless, the series can be assumed as representative of the main (*i.e.* most severe) damaging events, and so compared with the results of the hydrologic and geomorphologic analyses.

Historical information was processed by hydrologic years (*i.e.* from October 1st to September 30th), ascribing data to villages' territory (the area of study is subdivided into 15 administrative partitions): different types of hydrogeologic events, both in terms of spatial distribution and severity of damage suffered, were recognised. When damage was recorded in almost all the territories, a severe hydrogeologic event was identified, and geomorphologic and hydrologic features were analysed in detail.

4 CLIMATIC SETTING AND HYDROLOGIC ANALYSIS

Climate in AJ is of Mediterranean type, characterised by a winter maximum-value and a summer minimum-value of average monthly rainfall. On average, annual rainfalls range from 504 mm (Villapiana rain gauge) to 1097 mm (S. Lorenzo Bellizzi rain gauge). The area, located on the Calabrian Jonian side, experiences rare rainstorm events of high severity and short duration (Versace *et al.*, 1989). The typical surplus period spans from October to April.

Available pluviometric data are the daily rainfalls recorded at several rain gauges since 1951 (in some cases, starting from 1922). As the majority of slope movements affecting the area of study – and responsible of recorded damage – is not "shallow" (i.e. their thickness is commonly greater than 2 meters), the use of daily rainfall is justified.

Daily rainfall intensities, aggregated for various periods of *n* consecutive days (I_1, I_3, I_5, .. I_{180}), were analysed, by fitting the GEV distribution to the annual maxima of each temporal aggregation, extracted from hydrologic year. In this way the rainfall intensity-duration curves for different return periods were obtained (Ferrari *et al.*, 1998).

Analyses of both antecedent precipitation indexes (API) and occurrence of high return periods for aggregated daily rainfalls (I_n) pointed out remarkable rainy periods, leading to the identification of the wettest winter seasons. The exceptional rainy periods, so identified, match well with the principal damaging events recognised through the historical analysis.

5 RAINFALL TRIGGERING OF LANDSLIDES IN AJ

The relationships between rainfall and landslide activations are often based on the behaviour of some function Y(t) of rainfall intensity X(t). One of the most common approaches to the evaluation of this function is represented by "threshold" model: in this way, it is possible to relate the probability of a landslide event to a specific threshold value of rainfalls. Particularly, the critical values of the n-days cumulative rainfall which can trigger landslides can be derived from the statistical analysis of the annual maxima of daily rainfalls aggregated in n-consecutive days (Cascini & Versace, 1988).

In order to evaluate rainfall thresholds for landslide activation in AJ, the four most severe hydrogeologic events (occurred in hydrologic years 1953-54, 1959-60, 1972-73, 1976-77), as identified from both hydrologic and historical analyses, were studied in detail.

The pluviometric characterisation of these periods was performed through some simple parameters, such as the concentration ratio of cumulated rainfalls and the number of rainy days (Tab. 1). Depending on the "shape" of the cumulative rainfalls (*i.e.* on the presence and position of rainfall peaks with respect to the rainy period), different types of hydrologic year can be distinguished. For example, hydrologic years characterised by dry autumn months and wet winter months show values of concentration ratios less than unity; on the contrary, values greater than unity correspond to hydrologic years with wetter autumns.

Hydrologic year	*1953-54*	*1959-60*	*1972-73*	*1976-77*
Concentration ratio	1.24	1.16	0.85	1.38
Number of rainy days	74	81	54	40
Barycentre of rainy days > 40 mm	Nov. 16th	Nov. 18th	Feb. 7th	Nov. 21st

Table 1. Pluviometric characterisation of considered rainy periods (October 1st - April 30th). Concentration ratio stands for the ratio between the area under the observed cumulated rainfalls, and the corresponding expected area in the case of constant daily rainfalls (total amount of cumulated rainfall being equal).

Geomorphologic, hydrologic and historical data, concerning the above mentioned hydrogeologic events, were compared (Figs. 2 and 3). The hydrologic exceptionality of these events can be expressed through the combined analysis of the return periods (Tr_n) of the n-daily cumulated rainfalls. In Tabs. 2-5, Tr_n evaluated for the dates in which damage was recorded are shown.

5.1 Hydrogeologic events of 1953-54

In 1953-54 (mainly in October), all the Jonian sector of Calabria was strongly hit by a series of hydrogeologic events, resulting in loss of lives and damage to property (Petrucci & Polemio, *in press*). Almost all the villages' territories in AJ, except for its northern sector, were damaged (Fig. 2). Landslides, floods and urban flooding hit variously the area. The majority of landslides strongly affected the road network. Landslide phenomena were also triggered near the villages of ORI, SLB and CER. Damage caused by unconfined river floods (11 cases) was mainly recorded along the coastal sector. Urban flooding was recorded in only 3 cases, being probably unnoticed owing to the greater severity of damage caused by floods and landslides (19 cases).

The cumulated rainfalls show the same behaviour for all the AJ rain gauges. The hydrologic year started with a heavy rainy period of about a month, during which two short storms characterised by an intense rain peak occurred. Three almost dry months followed, after which a group of rain pours of minor entity were observed. Two heavy storms were observed on October 22nd and November 9th in many rain gauges of the areas. Anyway, only the latter storm was characterised in several rain gauges by the highest values of Tr for the whole hydrologic year, with a maximum value (greater than 100 years) for Tr_{30} observed at ALE.

date	*gauge*	*d*	Tr_1	Tr_3	Tr_5	Tr_{10}	Tr_{15}	Tr_{30}	Tr_{60}	Tr_{90}	Tr_{120}	Tr_{150}	Tr_{180}
21.10.53	ALB	F	--	--	--	--	--	--	--	--	--	--	--
29.10.53	ALB	L	--	--	--	3	5	3	--	--	--	--	--
29.10.53	ALE	L	--	--	--	4	4	--	--	--	--	--	--
29.10.53	AME	L	--	--	--	**20**	**17**	9	5	4	3	2	2
29.10.53	CAS	L	--	--	--	--	2	--	--	--	--	--	--
29.10.53	SLB	L	--	--	--	4	3	--	--	--	--	--	--
09.11.53	ORI	L	**12**	**13**	**12**	**8**	**8**	**46**	**55**	**14**	5	3	3
09.11.53	TRE	L	**10**	**16**	**25**	**25**	**17**	**67**	**50**	**33**	14	7	5
10.11.53	AME	F	--	13	23	17	14	**62**	**63**	**41**	22	12	10
18.11.53	TRE	*	--	--	--	--	10	35	35	**33**	14	7	5
19.02.54	SLB	L	--	--	--	2	2	4	3	--	5	**10**	**10**
22.02.54	AME	L	--	--	--	--	--	--	--	--	4	**32**	**33**

Table 2. Hydrologic year 1953-54: return periods of n-days rainfalls evaluated for the dates characterised by damage notices. Key: (*d*) type of damage, L=landslide, F=flood, U=urban flooding, *=L+F+U; (--) $Tr_n < 2$ years. In bold, maximum values for the whole period October, 1st – April, 30th. In italic, dates preceded by high Tr_n.

In 67% of cases, damage notices match well with high values of Tr_n evaluated for the same date and/or for the preceding days (Tab. 2). On the contrary, damage recorded on October 21st in ALB and on October 29th in ALE, CAS and SLB does not match with exceptional values of Tr for all the aggregation periods.

On the other hand, even though showing very high values of Tr_n at ALB, ALE, CAS and SLB, the period 9-12 November was not characterised by "observed" damage.

5.2 Hydrogeologic events of 1959-60

In November 1959, almost all the Calabrian region was hit by a severe hydrogeologic event caused by heavy rains (Caloiero & Mercuri, 1980). Even though damage was less severe than in the rest of Calabria, in AJ rain-induced effects were diffusely observed (except for its southern sector, Fig. 2). Landslides and floods were triggered: the former represent the majority of recorded phenomena (25 cases), since only two floods and no urban flooding were noticed. It must be stressed that the number of landslides is underestimated: documents, in fact, generally refer to "*various phenomena occurring along the urban and rural road network*".

The pattern of cumulated rainfalls is practically the same for all the rain gauges. The most intense rainfalls occurred in November, but no dry intermediate period can be clearly identified as in the previous case. In almost all the rain gauges the same range of values characterises the different n-days aggregation rainfalls.

date	*gauge*	*d*	Tr_{1}	Tr_{3}	Tr_{5}	Tr_{10}	Tr_{15}	Tr_{30}	Tr_{60}	Tr_{90}	Tr_{120}	Tr_{150}	Tr_{180}
20.11.59	CAS	L	--	--	--	--	--	--	--	2	2	2	3
26.11.59	ALB	L	--	3	5	**4**	**9**	**8**	**9**	**8**	**7**	**6**	**6**
26.11.59	ALE	L	--	3	**4**	**3**	**21**	**15**	7	6	4	3	3
28.11.59	ALE	L	--	--	2	**3**	10	13	6	6	4	3	3
30.12.59	ALE	L	--	--	--	--	--	--	8	**8**	**6**	5	4
17.01.60	AME	L	--	--	--	--	--	--	5	9	10	**13**	12
17.01.60	ORI	L	--	--	--	--	--	--	4	**19**	10	11	7

Table 3. Hydrologic year 1959-60: return periods of n-days rainfalls evaluated for the dates characterised by damage notices. Key: (*d*) type of damage, L=landslide, F=flood, U=urban flooding; (--) $Tr_n < 2$ years. In bold, maximum values for the whole period October, 1st – April, 30th. In italic, dates preceded by high Tr_n.

In 86% of cases, damage notices match well with high values of Tr_n evaluated for the same date and/or for the preceding days (Tab. 3). On the contrary, damage recorded on November 20th in CAS does not match with exceptional values of Tr for all the aggregation periods.

Nevertheless, it must be stressed that all the damage notices are not related to very high values of Tr_n.

5.3 Hydrogeologic events of 1972-73

Starting from the end of December ’72, almost all the Calabrian region was hit by a severe hydrogeologic event. In AJ, the great part of phenomena was triggered during March and April 1973. They consisted mainly of landslides (34 cases), whereas floods and urban flooding were each represented by only one case. Only for the southern sector of AJ, there were no recorded effects (Fig. 3).

This period was characterised by very scarce rainfalls almost until the end of December ’72. Then, several short rainstorms closely occurred during a temporal window of about 3 months. Among the highest peak values, heavy rains occurred at the end of January ’73, followed by another event at the end of March ’73 (lasting few days) which practically closed the extraordinarily wet period.

Remarkable return periods were observed for the longest aggregation periods: *e.g.* on February 18th and between March and April ’73, values greater than 90 years were estimated in SLB rain gauge for Tr_{90}, Tr_{120}, Tr_{150} and Tr_{180}.

date	*gauge*	*d*	Tr_1	Tr_3	Tr_5	Tr_{10}	Tr_{15}	Tr_{30}	Tr_{60}	Tr_{90}	Tr_{120}	Tr_{150}	Tr_{180}
01.11.72	ALE	L	--	--	--	--	--	--	--	--	--	--	--
01.12.72	ALB	L	--	--	--	--	--	--	--	--	--	--	--
03.01.73	ORI	L	--	--	**2**	3	**4**	2	--	--	--	--	--
04.01.73	NOC	F	--	2	7	9	**19**	**11**	4	3	3	3	3
25.01.73	ORI	L	--	**2**	--	--	--	**3**	3	--	--	--	--
12.02.73	AME	L	--	--	--	--	--	--	5	3	3	2	3
28.03.73	ALB	L	--	--	**5**	3	3	2	2	11	19	12	11
30.03.73	MGI	*	--	--	6	17	10	6	11	11	21	13	16
31.03.73	CAS	L	--	--	--	**6**	**4**	**2**	--	**5**	**11**	**5**	**5**
31.03.73	ORI	L	--	--	--	4	**4**	**3**	3	**10**	14	**6**	**6**
01.04.73	ALB	L	--	--	--	**12**	**9**	**4**	4	**16**	**36**	**20**	**20**
01.04.73	CAS	L	--	--	--	**6**	**4**	**2**	--	3	**11**	**5**	**5**
01.04.73	MGI	L	--	--	--	**30**	**13**	7	**13**	**12**	**23**	**15**	**18**
01.04.73	ORI	L	--	--	--	**5**	**4**	**3**	3	7	**15**	**6**	**6**
01.04.73	SLB	L	--	--	--	6	3	2	3	26	65	43	44
02.04.73	ORI	L	--	--	--	**5**	3	**3**	3	4	14	**6**	5
03.04.73	CAS	U	--	--	--	4	**4**	**2**	--	3	**11**	**5**	**5**
04.04.73	ALE	L	--	--	--	--	--	--	--	--	**8**	**5**	**4**
04.04.73	NOC	L	--	--	--	--	5	4	3	3	**19**	**18**	**15**
04.04.73	ORI	L	--	--	--	2	3	**3**	2	4	**15**	**6**	5
05.04.73	MGI	L	--	--	--	--	**13**	**8**	8	10	**23**	**15**	17

Table 4. Hydrologic year 1972-73: return periods of n-days rainfalls evaluated for the dates characterised by damage notices. Key: (*d*) type of damage, L=landslide, F=flood, U=urban flooding, *=L+F; (--) Tr_n < 2 years. In bold, maximum values for the whole period October, 1st – April, 30th. In italic, dates preceded by high Tr_n.

In 76% of cases, damage notices match well with high values of Tr_n evaluated for the same date and/or for the preceding days (Tab. 4).

On the other hand, even though showing very high values of Tr_n at SLB and AME, the periods 25-28 January and April were not characterised by "observed" damage, respectively.

5.4 Hydrogeologic events of 1976-77

Mainly between October and December '76, heavy rains hit almost all Calabria. With respect to the spatial distribution of the effects, this damaging event was similar to the 1972-73 one, but both the number of triggered phenomena and their severity were lower (Petrucci *et al.*, 1996). In AJ, the effects were mainly represented by urban flooding (10 cases). For some territories of the central part of AJ, there was no recorded damage (Fig. 3).

The meteoric event was homogeneous over the whole area, as regards extreme values of rainfalls, and was characterised over the shortest periods: the highest values of Tr_n, for all the rain gauges, were observed at the beginning of November ’76. Other remarkable values of Tr_n were also recorded for 30-days cumulative rainfalls.

date	*gauge*	*d*	Tr_{1}	Tr_{3}	Tr_{5}	Tr_{10}	Tr_{15}	Tr_{30}	Tr_{60}	Tr_{90}	Tr_{120}	Tr_{150}	Tr_{180}
04.11.76	ALB	U	--	--	--	--	--	--	--	--	--	--	--
04.11.76	AME	U	--	--	--	--	3	3	--	--	--	--	--
04.11.76	MGI	U	--	--	--	--	3	3	--	--	--	--	--
04.11.76	NOC	U	--	--	--	--	--	--	--	--	--	--	--
04.11.76	VIL	U	--	--	--	--	2	--	--	--	--	--	--
05.11.76	ALB	L	--	--	--	--	--	--	--	--	--	--	--
06.11.76	MGI	U	**36**	**24**	**13**	**9**	**15**	**19**	**10**	**8**	**7**	**4**	**5**

Table 5. Hydrologic year 1976-77: return periods of n-days rainfalls evaluated for the dates characterised by damage notices. Key: (*d*) type of damage, L=landslide, F=flood, U=urban flooding; (--) $Tr_n < 2$ years. In bold, maximum values for the whole period October, 1st – April, 30th.

Only in 14% of cases, damage notices match with high values of Tr_n evaluated for the same date and/or for the preceding days (Tab. 5).

On the other hand, even though without damage notices, on November 6th high values of Tr_1 were estimated at AME, NOC and TRE rain gauges.

6 DISCUSSION

Among the considered hydrogeologic events, the ones occurred in 1959-60 and 1972-73 show the highest severity level. They both triggered mainly landslides: the greater number of phenomena (34 vs. 25) observed for the latter event can be explained with the better level of information which, generally, characterises the last decades. Moreover, some documents concerning the 1959-60 event refer to a high - though not better defined - number of phenomena affecting the road network.

Only the 1953-54 event triggered all the three kinds of analysed phenomena (landslide, flood and urban flooding). In this case, the low number of recorded damage can be due to the quality of information and, also, to the minor economic losses induced by numerous river floods (11 cases) that hit the sparsely populated coastal sector.

The 1976-77 event shows the lowest severity level, according to the limited spatial extension of affected area and to the type of triggered phenomena (mainly urban flooding).

For almost all the considered notices of damage, high values of Tr_n are to be found for aggregation periods greater than 10 days. Only in four cases (two of which represented by landslides), high recurrence intervals characterises the shortest aggregations. In some cases, notices of damage do not match neither with high values of Tr_n for the date of occurrence nor for the preceding days. This can be related to either shallower phenomena (for which hourly rain data are needed) or to peculiar "weaknesses" induced by human alterations of the natural thresholds.

The combined use of daily rainfall and event classification – as exploited in this paper - seems, then, suitable for hazard evaluation in order to define strategies for risk management in the study area.

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