Characteristics of debris flow events in eastern Umbria, central Italy

DIANA SALCIARINI[1], PIETRO CONVERSINI[2], JONATHAN W. GODT[3]

[1] *University of Perugia. (e-mail: diana@unipg.it)*
[2] *University of Perugia. (e-mail: pconver@unipg.it)*
[3] *United States Geological Survey. (e-mail: jgodt@usgs.gov)*

Abstract: In this paper we present the results of a study carried out in an area of eastern Umbria (central Italy) in order to characterize the debris flows phenomena of this region. We intend to achieve a double aim: to investigate specific sites which have been affected by debris flows in the past and to describe the main characteristics of these natural phenomena, based on historical accounts, monitoring data, and surveys. In the study area, debris flows typically prove to be high magnitude and low frequency processes, significantly modifying the morphology of the area. We begin with a description of debris-flow volumes, triggering rainfall, debris-flow morphology, and topographic setting of previous debris-flow events in the region. Four case studies are then introduced that represent a range of debris-flow activity in central Italy. The first two are examples of debris flows triggered by intense rainfall and have been repeatedly active in the recent past, and the second two are examples of dormant debris flows that are perhaps only active under exceptional rainfall conditions. Finally, we suggest a simple method for preliminary hazard assessment of the study areas. This method will need to be validated with future works.

Résumé: Ce dossier va présenter les résultats d'une étude conduite dans une aire de l'Ombrie orientale (Italie centrale) aufin de caractériser les cas de debris flows qui ont eu lieu dans cette région. Le but qu'on entend poursuivre est double: étudier les sites qui ont été intéressés par ces phénomènes-ci et décrire les caractéristiques les plus importantes de ces événements naturels en se basant sur des données historiques, sur la méthode de la recherche et data monitoring. Dans cet étude les debris flows se caractérisent comme des procès ayant haute magnitude et basse fréquence; des procès dont l'effet principal est le changement morphologique de l'aire intéressée. On commence par une description des volumes et de la morphologie des debris flows, des pluies qui ont causé les phénomènes et de la situation topographique des debris flows qui ont eu lieu en passé dans cette région. On a introduit, en suite, quatre case-studies qui représentent un échantillon de l'activité des debris flows en Italie centrale. Les deux prémiers examples ici présentés montrent des debris flows dus aux pluies battantes qui ont été actifs dans le passé récent. Les deux examples suivants montrent des debris flows dormants qui ne pourraient devenir actifs qu'à l'occasion de conditions de pluie exceptionnelles. Enfin on va suggérer une méthode pour la valutation préliminaire du risque de l'aire étudiée. Cette méthode devra être validée par des études futures.

Keywords: geological hazards, mass movement, case studies, risk assessment, rivers and streams, sediments.

INTRODUCTION

Debris flows occur in mountainous region throughout the world (i.e. Cannon & Ellen 1985; Jibson 1989; Rickenmann & Zimmermann 1993; Wieczorek 1987). In Italy they are frequent and widely studied in the areas of the Alpine chain (i.e. Arattano, Deganutti & Marchi 1997; Tropeano & Turconi 1999), where they cause widespread damage to people and the built environment. Such phenomena also occur in the Apennine zone, although the morphology, the lithology of the available loose materials and the climate are different from those of the Alpine zone. In this paper we aim to give a characterization of typical debris flows events in the eastern Umbria region, situated in the central Apennine area.

The analysis of historical occurrence of debris flows in a given area is important because it enables both the identification of the predisposing factors for the instability, and because it supplies information concerning the mechanisms of initiation, propagation, and deposition of the debris flow materials typology. Thus, four areas prone to debris flows hazard have been analyzed by collecting information on past events through historical records, surveys, and eyewitnesses' accounts. These four case studies, because of their different settings and features, may be considered as representative of the debris flows in Umbria.

For each study area we give a description of the triggering mechanism, average gradient of the slope, source area steepness, presence of vegetation cover, characteristics of the involved material, and volume of material deposited on the fan. We classify debris flows into two categories in the watersheds we examined:

- Rainfall-triggered shallow landslides which rapidly evolve into debris flows, channellized by topographical convergences. In these cases part of the hillslope is covered by a mantle of loose material with variable thickness, and the boundary between the soil and the underlying bedrock is generally abrupt. Typically the cover is a loose, highly permeable, layer of colluvium. In such conditions, shallow landslides exclusively involve the soil mantle with failure planes near the interface with the bedrock. Debris flows generated by these

shallow landslides may travel long distances, commonly eroding the channel down to the bedrock and depositing an amount of sediments downslope.
- Dormant debris flows, which have not presented evidence of reactivation for several decades. Typically, the hillslope is covered by well vegetated colluvial material. The absence of recurrent events for a number of years does not mean that the debris flow could not be reactivated by exceptional rainfall conditions.

HAZARD ASSESSMENT

Debris flows generally cause property damage in three different ways: through erosive processes due to the action of water (scouring, erosion, and under- or side-excavation of the watercourse); through direct and indirect impact of debris and water; and through flooding, as result of blockage or diversion of important channels by sediment deposits (Crosta et al. 1990). In the study zone, urbanized areas and infrastructure have been periodically exposed to debris flow events, triggered by intense and localized storms. Considerable volumes of sediment have been moved and deposited on the fans, creating structural damages to villages and to state and provincial roads. In general, the vast majority of damage occurs in the depositional zone of the debris flows, which is referred to as the fan. Fans are classified as alluvial fans if formed by fluvial processes, and colluvial fans if formed by landslide processes including debris flows (Jacobs 2005). Fans are preferred location for urban development because they are well drained, gently sloping, and often provide good aquifers.

To reduce debris flow hazard, both structural and non-structural methods of protection are used. These methods, as well as the protection plans, require the zoning of risk of the depositional areas that is commonly carried out by means of simulation with mathematical models, even though a reference modeling procedure is still lacking today. It can be stated that the hazard evaluation and management demand knowledge of two main arguments in order to assess the potential damage to structures and humans. First, it is necessary to estimate the probability that an event occurs in a given place and to a given moment; secondly, once the event has been triggered, it is essential to know the behaviour of the moving mass (in terms of location of paths and places reachable by sediments). Thus, to identify areas prone to debris flows hazard and to plan their defence, it is necessary to understand where and when they are likely to happen, their probable distance and deposit, and their potential consequences.

Typically, debris flows are present where topographical convergences and fan geometries are particularly pronounced, which are the result of successive shallow mass movement. If the debris flow is channelled and the water-drainage network is known, the potentially hazardous areas are easily identified. However, fan morphology indicative of debris flows is not always evident because of the long return periods of these events. The long period of dormancy permits the progressive vegetation and transformations due to the natural tendency of hillslopes to evolve towards equilibrium conditions. To these natural processes, human activity must be added, which considerably transforms the environment and obscures the natural morphology created by debris flows. Furthermore, it is not always possible to identify the source areas or to quantify the mobilized material. Thus, an approach based on multiple parameters that can take into account geomorphic evidences as well as common features of historical events is useful for preliminary hazard assessments.

METHODOLOGY OF INVESTIGATION OF THE STUDY AREAS

Although debris flow events have affected the areas for many years, public and scientific interest towards these phenomena is very recent in Umbria region. Hence, the study area lacks complete monitoring systems and quantitative data on previous debris flow events. Thus, the collection of historical documents, photos, administrative reports, and eyewitness accounts is very important for the reconstruction of several debris flows events and the assessment of potential hazards. However, this approach needs to be supplemented with mapping, event inventories, and field investigations. This work is composed of two parts. In the first part we focus on identifying some common predisposing factors of historical debris flow events. In particular, we examined:

- the geologic characteristics of the study area, related to the lithologic and structural features of the superficial formations and the bedrock, directly control the mechanical behaviour of the slopes and indirectly control the hydrological behaviour. As consequence, a particular geologic and geomorphologic environment, characterized by specific lithotypes and structural characteristics, predetermine a certain type of triggering mechanism for debris flow events;
- the hillslope morphology, which may control the evolution of a shallow mass movement into a debris flow (i.e. the presence of topographic convergences), and the morphometric characteristics of the watershed (i.e. the slope gradient, the source area steepness, etc) which may control the discharge of the debris flow;
- the characteristics and the availability of the loose material that may be mobilized, which controls the volume of debris flows;
- the presence of a vegetation cover, which can be considered an indicator or proxy of the activity and recurrence of the events in a basin;
- the rainfall patterns that can triggered debris flows, which may control the timing of initiation.

We consider these factors as representative for a complete description of debris flow events. Although we do not intend the small sample considered by these case studies to be statistically significant, they should provide a useful overview of these phenomena.

In the second part, we describe a simple method of reconnaissance debris flow hazard assessments and then apply this method to the case-study sample. This method still needs to be validated by future work.

GEOLOGIC AND GEOMORPHOLOGIC SETTING OF THE STUDY AREAS

The study areas, located in the central Apennines chain, are underlain by some of the main units of the Umbro-Marchigiano formations and are characterised by hilly landscape with deep, narrow valleys and steep slopes. In the central Apennines, the bedrock is a calcareous and marl limestone sequence 2200 m thick (Calamita & Deiana 1986). The bedrock outcropping in the study area is characterised by a limestone sequence with more marl fraction in the upper part of the sequence. Also, there is a percentage of landscape in which the colluvium outcrops, with different thickness, basically depending on the steepness. The morphology of the area is influenced by the structural-geological setting of the Umbro-Marchigiana area. The ridges that divide the basins are usually constituted of carbonaceous rocks with slope gradients even greater than 60°. The carbonaceous rock faces are connected to the lower parts of the slopes composed of talus and scree deposits and usually considerably steep (values ranging from 25° to 40°). Rocky slopes are usually characterized by discontinuous vegetation, whereas soil mantled slopes are often covered by dense forests.

All the territory in examination is scarcely populated with few villages developed on fans that constitute the main elements to which pay attention in the zoning of the risk. The road network is limited to some main roads close to valley bottoms and to some secondary roads leading these small villages.

CLIMATIC SETTING

The climatic setting of the central Umbro-Marchigiano Apennines derives from the interaction between the morphological features of the mountain chain and the characteristics of the local atmospheric path. The location, shape, and altitude of the Apennines intercept the western and local perturbations of Mediterranean origin. Also, the pluviometric regime is characterized as typical of to the Apennine–Mediterranean type, with dry summers and mild winter, with two seasonal peaks of rainfall: one in late autumn (November) and one in spring (April). In the proximity of the four study watersheds three rain gauges are present (Figure 1).

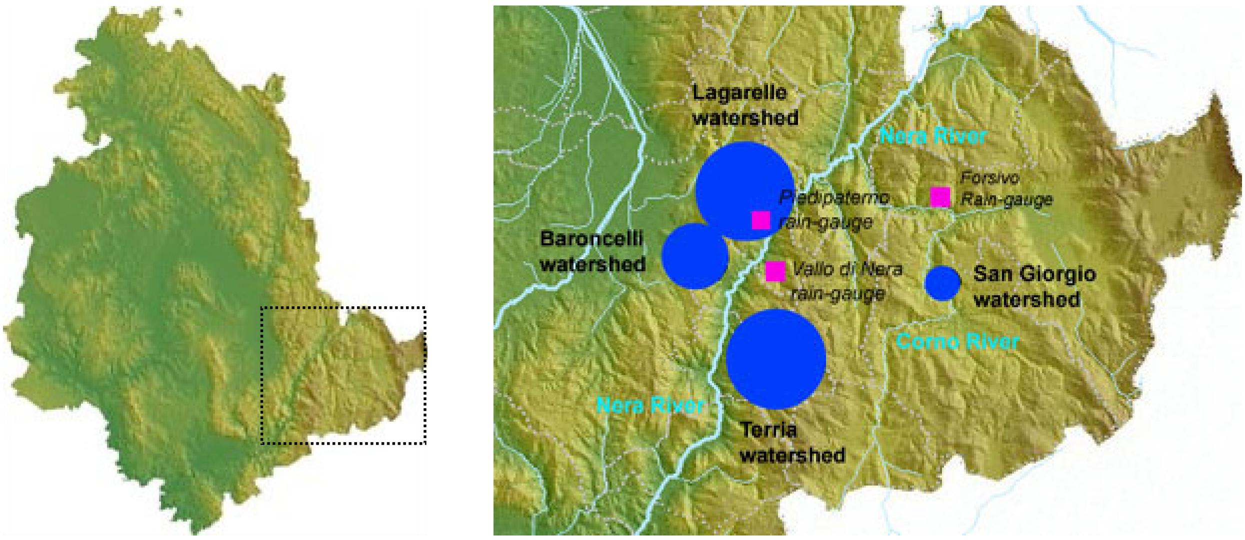

Figure 1. Location of the rain-gauges (purple quadrangle) and of the four watersheds (blue circles) in eastern Umbria region (central Italy).

The first, at Piedipaterno, 333 m above sea level, was in use until 1999, managed by the National Hydrological Service (N.H.S.), and data for this gauge for the previous 50 years are available. The others, at Forsivo, 818 m above sea level and Vallo di Nera, 467 m above sea level, are managed by the Regional Hydrological Service (R.H.S.) and hourly rainfall information is available for the period 1992 to present and 1996 to present, respectively.

We summarized rainfall records, in order to identify the average values of cumulated monthly rainfall (Figure 2a), and the average of the maximum daily precipitation (Figure 2b), for each rain gauge.

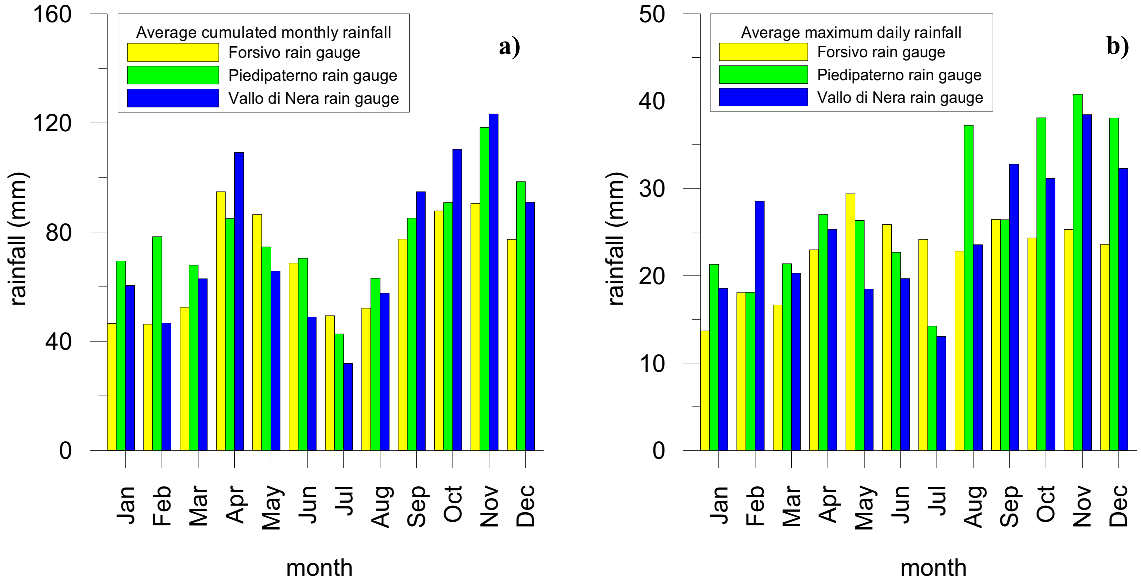

Figure 2. Pictures show for each rain gauge: a) Average values of cumulative monthly rainfall; b) Average values of maximum daily rainfall.

Average annual rainfall ranges from 830 mm to 944 mm. The heaviest rainfalls typically occur in November and April, while the minimum is in July (Figure 2a). The average monthly rainfall over a year varies between 69.13 mm (Forsivo rain gauge) and 78.68 mm (Piedipaterno rain gauge) (Figure 2a). The average of the maximum daily rainfall over a year varies between 22.77 mm (Forsivo rain gauge) and 27.63 mm (Piedipaterno rain gauge) (Figure 2b).

CASE STUDIES

The four basins examined in this paper are typical mountainous catchments with limited extent (Figure 1). The Terria basin, with outlet at Terria village, covers an area of about 2 km^2. The San Giorgio basin, tributary of the Corno River, has an area of about 0.6 km^2. The Grotti basin has an area of 1 km^2 at the Grotti section; and the Lagarelle creek basin, right hand tributary of the Nera River too, is 2.4 km^2 extended.

Catchments and fans were identified and digitized within a Geographical Information System (GIS), using 1:10000 and 1:5000 scale topographic maps. Morphometric characteristic were obtained from a regional-wide DEM with a ground resolution of 5 m and fieldwork.

Debris flows in the Terria watershed

The Terria basin is in Ferentillo Municipality; the elevations range between 1150 m above the sea level, and 360 m at the fan where Terria village is located. The geomorphologic setting of the watershed is characterized by mountainous relief with steep slopes. The upper part of the watershed has average steepness of approximately 25°. The middle and lower parts, where shallow landslides source areas are located, are steeper, with average values up to 40°. In the upper part of the Terria basin the formations of Maiolica and Calcari Diasprigni outcrop in overturned succession. Also, the Calcari Diasprigni formation outcrops in the lower portion of the watershed, where the village is located. Elsewhere, white layered limestone (very fine grained) with calcite veins, belonging to the Maiolica formation, emerges (Regione dell'Umbria 1995). The upper-middle part of the hillslope is widely covered by colluvial mantle, both loose and poorly-cemented, a thickness of between 1 and 5 m (Regione dell'Umbria 1996).

In 1965 a large debris flow event occurred in the watershed. From the direct accounts of the inhabitants of Terria village, we know that the Nera River (Figure 1), about 280 m above the sea level, was partially obstructed by the sediments which crossed the village and reached this main watercourse, creating widespread flooding in the area. Fortunately no casualties occurred, however the event created both localized structural damages to the village and indirect damage from the consequent flooding.

Recently, two debris flow events have occurred in the Terria basin. The first occurred on 30 June 2005 (Figure 3) triggered by a heavy rainstorm that was concentrated over a small area, including the basin. The rainstorm broke out in a violent downpours in the late afternoon and after two hours of heavy rainfall, the surge of the debris flow occurred. The second debris flow event occurred in the early evening of 31 August, after a shorter heavy rainfall lasting about 1 hour and half.

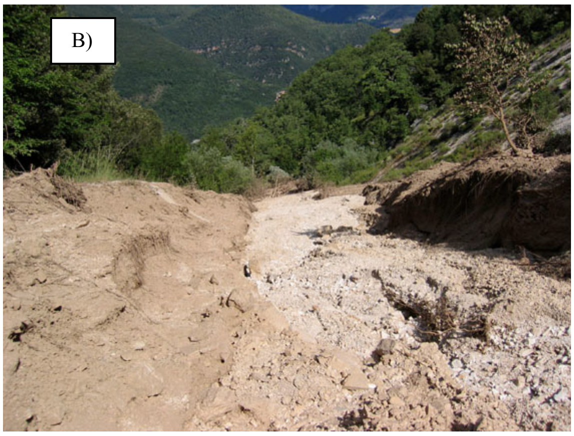

Figure 3. Pictures of Terria Creek: A) before the event; B) after the of 30 June 2005 event.

Within the basin there are no rain gauges for recording rainfall. In both cases, the storm was so localised that the nearest rain gauge (Vallo di Nera rain gauge which is about 8 km far from the Terria village, Figure 1) recorded no rainfall. A peak of rainfall intensity, one hour before the triggering of the events, was assessed at 35 mm.

In both the cases the principal damage by these two debris flows events were a temporary closing of the local road and limited damages caused to the road-bridge. The sediment from the flows was deposited on the fan, but did not hit the village which is built on the two lateral sides of the fan. In Figure 4 we show a picture taken after the event, highlighting the Terria village's hazardous location. The volume of sediment which came to rest on the fan was estimated to be in about 16,000 cubic meters, based on field surveys and GIS calculations.

Figure 4. Landscape showing the Terria debris flow and the Terria village location.

Debris flows in the San Giorgio watershed

The San Giorgio basin is a small catchment in the Cascia Municipality (Province of Perugia – Figure 1). The upper part of the basin reaches an elevation of 901 m above sea level and drains into the River Corno at 533 m. The upper part of the basin is characterized by a narrow, deep cut, rocky hollow, where loose material accumulates. The lower part is mantled by colluvium, varying in size from gravels to fines. The entire watershed is characterized by steep slopes, with average values of 35°. State road n. 320 which is one of the major routes of the eastern Umbria region, connecting Umbria to Lazio is located near the mouth of the basin. During intense rainfalls, large quantities of debris material ranging up to 3,000 cubic meters, have reached the River Corno riverbed, crossing the road and disrupting transportation (Conversini, Salciarini & Felicioni 2004).

In the watershed several debris flow events have been observed in the recent past, which did not cause any casualties but indirect damage due to the interruptions of transportation. In the summer 1996 a countermeasure to mitigate the hazard was attempted by building check-dams made with gabions. However, such work turned out to be ineffective in the following season (on 20 November 1996), when the heavy precipitation caused the triggering of shallow landslides in the uppermost section of the basin which quickly evolved into a debris flow channelled along the hollow. The debris flow destroyed the check-dams (Figure 5) and reached the road depositing a large quantity of material.

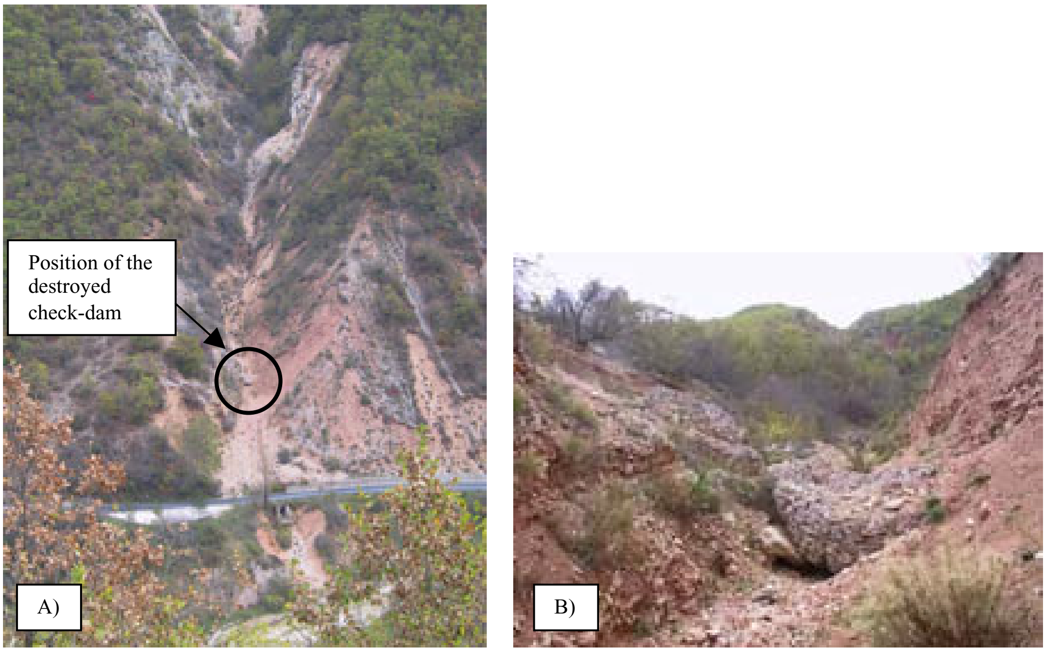

Figure 5. A) Final part of the San Giorgio creek, cut by the state road; and B) image of the check-dam destroyed by the debris flow.

Another similar episode occurred on 10 February 1999 creating once again disruption of transportation along n.320. On this day other minor shallow landslides near the basin were triggered but did not evolve into debris flow probably because the absence of topographical convergences. Finally, the most recent debris flow was recorded on 31 August 2000 highlighting the vulnerability of the path.

Figure 6 shows the daily rainfall records from the nearest rain gauge (Forsivo, Figure 1) associated with the debris flow occurrences described above. Daily rainfalls which triggered the events always exceeded the monthly average value of the daily peak rainfall measured at Forsivo rain gauge, and often happened after a rather dry period (no rainfall or very moderate rainfall).

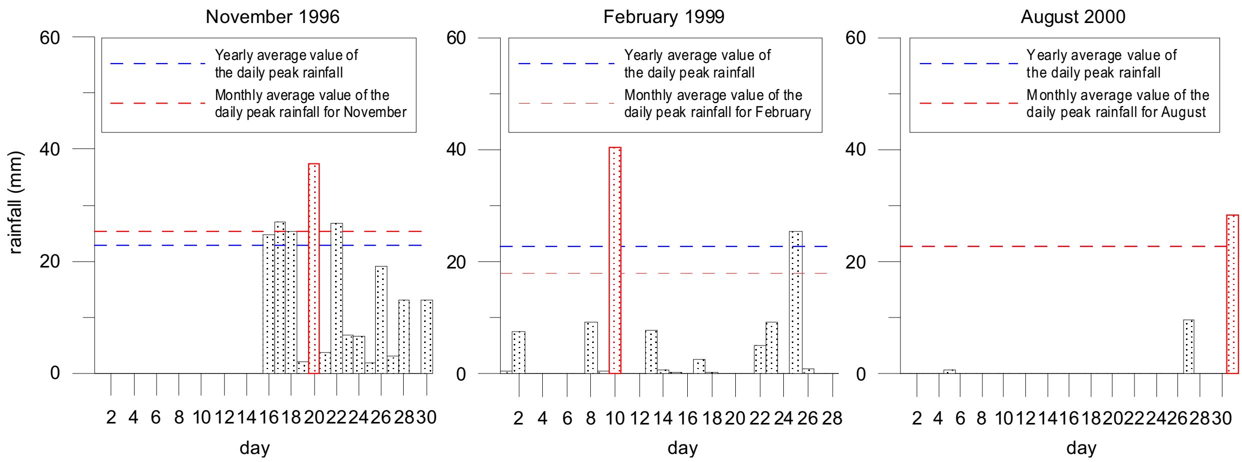

Figure 6. Daily rainfall at Forsivo rain gauge for the three debris flow events.

Debris flows in Lagarelle Creek watershed

The Lagarelle Creek watershed, with a basin-outlet at Piedipaterno village, is in the Vallo di Nera Municipality. The basin extends for approximately 2.4 km^2; it starts at an elevation of 1060 meters, and drains into the Nera River at 313 meters above the sea level. The creek is characterised by prevalent subsurface flow, favoured by the high permeability of the streambed. A concentrated streamflow in the channel verifies only in case of heavy rainstorms or rapid melting of snow. In the upper part of the watershed, formations of the Umbro - Marchigiana Series crop out in overturned succession: the formations are mainly calcareous, highly jointed and permeable. In the lower part of the basin, formations with a major marly component and less permeable are present. Recent alluvial and landslide deposits cover this bedrock, with variable thickness. Slopes exceeding 25° characterize the general morphology of the upper part of the basin. In the lower part the slopes are gentler, with average values of approximately 17°, with the exception of local situations, due to landslide escarpments, where the steepness can significantly increase. A pronounced morphological element is the alluvial fan located at the outlet of the Lagarelle Creek basin, where the recent part of Piedipaterno village is developed (Figure 7).

Figure 7. Piedipaterno village, built up on the Lagarelle creek alluvial fan.

During the last century, two important debris flow events occurred in the basin. The first one was in 6 September 1945. In the early afternoon heavy rainfall began that lasted for four hours before the mass movements were triggered. An initial flood wave arrived in the village bringing along considerable debris of variable size, including rocky blocks as large as 3 m^3. The mixture of water and sediments crossed the village and reached the Nera River that, in a short time, was obstructed. After the first wave, four additional waves followed with intervals of ten to fifteen minutes. The successive build-up of sediment raised the debris deposit to the height of the bridge that connects the two banks of the Nera River, completely obstructing the cross section of this watercourse. The water level rose more than 1 meter above the bridge, invading and causing damage to the countryside, and to the Spoleto-Norcia railroad that ran along the side of the river. Then, in a short time the water of the Nera eroded the obstruction generating a wave that flooded all the lands downstream, with serious consequences to the local agricultural economy.

A second important event occurred on 2 September 1965. The type of triggering and propagation of the debris flows was almost identical to those of the 1945 event. Some rocky blocks stopped at the beginning of the Piedipaterno fan, others reached the village and others the riverbed of the River Nera. In this case the debris flow obstructed the riverbed only partially; most of the sediment invaded the village and stopped there, structurally damaging several buildings.

The volume of sediment that reached the alluvial fan was estimated to vary between 3,000 and 8,000 cubic meters (Conversini et al. 2005), based both on geomorphologic methods (Hungr, Morgan & Kellerhals 1984) and semi-empirical equations (D'Agostino & Marchi 2001), although the total volume of material mobilized along the streamcourse could exceed that deposited on the fan by an order of magnitude.

We have no rainfall records for the 1945 event, because the World War Two was in progress; daily rainfall for the 1965 event is available and is shown in Figure 8.

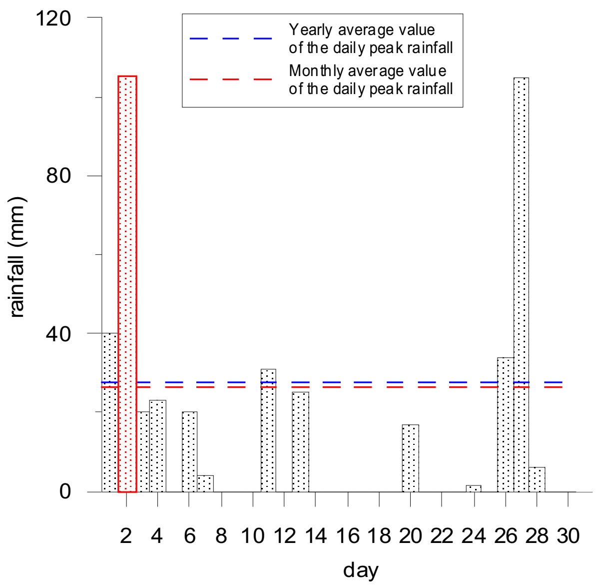

Figure 8. Daily rainfall record for the 1965 event, at the Piedipaterno rain gauge.

Debris flows in Baroncelli watershed

The Baroncelli basin (1.0 km^2) is located on the adjacent hillslope on the same mountain to Lagarelle Creek basin (Figure 1). The outlet of the basin is located at the Grotti village. In the middle part of the basin, around 700 m of elevation, zones in erosion with average steepness of 30° are evident, where the source area for the debris flow may be located.

In September 1965, after a heavy rainstorm (historical monthly rainfall is shown in Figure 8) multiple shallow landslides from the lateral scarps in the eroded zone were triggered. They quickly developed into a debris flow, channelled along a pronounced topographical convergence. A photographic record of the phenomenon shows that materials with rough and uniform size reached the village, destroying and partially submerging the houses located on the upper part of the fan. However, the main effect of the event was the deep erosion of the topographical convergence along which the debris flow was channelled (Figures 9).

Figure 9. Historical pictures of the 1 September 1965 event.

After the 1965 debris flow event, a series of nine concrete check dams where built, starting at an elevation of 680 m and continuing down to the beginning of the Grotti village. Although no other debris flow events were recorded after 1965, aerial photos of 1977 show the check dams filled with debris, a sign of continuing activity of erosion of material from the lateral hillslopes. Until 1977 the watercourse was unvegetated; currently there is a dense flora lining the stream (Figure 10).

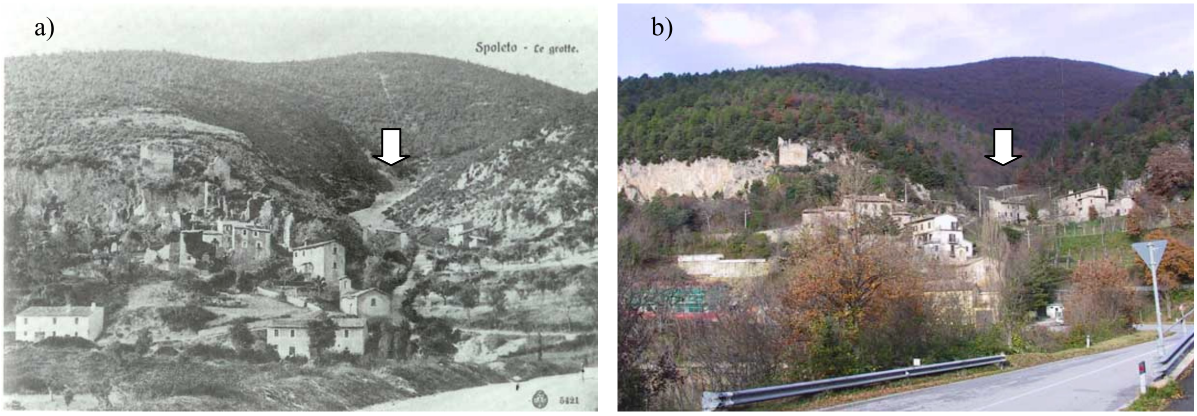

Figure 10. Landscape of Grotti village, built up on the Baroncelli Creek alluvial fan: a) 1930's picture showing the exposed gravel bed of the watercourse; and b) currently, where dense vegetation lines the streamcourse. The position of the watercourse is indicated in a) and b) by the white arrow.

SUMMARY OF THE COMMON CHARACTERISTICS FOR THE CASE STUDIES

In the study area debris flow events occurred in small basins (with areas less than about 3 km^2), in a hilly environment with average elevation of 800 m above sea level. The average slope gradient of the basins is about 30° and the average steepness of the potential source area for debris flow and shallow landslides is between 27° and 38°. The deposits of mobilized sediment on the fans from these events varied from 3,000 to 16,000 cubic meters, which represent a significant risk for people and the built environment on the fans.

In Table 1 the summary of the main characteristics of the case study is shown.

Table 1. Summary of the main characteristics of the study watersheds.

	Terria	San Giorgio	Lagarelle	Baroncelli
Debris flows activity	active	active	dormant	dormant
Area of the watershed (km^2)	2.0	0.25	2.4	1.0
Maximum elevation above sea level (m)	1326	901	1212	1044
Minimum elevation above sea level (m)	287	533	310	620
Mean slope gradient within the basin	25º	35º	17°	25º
Mean source area steepness	32º	38º	27º	30º
Availability of sediments	supply-unlimited	supply-unlimited	supply-limited	supply-limited
Volumes of sediments deposited on the fan during previous events (m^3)	16000	3000	3000-8000	5000
Presence of vegetation cover	partial	absent	dense	dense
Frequency of debris flows occurrence	3 in the last 50 years	3 in the last 10 years	1 in the last 50 years	1 in the last 50 years
Rainfall duration that triggered previous debris flows	2 hours	1 hour	3 hours	4 hours
Daily rainfall intensity that triggered previous debris flows (mm/day)	35	28.3– 40.4	105	105

We have identified three main factors in the triggering conditions for debris flows in the study area:

- The main triggering factors for debris flow occurrence are rainstorms with very short rainfall events (varying from less than an hour up to four hours), which hit a very localized area. Analyses of previous events revealed that daily cumulative rainfall which triggered shallow landslides, and which then evolved into debris flows, frequently exceeded the average peaks daily values (>28 mm/day). Often, this rainstorm occurs after a rather dry period.
- Debris flows, which typically started as shallow landslides, exclusively involved the soil, which can be classified into colluvium (loose material, heterogeneous, matrix supported and deposited either by superficial rainwash or by gravity) and talus (debris material usually coarse and angular, deposited at the base of the slope by gravity and clast-supported). The shallow landslide typically started in hollows underlain by calcareous or marl bedrock on steep slopes (about 30°).

APPLICATION OF A SIMPLE METHOD FOR HAZARD ASSESSMENT

The assessment of debris flow hazard in urban areas is a pressing need. However, the level of hazard is not always easily recognized, particularly on fans that are subject to high-magnitude, low-frequency events. One approach to the problem is the direct observation of geomorphic characteristics of the watersheds, of the main features of previous debris flow events, and of the expected potential consequences to urban areas. Thus we propose a simple method that accounts of all these factors in order to identify the debris flow hazard within a basin. The method considers:

- geomorphic evidence and morphometric characteristics of the watershed;
- magnitude of previous debris flow events in the same watershed;
- rainfall patterns that triggered previous debris flow events in the same watershed or in the proximity;
- debris flow events frequency in the watershed;
- potential consequences on structures, infrastructures and people.

We give a score to each of these components, varying from 1 to 3, as shown in Table 2, assuming that each of the described components has the same weight in the evaluation of the hazard. The total score obtained by adding the single score of each component can give preliminary indication of the expected hazard in the study zone. We consider a subdivision of the hazard degree into three categories: low, medium, and high. We classify the hazard as High, when the total score is higher than 12, because in this case at least 4 components of 5 have the maximum score. We propose to classify the hazard as Low, when the total score is equal or less than 6, because in this case at least 4 components of 5 have the minimum score. Results derived from the application of the method for the hazard assessment to the four case studies are summarized in Table 2.

Table 2. Summary of the methodology application for the hazard assessment to the study watersheds.

		Score	Terria	San Giorgio	Lagarelle	Baroncelli
Morphometric features	Mean slope < 15° and Average steepness of source area < 20°	1	3	3	2	2
	Average slope = 15° - 25° and Average steepness of source area = 20° - 30°	2				
	Average slope > 30° and Average steepness of source area > 35°	3				
Volume (m^3)	< 5000	1	3	1	2	3
	5000 – 10000	2				
	> 10000	3				
Frequency	At least 1 event in the previous 100 year	1	2	3	2	2
	At least 1 event in the previous 50 year	2				
	At least 1 event in the previous 10 year	3				
Cumulative daily rainfall triggering conditions (mm/day)	> 60	1	2	2	1	1
	20 – 60	2				
	< 20	3				
Consequences on structures, infrastructures and human being	Could damage or block streets and bridge	1	3	1	3	3
	Could damage or block streets and bridge, and destroy small building	2				
	Could destroy parts of villages and sections of infrastructures and corridors.	3				
Total Score			**13**	**10**	**10**	**11**

The total score of each watershed shows that the hazard in the watersheds may be classified as Medium in three of the basins and as High in one basin. Although the methodology may suffer from some limits of applicability, it can be useful for preliminary information on debris flow hazards. The main limit of the methodology that we presented referred to the fact that some of the parameters may be subjective and this can introduce a bias in the assessment. However, any methodology of this type requires training and knowledge of the physical processes governing debris flow events to minimize the uncertainness due to the subjectivities.

CONCLUSIONS AND FUTURE PURPOSE

In this work we have presented four study cases of debris flow prone catchments. In order to identify debris flow predisposing factors, we have provided a description of the geologic and geomorphologic features these catchments, and of the rainfall-triggering conditions and final deposits for each past debris flow event. This summary of common debris flow characteristics constitutes a first step in describing debris flow phenomena in Umbria region. Future works are expected to take into account a larger number of debris flow events that have occurred in the study area or nearby, in order to create a statistically significant sample of events.

Also, we suggested a simple method that might be used by technicians and public administrators to supply preliminary assessments of the debris flow hazard. For instance, during the decision phase of the planning of mitigation measures, this method could give information that could be used to prioritize mitigation measures or might be useful in land-use management. We applied the simple methodology for hazard assessments to the four study watersheds, showing that debris flow hazard is classified as medium or high in the four basins. However, to understand if the selected parameters for the hazard evaluations are representative and appropriate, a larger number of case-studies are needed. Hence, in future works we intend to provide more applications of this methodology to other watersheds of the same region. Also, future works will consider the possibility of adding new parameters for the description of debris flow hazard assessment. In fact, a good quality assessment needs to be based on a number of representative parameters which can characterize the setting of each basin.

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Corresponding author: Prof Pietro Conversini, University of Perugia, via G. Duranti, 93, Perugia, 06125, Italy. Tel: 0039-75-5853761. Email: pconver@unipg.it.

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