Evaluation of rainfall triggering threshold of a large landslide in clay material: an application on the Nevissano landslide (Central Piedmont, Italy)

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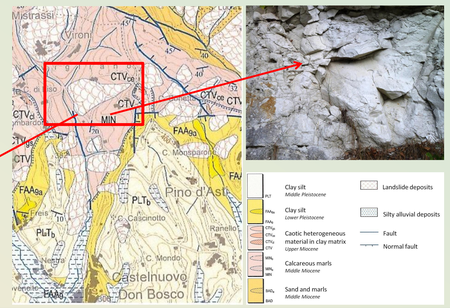
The triggering factor for different types of gravitational phenomena is rainfall. Then, the evaluation of rainfall thresholds for landslide triggering is a useful technique for forecasting such phenomena and can therefore be useful to the public authorities and local population by providing the critical rainfall values beyond which it is appropriate to consider a state of alert. This study evaluates the performances of the "Moving sum of daily rainfall" method in assessing Nevissano landslide triggering threshold near Castelnuovo Don Bosco (Piedmont, Italy). In order to establish a relationship between landslide occurrence and the amount of rainfall, an inventory of all the movements of the landslides occurred in the area in the past 30 years has been carried out by field survey, archive investigation, analysis of stratigraphy. The landslide has been affected by paroxysmal events over the last twenty years due to heavy rainfall occurred in November 1994, February-March 2002, December 2008, April 2009, March 2011 and March 2014. In particular the last one involved the road down the slope, isolating two dwellings. Correlations between heavy rainfall events and the downstream slope movement historical records have been sought. The analysis showed a noticeable correspondence between the precipitation events and the paroxysmal phases of the landslide reactivations. Through the "Moving Sum" method it was possible to obtain the most probable threshold rainfall values which could trigger a slope movement: they are fixed at 105 mm and 193 mm respectively in the 3 and 30 days prior to the event. It also emerged that the landslide seems now to be active, but only with millimetric displacements, corresponding to preferential rupture surfaces highlighted by inclinometric informations at specific depths, have been localized. It is desirable that the automated rainfall monitoring station, calibrated and supported by real time underground data detection, is used as a prevent alert tool in order to mitigate risk close-by tested slope.

1- GEOLOGICAL SETTING

The study area is located in central sector of Piedmont (north-western Italy) nearby Nevissano in Castelnuovo Don Bosco (AT) municipality. The investigated landslide has an approximate extension of 0,2 km^2 and is situated in the Turin Hill, where a remarkable thickness sedimentary sequence belonging to the Tertiary Piedmont Basin (TPB) outcrops. The TPB is transgressive on Mesozoic crystalline basement and is made up of Oligocene-Miocene marine prevalent facies.

In detail the lithologies outcropping in the surroundings of the study area are made of predominantly marls called "Marne di Mincengo" Formation. The foot of the slope is eroded by Nevissano river whose flow rate is seasonally variable. Two other factors improve the landslide susceptibility of the area: the slope steepness and the soil consolidation reduction related with the agricultural practice.



A special mention to the Piedmont Region Agro-Meteoric sector for rainfall data.

3- METHODOLOGY

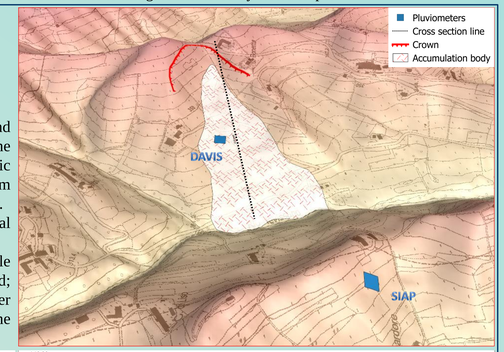
The "Moving Sum" method has been performed in order to identify the most likely precipitation threshold value, beyond which slope instability occurs. All the input data are continuous series of cumulative daily precipitation including one or more landslide occurrences. Rainfall data have been collected by instruments as close as possible to the slope, to obtain an acceptable result.

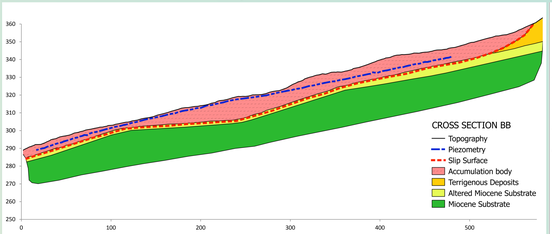
The method consists in four distinct phases:
1. Getting the sum of the rainfall recorded in the 3, 7, 15, 30, 60 and 120 days before each monitoring day. Six different numerical series are defined.
2. Representing each series in a "date / cumulative rainfall" graph with a focus on the day in which a landslide occurred.
3. Analyzing the best defined, higher gradient peaks of each series: the cumulative rainfall observed for each event directly represents the threshold value.
4. Checking how many times the threshold value in the full set of data has been exceeded: for an excellent performance of this method, the number of days is expected to be as close as possible to the landslide events.

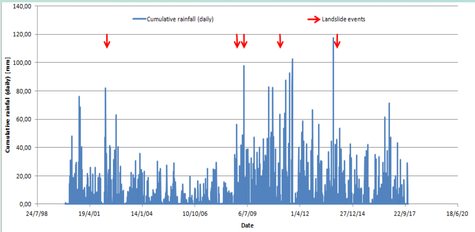
2- DATASET

The preliminary data are:
- rainfall data
- data records of landslide occurrences
- detailed stratigraphy

The daily rainfall data have been obtained by two pluviometers: one installed and monitored by the Department of Earth Sciences of Turin, and one produced by the SIAP company, managed and monitored by the Piedmont Region, agro-meteoric sector (data holder). The latter continuously recorded the rainfall data from 01/01/2000 nowadays, while the former one has been used to calibrate the dataset.
The landslide occurrence events have been identified by technical reports, local newspapers and road closure city ordinances.
The stratigraphy has been obtained by detailed field survey coupled with borehole data and geophysical investigation. Four different complexes has been detected; two superficial, weathered and reworked by agriculture practice and two deeper ones. The sliding surface has been interpreted, even with the help of some inclinometers, at around 7 meters depth.







4-DISCUSSION AND CONCLUSION

Rainfall data from 01/01/2000 to 21/11/2017 have been analyzed. All the landslide occurrences actually correspond to a peak of the series. Therefore the rainfall should be taken as a triggering factor for the landslide activations.

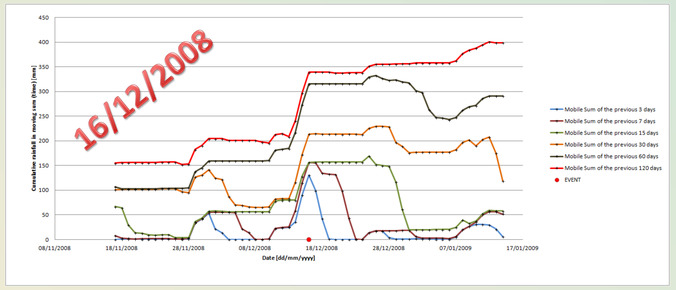
DATE	RAINFALL	EXCEEDED THRESHOLD	3	7	15	30	60	120	NOTE
dd/mm/yyyy	mm/day	if "YES" - THRESHOLD	days	days	days	days	days	days	
15/10/2000	68,60	THRESHOLD	107,00	113,60	121,20	255,60	269,80	396,40	
16/10/2000	8,80	THRESHOLD	107,80	122,40	130,00	264,40	278,60	405,20	
15/02/2002	82,00	THRESHOLD	120,20	120,20	183,20	193,40	193,40	253,60	Landslide
16/02/2002	9,00	THRESHOLD	129,20	129,20	192,00	202,40	202,40	261,60	
16/12/2008	42,00	THRESHOLD	130,60	156,00	156,40	214,00	315,20	339,00	Landslide
27/04/2009	97,80	THRESHOLD	140,60	146,60	207,20	354,80	435,80	566,40	
28/04/2009	9,60	THRESHOLD	150,20	154,20	216,80	341,20	445,40	575,40	Landslide
29/04/2009	0,00	THRESHOLD	107,40	154,20	216,80	341,20	445,40	574,80	
01/11/2010	82,40	THRESHOLD	152,00	152,40	199,40	257,60	344,40	511,80	
02/11/2010	11,40	THRESHOLD	132,60	163,80	210,80	268,80	355,80	523,20	
16/03/2011	63,60	THRESHOLD	111,60	183,00	199,20	287,60	309,00	509,20	Landslide
17/03/2011	1,80	THRESHOLD	113,40	184,80	201,00	273,00	310,40	510,00	
06/11/2011	102,60	THRESHOLD	230,20	240,00	272,20	272,20	368,80	511,60	
07/11/2011	22,80	THRESHOLD	209,80	262,80	295,00	295,00	391,60	524,20	
08/11/2011	20,00	THRESHOLD	145,40	282,80	314,60	315,00	411,60	544,20	
03/03/2014	37,40	THRESHOLD	105,60	174,80	181,40	290,60	428,00	738,80	Landslide
04/03/2014	45,60	THRESHOLD	107,40	220,40	225,00	333,80	473,60	784,40	
25/11/2016	31,00	THRESHOLD	131,80	173,20	173,60	194,20	264,40	404,20	

3 and 30 day series have been selected because they allowed:
- to remark the best defined, higher gradient peaks
- to get the most accurate match between landslide activations and monitored days.

The thresholds were deduced by picking out the minimum values among them.

The table shows 18 days in which selected thresholds have been exceeded with the relative cumulative values of the six series. 15/02/2002 and 06/03/2002 graphs showed the two landslide recorded events were correlated: since 15/02/2002 event continuous rainfalls contributed to 06/03/2002 following event. Threshold values of the latter weren't taken into account.

Five landslide events with relative cumulative rainfall were checked. In only four instances no landslides occurred despite the thresholds were get through. These results have shown that the performed method is appropriate for this case study and should be replied to landslides with similar triggering conditions.



Paroxysmal activation of the monitored landslide	Summary of the cumulative events					
days of events recorded	3	7	15	30	60	120
	days	days	days	days	days	days
February 15, 2002	120,20	120,20	183,20	**193,40**	193,40	253,60
March 6, 2002	40,00	47,20	47,20	238,80	249,60	278,60
December 16, 2008	130,60	156,00	156,40	214,00	315,20	339,00
April 27, 2009	140,60	146,60	207,20	354,80	435,80	566,40
March 16, 2011	111,60	183,00	199,20	287,60	309,00	509,20
March 3, 2014	**105,60**	174,80	181,40	290,60	428,00	738,80
Thresholds	***105***	***0***	***0***	***193***	***0***	***0***
Events that exceed all threshold values at the same time			***18***			
Monitored Days			***6463***			
Percentage of exceeding thresholds			0,28%			
Numbers of case of exceeding thresholds without event			4			
Percentage of case of exceeding thresholds without event			**0,06%**			

SIX EVENTS IN 6463 DAYS – ONLY FOUR POSITIVE FALSE

Four hypothesis have been proposed to justify these four "false positive" cases:
1. frozen soil increases the shear strength in colder periods
2. the cumulative values are probably not rainfall but snowfall
3. landslides actually occurred but the event was not reported
4. natural processes cannot be accurately modelled by numerical analysis.

Furthermore, the 3 and 30 day series are compatible with geological and geophysical model:
- 3 rainy days are sufficient to saturate the shallow layer
- 30 rainy days allow water to reach the sliding surface.

Saturation is the decisive factor for the landslide activations.

The very reliable thresholds deduced by the "Moving Sum" method can eventually permit to provide an essential support for Administrations to set civil protection plans and alert systems.

CUMULATES AT 3 AND 30 DAYS WITH THRESHOLDS
105 mm (3 DAYS) 193 mm (30 DAYS)