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Rainfall and shallow landslides in the Middle Serchio River Valley (Northern Tuscany, Italy): possible duration/intensity critical threshold curves

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1 – INTRODUCTION

Heavy and concentrated rainfall often causes damage and death, owing to landslides, debris flow and debris torrents. This is particularly frequent in the Northern-Western Tuscany, one of the rainiest areas in Italy (more than 3000 mm/year in the Apuan Alps) and commonly hit by downpours. The Serchio River Valley is adjacent to the Apuan Alps, suffering similar climatic conditions. This valley is located between the Apuan Alps to the W-SW and Tuscan-Emilian Apennines to the E-NE (**Fig. 1A**). The main peaks reach almost 2000 m a.s.l., while the valley bottom is about 50-100 m a.s.l.

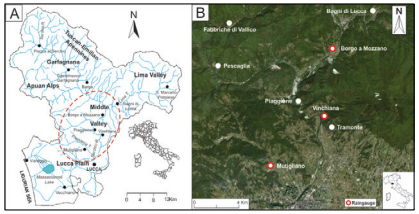

Fig. 1 – Sketch map of the Serchio River Valley (A); Satellite image of the Middle Serchio R. Valley, with location of the raingauges used (B).

In several cases, the storms hitting the area triggered many landslides, which exposed the population at risk: for example, during the 20 November 2000 rainstorm in the Middle Serchio R. Valley (**Figs. 1A, 1B**) hundreds of landslides were triggered and 5 people died (**Fig. 2**). Recently, the rainfall events occurred in January and December 2009 and on June 19, 2010 triggered many landslides (**Fig. 3**). These landslides are mainly defined as shallow landslides (in particular soil slip-debris flows) and hyperconcentrated flows.

The assessment of the critical rainfall thresholds is consequently very important in order to arrange efficient alarm systems and to manage risk situations, especially in a mostly touristic and industrial area.

Fig. 2 – Complex, debris slide-flow at Vinchiana village (photo by Lucca Province).

Fig. 3 – Canalized debris flows triggered during the June 19, 2010 rainstorm near Vinchiana village.

2 – METHODOLOGY

Aspiring to establish the critical rainfall thresholds for landslides the main rainfall events occurred in the Middle Serchio R. Valley from 1935 to 2010 were identified and analyzed. In particular, the data recorded in three raingauges were considered: Borgo a Mozzano (141 m a.s.l., from 1942 to 2010), Vinchiana (45 m a.s.l., from 1964 to 2010) and Mutigliano (33 m a.s.l., from 1935 to 2010) (**Fig. 1B**).

During the research 500 significant rainfall events were identified and analyzed (200 recorded by Borgo a Mozzano raingauge, 140 by Vinchiana and 160 by Mutigliano). Events with low duration (1-2 hours) and high intensity (20-45 mm/h), or high duration (80-100 hours) and low intensity (1.5-3 mm/h) were considered.

For all the events selected, a detail archive research was carried out in order to verify the consequences (landslide, flood, damage) caused in the study area. The most important rainstorms that caused damage and landslides occurred in September 1942, November 1952, June 1992, September 1994, August and November 2000, January and December 2009 and June 2010.

With reference to the seasonal distribution, the intense rainfall preferentially occurred in autumn (almost 50% in the three-month period September-November - **Fig. 4**), when the polar front transits at the latitude of the North-Western Tuscany. Giannecchini (2005, 2006) found analogous distribution for the Southern Apuan Alps, while Guzzetti (2000) obtained similar results on a national scale.

For each event analyzed, the following parameters were collected: rainfall amount (mm), duration (hours), mean intensity (mm/h), mean annual precipitation (MAP - mm).

The 500 rainfall events investigated were subdivided into three groups on the basis of the extent of the effects caused: events inducing several shallow landslides and floods (events A in the following graphs); events locally inducing some shallow landslides and small floods (events B); no information about the consequences produced (events C).

For the first group, the information on the effects produced was very clear: many landslides and floods and, in some cases, also deaths, such as during the 20 November 2000 rainstorm (5 deaths).

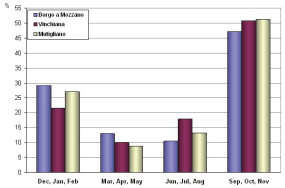

Fig. 4 – Seasonal distribution of the main rainfall events occurred in the Middle Serchio R. Valley from 1935 to 2010.

3 – DURATION/INTENSITY THRESHOLD CURVES

Significant results emerged from the duration/intensity relationship. The graphs were elaborated for Borgo a Mozzano, Vinchiana and Mutigliano raingauges according to a bi-logarithmic scale, with duration in x-axis and intensity in y-axis. Using a manual fitting and separating events A, B, C - type, two critical threshold curves, separating fields having different stability condition, are reasonably recognisable (**Fig. 5**).

For each raingauge, the curves are represented by the following equations:

Borgo a Mozzano:	$I = 71.225\ D^{-0.734}$	(upper curve)	$I = 41.656\ D^{-0.718}$	(lower curve)
Vinchiana:	$I = 63.458\ D^{-0.722}$	(upper curve)	$I = 41.385\ D^{-0.763}$	(lower curve)
Mutigliano:	$I = 75.21\ D^{-0.747}$	(upper curve)	$I = 43.25\ D^{-0.781}$	(lower curve)

Some exceptions are obviously recognizable (for example, a number of A events fall in the B events field and vice versa). This is probably attributable to possible uncertainty in the attribution of the damage extent by means of the historical information available. Alternatively, we cannot be sure of the perfect functioning of the rainfall monitoring instruments.

With regard to Figure 5 the probability of each kind of event (A, B, C) falling within each defined stability field could be estimated. The results are shown in Table 1.

Raingauge	*Event type*	*No. events*	*Stability field (%)*	*Intermedie (%)*	*Instability field (%)*
Borgo a Mozzano	A	6	0	0	100
	B	34	14.7	85.3	0
	C	159	88.1	11.9	0
Vinchiana	A	6	0	0	100
	B	25	4	84	12
	C	109	80.7	19.3	0
Mutigliano	A	5	0	20	80
	B	25	4	84	12
	C	130	78.5	21.5	0

Tab. 1 – Frequency of A, B and C types events in each stability field for the three raingauges considered. The percentages within the grey boxes theoretically should be 100%.

The critical threshold curves obtained were also compared with those proposed by several authors for several areas of the North-Western Tuscany and Eastern Liguria (**Figs. 6, 7**).

Moreover, the curves obtained were compared also with some global duration-intensity curves for initiation of shallow landslides proposed by several Authors (**Fig. 8**). The comparison shows a higher value of the rainfall threshold for shallow landslide activity in the Middle Serchio R. Valley. This is probably linked to the high mean annual precipitation and frequency of rainstorms in this area.

Fig. 6 – Areas between Liguria and Tuscany for which different Authors found critical rainfall threshold curves (base map by Google Maps, 2010).

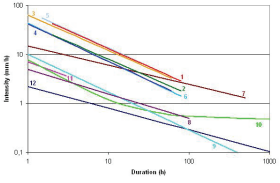

Fig. 8 – Comparison of the duration/intensity curves defined in this study and some global (worldwide) threshold curves: 1) Borgo a Mozzano upper curve; 2) Borgo a Mozzano lower curve; 3) Vinchiana upper curve; 4) Vinchiana lower curve; 5) Mutigliano upper curve; 6) Mutigliano lower curve; 7) Caine (1980); 8) Innes (1983); 9) Clarizia et al. (1996); 10) Crosta and Frattini (2001); 11) Cannon and Gartner (2005); 12) Guzzetti et al., (2008).

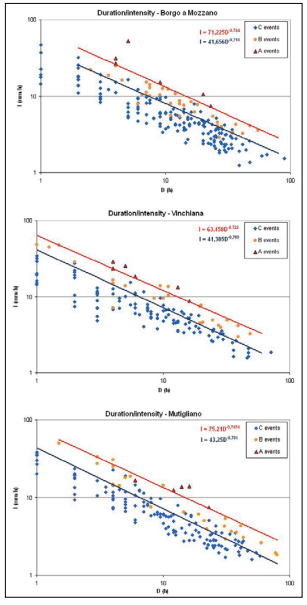

Fig. 5 – Duration/intensity relation obtained for the Borgo a Mozzano, Vinchiana and Mutigliano raingauges. The lower (blue) and upper (red) threshold curves are recognizable.

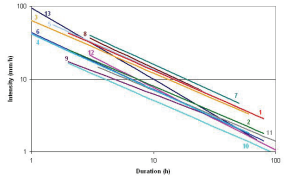

Fig. 7 – Comparison between duration/intensity curves proposed for Middle Serchio R. Valley and for surrounding areas: 1) Borgo a Mozzano upper curve; 2) Borgo a Mozzano lower curve; 3) Vinchiana upper curve; 4) Vinchiana lower curve; 5) Mutigliano upper curve; 6) Mutigliano lower curve; 7) Northern Middle Serchio R. Valley (Governi, 2005); 8) Southern Apuan Alps upper curve (Giannecchini, 2006); 9) Southern Apuan Alps lower curve (Giannecchini, 2006); 10) Carrara (Carrara Marble Basin - Giannecchini et al., 2011); 11) Fossacava (Carrara Marble Basin - Giannecchini et al., 2011); 12) Rifugio Belvedere (Carrara Marble Basin - Giannecchini et al., 2011); 13) Portovenere (Cinque Terre) upper Curve (Giannecchini et al., 2010).

4 – MAP NORMALIZATION

In order to normalize the rainfall data, several authors (e. g. Govi and Sorzana, 1980; Giannecchini, 2006) asserted that each area is in equilibrium with its usual climatic and rainfall conditions and related the rainstorm features to the mean annual precipitation (MAP).

For the study area the MAP was calculated relating to the three raingauges used: Borgo a Mozzano (1565 mm, from 1921 to 2010), Vinchiana (1388 mm, from 1930 to 2010) and Mutigliano (1331 mm, from 1934 to 2010). Introducing the normalization parameter NSR (Normalized Storm Rainfall – Corominas, 2001), namely the rainfall event/MAP ratio, the relationship intensity/NSR and duration/NSR were analysed for each raingauge considered (**Figs. 9, 10**).

On the basis of the same empirical approach used for the individuation of duration/intensity threshold curves, also in these graphs critical threshold curves are recognizable with good approximation.

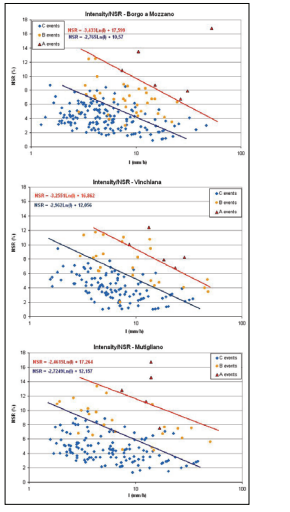

Fig. 9 – Semi-logarithmic intensity/NSR relation for the Borgo a Mozzano, Vinchiana and Mutigliano raingauges. The lower (blue) and the upper (red) threshold curves are recognizable.

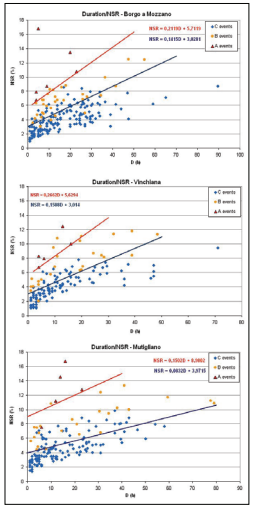

Fig. 10 – Duration/NSR correlation for the Borgo a Mozzano, Vinchiana and Mutigliano raingauges. The lower threshold curves (blue) and the upper threshold curves (red) are recognizable.

5 – CONCLUSIONS

The critical threshold curves obtained for the Middle Serchio River Valley show in general an acceptable validity. The comparison with some global duration-intensity curves emphasized the high critical rainfall value for triggering shallow landslide in the study area. This high threshold may be probably linked to the high mean annual precipitation and to the high frequency of rainstorms hitting the study area, as consequence of the equilibrium which establishes between climatic conditions and slopes.

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