Landslide volumes and evaluation of landslide mobilization rates in an area in Umbria, central Apennines

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INTRODUction

Landslides are common geomorphological processes that contribute to shape landscapes in all continents. To determine erosion rates in landscapes dominated by slope wasting processes, chiefly landslides, one needs to know: (i) the geographical distribution and abundance of landslides, (ii) the temporal frequency or the average landslide mobilization rates, and (iii) the volume of material mobilized by individual landslides. Information on landslide abundance and frequency can be obtained from multi-temporal landslide inventory maps, which can be prepared through the systematic interpretation of multiple sets of stereoscopic aerial photographs, high and very-high resolution, mono- and stereoscopic satellite images, and dedicated field campaigns executed after events that have resulted in landslides (event landslide inventory maps) (Malamud *et alii*, 2004; Galli *et alii*, 2008).

Determining the volume of a single landslide is a complex problem that requires information on the surface and subsurface geometry of the slope failures, which is difficult to obtain. Deciding the volume of individual landslides in a large population of failures comprising hundreds or thousands of landslides is an even more difficult task (Malamud *et alii*, 2004) that, at present, can only be achieved adopting empirical relationships to link the volume (*V*L) of a landslide to geometrical measures of the slope failure, chiefly landslide area (*A*L) (Simonett, 1967; Rice *et alii*, 1969; Innes, 1983; Hovius *et alii*, 1997; Guthrie & Evans, 2004; Korup, 2005; ten Brink *et alii*, 2006; Imaizumi & Sidle, 2007; Guzzetti *et alii*, 2008, 2009; Imaizumi *et alii*, 2008).

landslide volume

From a global catalogue of 5800 mass movements for which landslide area (*A*L) and volume (*V*L) are known independently, we selected 677 landslides of the slide type (Cruden & Varnes, 1996), and we used the geometrical measurements to define an empirical relationship to link *A*L (in m2) to *V*L (in m3). The relationship takes the form of a power law with a scaling exponent α = 1.450 (standard error = 0.0086), and holds for eight orders of magnitude of *A*L and twelve orders of magnitude of *V*L, and is in good agreement with similar relationships in the literature (Simonett, 1967; Rice *et alii*, 1969; Innes, 1983; Hovius *et alii*, 1997; Guthrie & Evans, 2004; Korup, 2005; ten Brink *et alii*, 2006; Imaizumi & Sidle, 2007; Guzzetti *et alii*, 2008; Imaizumi *et alii*, 2008).

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The limited dispersion of the empirical data around the power law equation *V*L = 0.074 *A*L1.450 (R2 = 0.971), and the observation that the landslides occurred in different geological settings and climatic environments, and were caused by different triggers (chiefly rainfall and earthquakes), suggest that the dependency of *V*L on *A*L is independent of the physiographical setting, essentially.

landslide mobilization rates

We used the empirical relationship discussed in the previous section to determine the volume of landslide material (landslides of the slide type) in the Collazzone area, central Umbria, extending for 78.9 km2, and for which a detailed multi-temporal landslide inventory covering the period 1937-2005 is available. In this 69-year period, the total volume of landslide material was determined *V*LT = 4.78×107 m3, corresponding to an average mobilization rate *φ*L = 8.8 mm∙yr-1.

In the period 1937-2005, landslides mapped in the multi-temporal inventory range in volume *V*L from 1.3×101 m3 to 8.7×105 m3, with the most abundant landslides in the range 5×101 m3 < *V*L < 3×102 m3. In the multi-temporal inventory, the seven landslides with the largest volume (0.3% of the total number of landslides) represent 10% of the total landslide volume, and 4% of the total landslide area; and the 110 landslides with the largest volume (5.5% of the total number of landslides) represent 50% of the total landslide volume, and 32% of the total landslide area. These figures confirm the importance of large volume landslides in controlling the total volume of mobilized landslide material in an area (Hovius *et alii*, 1997; Guzzetti *et alii*, 2008, 2009).

Using the temporal information in the multi-temporal inventory, we determined the volume of material mobilized by new landslides and reactivations, for different periods. A period of accelerated landslide activity was singled out between 1937 and 1941. In this 5-year period, slope failures mobilized a volume of landslide material equivalent approximately to 45% of the total landslide volume mobilized in the 69-year period 1937-2005. This corresponds to a mobilization rate in the 5-year period *φ*L = 54 mm∙yr-1, six times larger than the long-term average mobilization rate in the period 1937-2005.

Even excluding the period 1937-1941, the majority of the landslide material was mobilized during specific landslide events, or particularly active landslide periods. Landslide mobilization rates during landslide events, or periods, are 9 to 11 times larger than the average rates for the inter-periods.

MAGNITUDE OF LANDSLIDE EVENTS

In the literature, we do not have an accepted definition for the magnitude of a landslide event (Malamud *et alii*, 2004). We defined the magnitude of a landslide event (or period) ***m****L* as the logarithm (base 10) of the total volume of landslide material mobilized during the event (or period), ***m****L* = log10(*V*LT). Based on this definition, an event that has resulted in 1×105 m3 of landslide material is a magnitude 5 event, and a period during which 1×106 m3 of landslide material were mobilized, is a magnitude 6 period. Using this scale, the period of augmented landslide activity between 1937 and 1941 has ***m****L* = 7.3.

COnCLUSIONS

The results obtained in the Collazzone area, central Umbria, are relevant for the definition of landslide hazard and the assessment of landslide risk, and for an improved understanding of the evolution of landscapes dominated by landslides in central Italy.

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