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LANDSLIDE EVENTS AND THEIR IMPACT ON THE TRANSPORTATION NETWORK IN THE UMBRIA REGION, CENTRAL ITALY

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ABSTRACT

We present the preliminary results of an attempt to evaluate the impact of mass movements along the transportation network in the Umbria region. We use three landslide-event inventory maps and two small scale regional landslide inventory maps. The different landslide maps were prepared through the interpretation of aerial photographs, bibliographical analyses, and field surveys, and were compared in a GIS with the spatial distribution of the major and secondary roads. Using GIS technology the areas where landslide intersect or are very close to roads were identified. An attempt is made to compare the effects of the three landslide events, and to evaluate their impact on the transportation network.

1 INTRODUCTION

The Umbria region extends for 8456 km^2 in Central Italy and has a long history of mass movements. In the region landslides occur in many types of terrain and under a variety of environmental conditions. Slope failures range from boulders a few cubic decimeters in size, to large and complex landslides extending hundreds of hectares (*Guzzetti et al*., 1996). In the Umbria region both small and large landslides can be destructive, costly, and dangerous. Small landslides occur almost every year, whereas large landslides may occur only once every few years. Despite landslides occurring every year, their economic impact remains largely undetermined. The Umbria Region Government estimates that, in the period 1989-1996, more than 35 million euro were spent to repair landslide damage. In this paper we present a preliminary evaluation of the impact of mass movements on the transportation network using three event inventories and two cumulative (historical and geomorphological) inventories. The various landslide maps were compared in a GIS with the spatial distribution of major and secondary roads.

2 TRANSPORTATION NETWORK

In the Umbria region roads were built along the valley bottoms, in the slopes and along the divides where topography is hilly, and along the major divides and at the bottom of the narrow valleys in the mountainous areas. The road network extends for more than 12,000 kilometers, including about 1600 kilometers of highways, freeways and major state roads (*http://www.umbriaterritorio.org/umbria/Relazione/principale_rel.html*). For the present study we used a digital map of the transportation network made available by the Umbria Region Planning Office. The data set contains most of the major roads and some of the secondary and minor roads, for a total extent of 4762 kilometers. The data set was obtained by digitizing the roads from the IGMI topographic maps at 1:25,000 scale, and was locally updated by the Umbria Region Planning Office.

3 LANDSLIDE DATA

Landslide inventory maps record the location of all landslides that have left discernible features in an area. Inventory maps can be prepared by different methods depending on the scope, the available resources, and the scale of the investigation (*Guzzetti et al*., 2000). To evaluate the distribution of landslides in the Umbria region we used information obtained form various sources and at different scales. The information available to us includes:

a) a national inventory of historical landslides, prepared through the analysis of thousands of newspapers and scientific reports;
b) a geomorphological inventory map, obtained through the interpretation of hundreds of medium scale aerial photographs of different age and scale, aided by limited field checks; and
c) three landslide events inventory maps, obtained through the analysis of aerial photographs taken after the events, and detailed field surveys carried out in the areas most affected by the landslides.

3.1 Historical archive of landslide events

A national archive of information on historical slope failures was completed for the period 1918-1998, through the systematic screening of newspapers, the interviews of experts, and the inspection of technical and scientific reports (*Guzzetti et al.,* 1994). In the Umbria region the historical catalogue lists 1488 landslide events at 1108 different sites, affecting 90 of the 92 municipalities in the region. For 404 historical landslide events information on damage along the transportation network is reported, of which 1.5% along the highways, 88.1% along all the other roads, and 10.4% along the railways.

3.2 Geomorphological landslide inventory map

The regional inventory of landslides was obtained through the systematic analysis of hundreds of black & white aerial photographs taken at 1:33,000 in 1954-55, and hundreds of color aerial photographs at 1:13,000, taken in 1977. The latter photographs were used where lake and marine sediments Plio-Pleistocene in age crop out. Landslides were classified according to the type of movement, relative age, degree of activity, estimated depth and mapping certainty. The inventory contains about 50,000 landslides, for a total landslide area of 750 km^2, which represents 8.9% of the Umbria Region. The inventory map records the location of all the landslides that have left discernible features in the study area, and shows the cumulative effects of many events over a period of hundreds or thousands of years (*Guzzetti et al.,* 1996*;* 1999*; AA.VV.,* 2002).

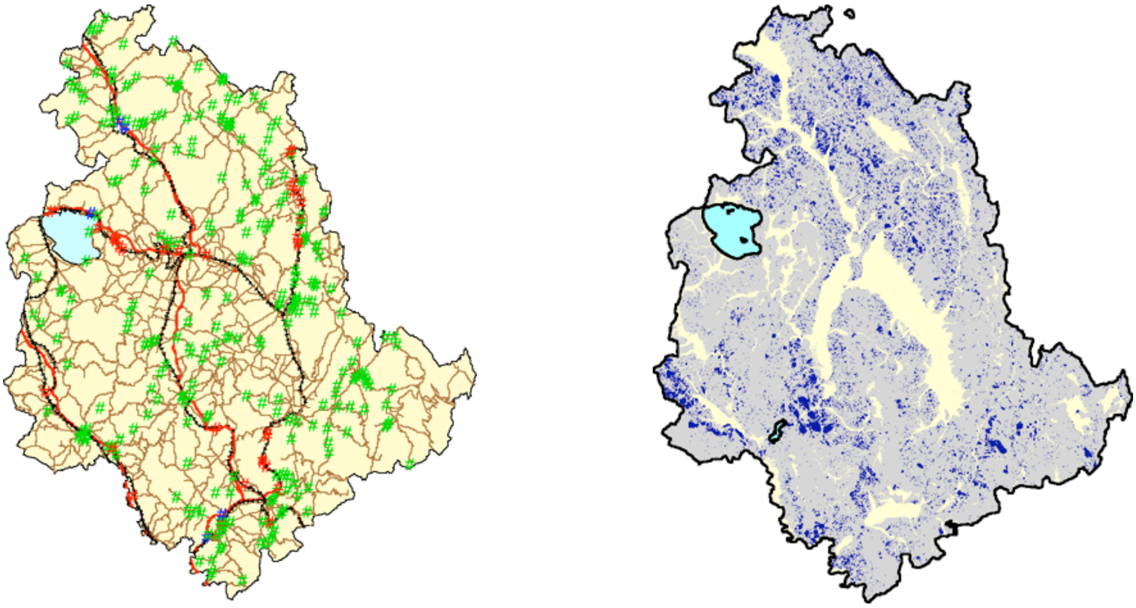

Figure 2. Umbria region. Left: historical inventory of landslide events. Red dots show sites where damage along the railways was reported, blue dots show sites where damage along the highways was reported, and green dots show sites where landslides along all the other roads were reported. Right: Regional geomorphological landslide inventory map. Landslides are shown in dark blue. Light yellow shows recent alluvial deposits along valley bottoms and intra-mountain basins; grey shows the other rock types in the region.

3.3 1937-1941 rainfall period

The period 1937-1941 was particularly wet in Umbria. Analysis of the historical archive reveals that several rainfall storms occurred during this period. High values of the average monthly precipitation were recorded at several places in the region. The historical catalogue of landslide and floods events lists information on more than 100 flooded sites and several landslide sites, mostly in the Tiber River basin. An inventory obtained through the interpretation of about 60 medium scale aerial photographs flown in 1941 was prepared for an area of about 135 km^2 between Deruta and Todi, in central Umbria. A total of 1072 landslides were mapped at 1:10,000 scale in this relatively small area, for a total landslide area of 4.4 km^2. This represents 3.2% of the study area, and it is equivalent to an average density of 8 landslides per square kilometer. Locally, landslide density was much higher, exceeding 50 landslides per square kilometer. Landslides were classified according to the type of movement, degree of activity, estimated depth and mapping certainty. Shallow landslides comprising soil slips, slumps and earth-flows were the most abundant, but a few deep-seated failures, comprising translational slides and complex slump-earth-flows, were also recognized.

3.4 January 1997 snow melting event

The last week of 1996 was characterized by a snowstorm that covered the Umbria region with 40 cm to 1 m of snow, and by air temperature well below zero °C. A sudden change in temperature melted most of the snow in about 24-

36 hours. The rapid snowmelt triggered several thousands landslides in the first days of 1997. Most of the failures were soil slips (53%) and slump earth flows (9%). Deep-seated failures, comprising complex and compound slides, some of which exceeded half a million m^3 in volume, accounted for 38% of the mapped landslides. Though the interpretation of aerial photographs flown a few weeks after the event, and through extensive field surveys carried out in about 2/3 of the Umbria territory, we mapped more than 4200 landslides, for a total landslide area of 12.7 km^2 i.e., 0.6% of the study area (*Cardinali et al.*, 2000). According to the Regional Government, the landslide damage to the road network reported immediately after the event exceeded 10 million euro. This figure is most probably underestimated.

3.5 September-October 1997 earthquake sequence

On 26 September 1997 the Umbria-Marche Apennines was shaken by two severe earthquakes of 5.6 and 5.8 local magnitude. On October 1997 the same area experienced another earthquake of similar magnitude. Following the main shocks fields surveys were carried out to map the landslides triggered by the earthquakes, and to determine the main landslide types. Information collected at more that 220 sites revealed that landslides were mostly rock falls, minor rock-slides and topples (*Antonini et al*., 2002). Damage caused by landslides was particularly severe along the roads, some of which remained closed for weeks after the earthquakes, while remedial works were completed. According to estimates of the Regional Government about 15 million euro were spent by the Region and ANAS, the National Road Company, to repair damage along the roads.

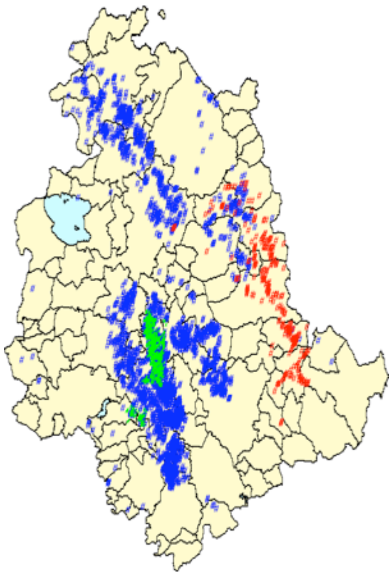

Figure 2. Umbria region. Slope failures caused by the three landslide triggering events considered in this study. Green dots show landslides triggered by the 1937-41 rainfall events; blue dots show landslides triggered by the rapid snow melting of January 1997; red dots show landslides triggered by the September–October 1997 earthquake sequence.

4 ANALYSIS

To estimate the impact of mass movements on the transportation network we compared in a GIS the different landslide maps available to us with the spatial distribution of the roads in the region. Both major and secondary roads were considered. To take into account uncertainty in mapping landslides and possible errors in the identification and mapping of the road network, we traced a buffer zone 50 meters large around each road. Intersection between the small-scale geomorphological landslide inventory map and the road network indicates that, on average, every 10 kilometers of road there are 9 areas where landslides intersect or come very close to a road. The historical archive lists one landslide every 10 kilometers of roads. This average value is 1/10 of the density measured by the geomorphological inventory, and represents a large figure in terms of the economic impact of historical landslides on the road network, particularly considering that the historical catalogue spans only 101 years and that it may not be complete.

We computed the number of landslide sites per 10 kilometers of roads for the three landslide triggering events. A comparison between the three events is not trivial, due to the different types of movements, the location of the transportation network, and the geomorphology of the study area. Earthquake induced landslides exhibit a density of 3.8 landslides every 10 kilometers. This considerably high density can be explained by the high number of rock falls that affected the roads, mostly along the Nera and Corno valleys. Along these valleys the density of rock falls was locally much higher. Along the two state roads (SS209 and SS305) running at the bottom of the valleys numerous landslides caused severe damage. At several sites rock falls damaged the existing elastic rock fall retaining structures and the artificial tunnels. The two state roads remained closed for weeks while remedial works were performed, causing severe mobility and traffic problems.

We then ascertained the impact of the 1937-41 rainfall events and the January 1997 snowmelt event on the road network. By intersecting in a GIS the inventory map showing the landslides triggered by the 1937-41 rainfall events with the map of the roads we identified 33 sites where landslides interfered with the road network. This corresponds to an average of about 3 sites every 10 kilometers of road. Repeating the same calculation for the landslides caused by the January 1997 rapid snowmelt event allowed identifying 101 sites where landslides intersected with the road network. This is an average of about 1 site every 10 kilometers of road. Interestingly, the percentages of landslides that have interfered with the road network were similar for the two events, i.e., 3.1% for the 1937-41 rainfall events and 2.6% for the January 1997 snowmelt event.

5 CONCLUSIONS

The assessment of the impact of landslides on the transportation network is not a trivial task. Results will depend on the types of mass movement, the location of the roads, and the geomorphology of the area. Geomorphological landslide inventory maps obtained through the interpretation of aerial photographs proved to be valuable tools for evaluating the total extent and the location of the expected landslide damage along the transportation network. Analysis of three landslide-triggering events revealed that the event had a different impact on the roads, depending on the type of landslide and on the magnitude of the event. The catalogue of historical landslide events proved useful in providing information on the frequency of landslides, a valuable information for assessing landslide hazard and risk (*Cardinali et al.*, 2002). The historical catalogue also provided information on the vulnerability of the road network to slope failures. In particular it showed that roads in the mountainous territory of the region are more vulnerable to rock falls, and that roads in the hilly part of the region are more vulnerable to slow moving, shallow and deep-seated landslides. This information is useful for determining the landslide risk along the transportation network, and for planning remedial and maintenance policies. Further investigations on the impact of landslides on the transportation network may include an in-depth analysis of the event inventories considering the spatial persistence of landslides in any given area, the geographical extent of the areas affected by the events, the different types of damage, and the types of elements at risk most affected by slope failures.

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