Landslides triggered by rapid snow melting: the December 1996-January 1997 event in Central Italy

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ABSTRACT

In the Mediterranean area widespread landslides can be triggered by high intensity or by prolonged rainfall as well as by snow melting. Snow-melting induced landslides were reported on January 1997 in Central Italy. The Autumn and Winter of 1996 where particularly wet in the Umbria Region. The last week of the year was characterised by a snowstorm that covered the entire region with 40 cm to 1 m of snow, and by air temperature well below zero °C. At New Years Eve a sudden temperature rise, possibly due to a *föhn* effect, melted most of the snow in about 24-36 hours, triggering several thousand landslides. Most of the failures were soil slips, but some were deep-seated, complex and compound landslides exceeding half a million m^3 in volume. Through the interpretation of aerial photographs flown after the event and through field surveys carried out in about 2/3 of the Umbria territory we mapped more than 4000 landslides. About 75% of the failures fell within 150 m of an already existing landslide, confirming the spatial persistence of landslide phenomena in the area. Most importantly, shallow landslides mainly concentrated on slopes which, in the recent years, owing to the EU agricultural policy, were converted to arable land.

1 INTRODUCTION

In the Mediterranean area widespread landslides can be triggered by high intensity or prolonged rainfall as well as by snow melting. Snow-melting induced landslides occurred in January 1997 in Central Italy. After the event, to gather as much information as possible on the extent of landsliding, different surveys were carried out using various techniques. Most of the snow melt induced landslides were located along the hilly terrain of the centre and eastern part of the region. The damage caused by landslides was estimated by the Local Government exceeding in excess of 50 millions US dollars.

2 CHARACTERISTICS OF THE EVENT

The Autumn and Winter of 1996 were particularly wet in the Umbria region. Starting from the second half of November storms with high daily rainfall intensity were reported in the central and eastern parts of the region.

A major storm occurred on November 16-20, 1996. Several rain gauges recorded in one day rainfall exceeding 70% of the average monthly precipitation. At several stations the November 1996 totals were twice the monthly averages. Floods were reported along rivers throughout the region, and damage was reported along the Topino river, and in particular along the Marroggia, Teverone, and Timia torrents, and in the Nera basin where a peak of 213 mm of daily rain was recorded. The second largest event with high daily rainfall intensity occurred on December 14, when 98 mm of rain were recorded. During this event rain gauges recorded precipitation exceeding 30% of the monthly averages. Rainfall produced minor floods along several rivers throughout the region and triggered few mass movements. Slide and slide earth-flows were particularly abundant where sandy and silty deposits, Plio-Plistocene in age, crop out.

The last week of 1996 was characterised by a snowstorm that covered the entire Umbria region with 40 to 100 cm of snow and by temperature well below zero °C (up to –15 °C). From the late night of December 31st to the early morning of January 1st the most critical phase of the event took place. At the Ponte Nuovo gauging station (166 m a.s.l.), along the Tiber River, in about 8 hours the temperature rose from –10 °C (at 8:00 pm), to +6 °C (at 4:00 am). On January 1st at 12:00 the temperature was already 12 °C. The sudden temperature rise, possibly due to a *föhn* effect, kept the temperature well above zero even along the mountainous area of the region, and melted most of the snow in about 24-36 hours. This produced in a very short period of time (less than two days) a large amount of water along the slopes already saturated because of the antecedent rainfall conditions.

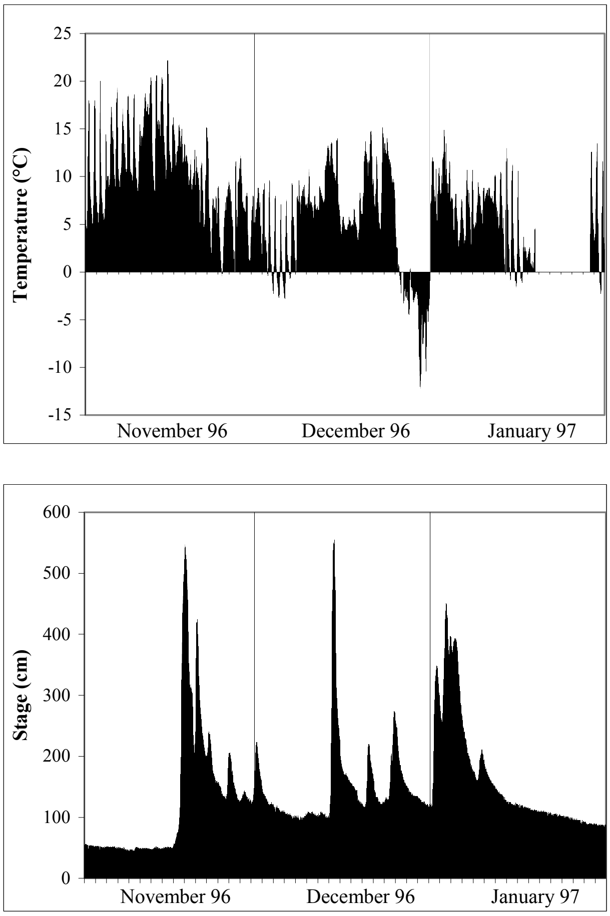

Figure 1: Umbria region. Temperature and river discharge at the Ponte Nuovo gauging station, along the Tiber RIver.

Meteorological conditions during Winter 1996/97 in Umbria and the basin response, are shown in Figure 1. Temperature can be considered representative of the entire region because the recording station is located at the centre of the study area. Figure 1 shows the temperature well below 0 °C during the last days of December and the sudden temperature rise on January 1st. River runoff is a proxy measure of the temporal and spatial response of a catchment to a meteorological event, as well as to the catchment antecedent conditions (*Reichenbach et al.,* 1998). In Figure 1 peaks in the mean daily discharge in

November and December show the response of the Tiber River basin to rainfall, whereas the peaks in January are mostly due to snow melt.

3 GROUND EFFECTS

Landslides triggered by the rainfall and snow melt were not homogeneously distributed in the region. This may be due to different meteorological conditions as well as to the different geological and morphological settings. The rainfall events in November and December triggered only few landslides, mainly deep seated, complex slides and slide-flows on sandy and silty sediments, Plio-Plistocene in age. The snow melting event triggered thousands of landslides both in Plio-Plistocene sediments and in flysch deposits, Miocene in age. In particular between January 3rd and 7th several hundreds mass movements of different size were reported. During the early morning of January 6th, at about 6:00 am, the most catastrophic landslide occurred at Valderchia, a small hamlet of the Gubbio Municipality. The landslide was a complex failure of about 800,000 m^3 that destroyed 3 houses and dammed the S. Donato torrent forming a small pond.

Following the large number of landslides reported from local Authorities and newspapers, we carried out various field investigations using different techniques. Immediately after the event we completed a general recognition by helicopter, followed by preliminary field surveys carried out in about 2/3 of the region and by the interpretation of aerial photographs flown after the event on the areas most severely affected by mass movements.

Recognition by helicopter was made throughout the region to acquire, in a short period of time, preliminary information on the extent of the landslide distribution and to evaluate the damage. The reconnaissance allowed to identify a pattern in the landslide distribution. Most of the landslides, regardless their size, were located along the hills of the central part of the region, along the Tiber valley, where sandy and silty sediments, Plio-Pleistocene in age, crop out. Fewer landslides were mapped along the central-eastern hillys, where flysch deposits, Miocene in age, crop out.

Preliminary field investigations were carried out in an area of about 2000 km^2. In about 10 days, 2 teams of 2 peoples mapped more than 1500 failures. For each landslide a synthetic description was prepared and ground photographs where taken, whenever possible in stereo to allow for a detailed geomorphological analysis of each landslide. The information was mapped at 1:10.000 scale and digitised to prepare a GIS based data-base of the effects of the snow melting event. Ground-based landslide mapping was integrated with the location of about 400 sites reported by the local Authorities or in more than 65 newspaper articles.

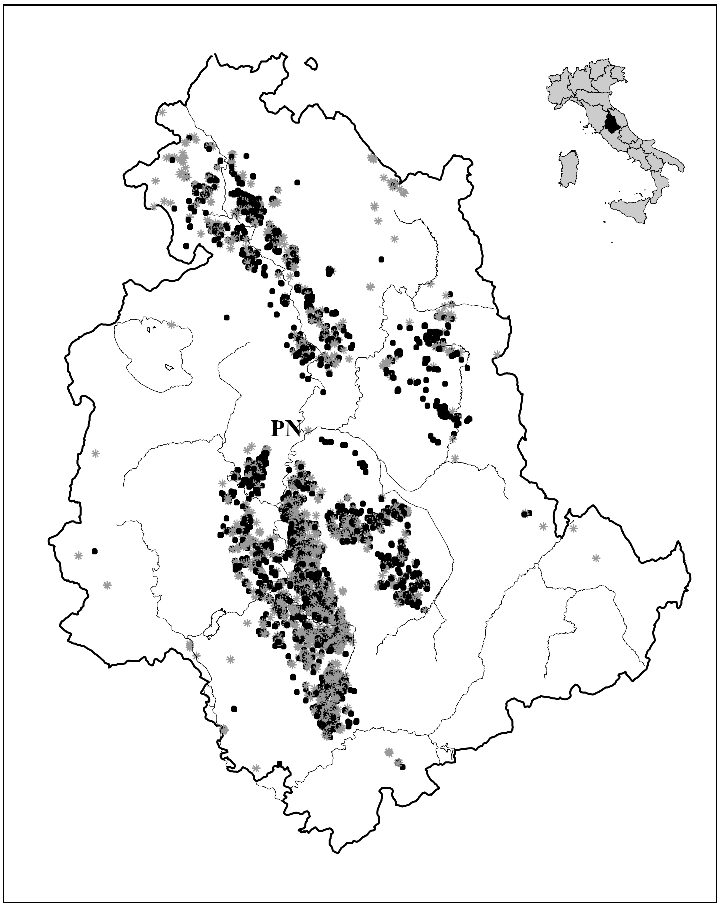

Figure 2: Umbria region. Map of landslides triggered by snow melting. Black dots are shallow failures; grey dots are deep-seated failures. PN is Ponte Nuovo gauging station.

Because of the extent of the event, an accurate mapping of the distribution and typology of failures was feasible only through the interpretation of aerial photographs flown after the event. A landslide inventory map was prepared through the interpretation of more than 400, 1:20,000 black and white aerial photographs, covering an area of about 1500 km^2. More than 4000 landslides were recognised and mapped at 1:10.000 scale (Fig. 2). Most of the failures were shallow, small size soil-slips and minor earth flows or slump-earth flows. Snow-melting triggered also a few deep-seated, complex or compound landslides up to 15 hectares in size.

Shallow landslides represent 62% of the total number of mapped failures. Trough the interpretation of aerial photographs more than 2000 soil slips (53%) and more than 400 earth-flows or slump earth-flows (9%) were recognised. Shallow failures took place mostly in cultivated areas, where infiltration to shallow depth is higher. Soil slips were rectangular or circular in shape, few meters long, and with an average area of about 0.2 hectares. The crown area was curved or rectilinear in shape, and the main scarp was short and vertical. The deposit was relatively undisturbed and locally subdivided into multiple portions. Locally, several soil slips covered an area of up to 10 hectares, making it impossible to map them separately. Shallow landslides took place on slopes not exceeding 20°, involving mainly soil or weathered material with shear surfaces parallel to the ground. Landslides stopped few meters after failure, probably because of the abundance of clay in the soil that prevents the landslide mass to mobilise into a debris flow (*Ellen*, 1988). The earth-flows and slump earth-flows were small (0.1 hectares) with elongate and lobate shapes. Their dimension ranged from few meters to few tens of meters in length. No clear relation with the local attitude of bedding planes or the structural setting was found. Shallow failures were related to the presence of slope concavities, depressions and seepage hollows, where soil moisture and ground water flow is greater (*Wieczorek*, 1987). Shallow failures were also related to the thickness of the surface deposits and the presence of weathered material or of pre-existing landslide deposits. Most of the morphological features that allowed the recognition and mapping of soil slips were concealed few months after the event by the intense farming activity.

Deep-seated landslides (38%) were mainly complex or compound movements, ranging from few tens to few hundreds of metres in length, and exceeding in some cases half a million cubic meters in volume. Landslide area ranged from 0.5 to 15 hectares, and covered a total of about 70% of all the mapped landslide area. Deep-seated failures were narrow and elongated in shape (length/width >> 1), locally with a distinct lobe at the toe. They exhibited typical morphological features, like: an extended, concave depletion zone with cracks and escarpments; a convex accumulation zone with irregular depressions and bulges up to one meter in depth; and narrowing of the river bed at the toe. Deep-seated landslides were controlled by the local structural and geological settings and by the presence of pre-existing landslide deposits (*Guzzetti et al.*, 1996).

4 COMPARISON WITH EXISTING LANDSLIDE AND LAND USE MAPS

An attempt was made to compare the distribution of failures triggered by snow melting with the previous distribution of landslides. A reconnaissance landslide inventory map for the entire Umbria region was completed in the years 1987-88, (*Guzzetti & Cardinali*, 1989) at 1:25,000 scale, through the interpretation of medium-scale (1:33,000), black and white aerial photographs. The inventory was partially updated in 1989-91 by *Antonini et al*. (1992).

To analyse the relationship between the two data-sets, we compared the large-scale landslide inventory map prepared after the snow melting event with the small-scale regional inventory. In a GIS graphic environment, simple buffering and map overlays showed that about 75% of all new failures occurred inside or within 150 meters of an already existing landslide, confirming the spatial persistence of landslide phenomena in the area (Fig. 3). Some of the newly formed failures were partial or total reactivations of pre-existing landslides, whereas others (mostly shallow) occurred in the softened cover of the landslide deposits. Consequently, the spatial persistence of shallow landslides in the area shows that the reconnaissance mapping at small scale can be a valid tool for a preliminary landslide risk assessment

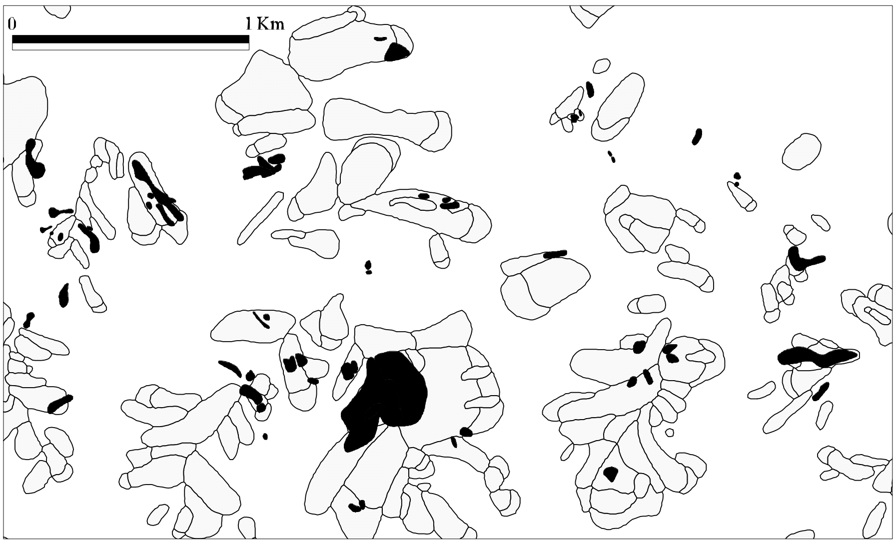

Figure 3: Umbria region. Montefalco area. Comparison of landslide inventory maps. Black polygons are landslides triggered by snow melt; grey polygons are pre-existing landslides mapped by *Guzzetti & Cardinali*, 1989.

An attempt was made to investigate the existing relationship between snow-melting induced failures and the local agriculture practices. Owing to complex and stringent economical and social issues of the European agriculture, the topic appears of major relevance. Indeed, during the past 20 years, EU legislation has encouraged and rather heavily subsidised major changes in land-use throughout Europe.

In the hilly and low mountainous areas of several countries, such as Italy, EU agricultural policies led to a progressive increase of arable land for cereal (mainly wheat) production in areas traditionally mantled by shrub and low forest, intended for pasture or totally abandoned. Furthermore, because of the advancements in earth-works machinery, the new agricultural practice was extended into land surfaces with slope angles frequently greater that 25 degrees and locally greater than 45 degrees. Most of these areas were never ploughed before. The impact on the stability of the slopes and river channels of such a major land-use change appears poorly investigated by the interested parties (Ministry of Agriculture, Ministry of Environment, etc.). At present, no quantitative data document the influence of such a transformation on the overall stability conditions of at the catchment scale throughout the Apennines. In spite of the lack of investigations and studies, scattered local sources of information and unsystematic field investigations in the Umbria region, as well as in the Southern Apennines (Lucania), would indicate a generalised increase of shallow landsliding and soil erosion in areas which underwent such a land-use change in the recent years.

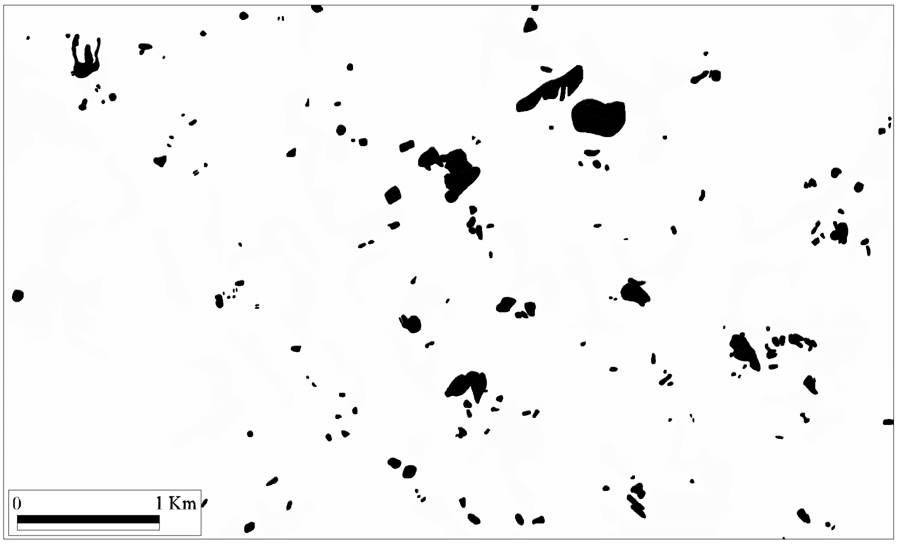

Figure 4: Umbria region. Todi area. Comparison of event landslide inventory map with existing land use map. Black area snow melting induced landslides; light grey cultivated areas and dark grey other type of land use.

By overlaying the snow-melting induced landslide map over a land-use map of the Umbria region (Fig. 4), it is apparent that most of the shallow failures took place on surfaces, generally steep or very steep, which in the past 10 years were transformed into subsidised arable land.

5 FINAL REMARKS

Due to the geographic location, snow storms followed by rapid temperature rise are not uncommon in the Italian peninsula. The event of Winter 1996-97 was particularly severe, producing more than 4000 landslides. At least 3 other, albeit probably less severe, events occurred in the last 15 years in Umbria, suggesting that snowmelt can be a particularly hazardous condition in the area.

Damage caused by landslides was estimated by the Regional Government of Umbria exceeding 50 millions US dollars. This figure does not include the agricultural damage. The economic impact is low when related to small, isolated and single shallow failures but can be considerable when related to successive and repeated or/and deep seated failures.

Most of the shallow landslides triggered by snow melt were soil slips that stopped few meters after failure. This is probably due to the abundance of clay material that prevented soil to mobilise into a debris flow. This is an important consideration for landslide risk assessment. The low probability of soil slips to mobilise into mud flows suggests that only rarely rapid mass movements can take place in the area.

The comparison of the snow-melting induced failures with the existing landslide deposits confirms the spatial persistence of landslide distribution in the area. This fact demonstrates that a reconnaissance mapping at small scale can be a valid tool for a preliminary landslide risk assessment.

Lastly, the study has shown a concentration of shallow landslides on slopes which in the recent years, owing to the EU agricultural policy, became arable land that was never ploughed before. This highlights the importance of systematically investigating the consequence on slope instability of agriculture changes induced by EU programs, which are solely founded on economic factors and market constraints.

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