Forecasting of rainfall-induced landslides in pyroclastic soil deposits through hydrometeorological information.

Abdullah, Pasquale Marino, Daniel Camilo Roman Quintero, Roberto Greco

Dipartimento di Ingegneria, Università degli Studi della Campania 'Luigi Vanvitelli', Via Roma 29, 81031 Aversa (CE), Italy.

abdullah.abdullah@unicamapania.it

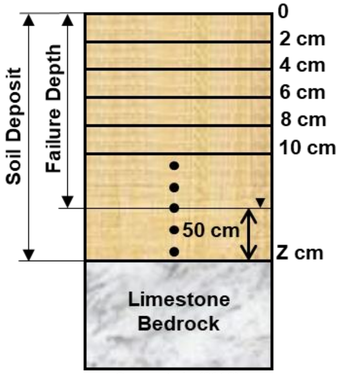
https://meetingorganizer.copernicus.org/EGU24/EGU24-13892.html

EGU General Assembly 2024
Vienna, Austria | 14–19 April 2024

Methodology

1. **Case Study**
   - Partenio mountains (Campania), South Italy.
   - Landslide prone area covered by loose granular pyroclastic soil deposits (mainly pumices and ashes) distributed in several layers laying upon limestone bedrock (Marino et al., 2020).
2. **Rainfall and DEM Data**
   - Rainfall data of 18 years (2002-19) from representative Cervinara rain gauge station was used.
   - The data was obtained from Multi-risk Function Center of Civil Protection for Campania Region.
   - 10 m × 10 m DEM was taken from Tinitaly official website.
3. **Soil Thickness Estimation**
   - Soil thickness was estimated using slope inclinations by the model of P. De Vita et al., (2006) for pyroclastic soils of Campania:

$$(Z[m] = -0.190\alpha + 9.5)$$



Greco et al., (2018)

4. **Simulation of Process**
   - 1D Richards' equation was used to simulate water infiltration process, getting soil suction and soil moisture at every 2 cm depth (Marino et al., 2020).
5. **Extraction of Landslides**
   - The Factor of Safety (FS) was calculated at the slip surface (assumed 0.5 m above the soil bedrock interface).
   - Landslide occurrence was assumed when FS < 1.1, leading to a number of landslides comparable to those reported in the area (Peruccacci et al., 2023).
6. **Dynamic landslide probability**
   - Landslide susceptibility, i.e., static probability of landslides was estimated from the simulation results.
   - Dynamic probability was calculated with Bayes theorem as conditional probability (Zhao et al., 2021).
   - The dynamic probability of landslides was conditional to rainfall and antecedent root zone soil moisture, individually and combined.

Simulation of hydrologic processes

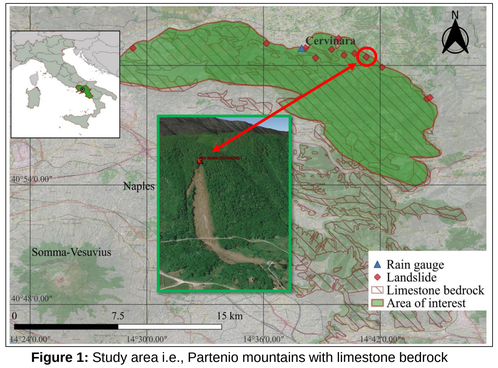


Figure 1: Study area i.e., Partenio mountains with limestone bedrock

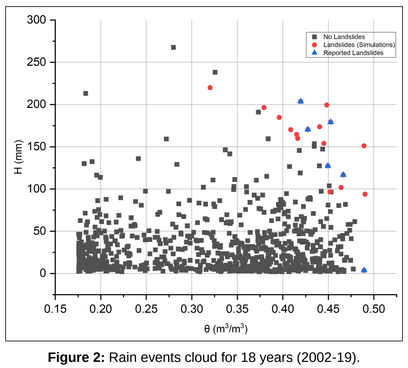


Figure 2: Rain events cloud for 18 years (2002-19).

Table 1: Classes for slope stability simulations

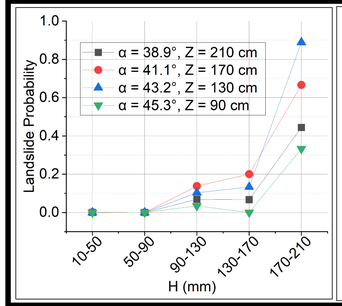
Slope Inclination α (°)	Soil thickness Z (m)	Slip surface depth D_f (m)	Landslide probability
34.7°	2.90	2.40	0
36.8°	2.50	2.00	0
38.9°	2.10	1.60	0.009
41.1°	1.70	1.20	0.017
43.2°	1.30	0.80	0.016
45.3°	0.90	0.40	0.006

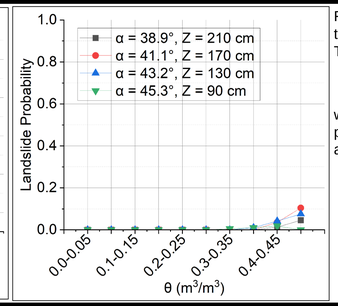
The slopes extracted from DEM were grouped in six classes for the simulations (Table 1). Soil parameters for the calculation of FS: porosity (**n**) 0.65, friction angle (**ϕ**) 37°, specific gravity (**Gs**) 2.67.
Table 2 shows the predicted landslides, and those highlighted in blue are those included in the landslide inventory (Peruccacci et al., 2023).

Table 2: Distribution of landslides among slope classes and hydrometeorological triggering conditions

H (mm)	θ (m³/m³)	Landslides Events (FS < 1.1)					
		α = 34.7°	α = 36.8°	α = 38.9°	α = 41.1°	α = 43.2°	α = 45.3°
184.6	0.40	-	-	-	-	✓	-
170.4	0.43	-	-	✓	✓	✓	-
101.8	0.46	-	-	-	✓	-	-
196.2	0.38	-	-	-	-	✓	✓
173.6	0.44	-	-	✓	✓	✓	✓
159.8	0.42	-	-	-	✓	-	-
116.6	0.47	-	-	✓	✓	✓	-
96.6	0.45	-	-	-	✓	-	-
203.6	0.42	-	-	✓	✓	✓	✓
154	0.45	-	-	-	✓	-	-
93.8	0.49	-	-	✓	-	✓	-
219.8	0.32	-	-	-	-	-	✓
179.2	0.45	-	-	-	✓	✓✓	-
151	0.49	-	-	✓✓	-	✓✓	-
170.2	0.41	-	-	-	✓	✓	-
164.4	0.42	-	-	-	✓	✓	-
199.4	0.45	-	-	✓	✓	✓	-
3.6	0.49	-	-	-	✓	-	-
127.2	0.45	-	-	-	✓	✓	✓
Total Landslides		**0**	**0**	**8**	**14**	**15**	**5**

Dynamic Probability of Landslide for triggering and antecedent conditions





From landslide susceptibility i.e., a static probability estimated either from historical dataset or from simulations, the dynamic probability is assessed as landslide probability conditional to triggering and antecedent condition. The Bayes theorem equation for the conditional probability of landslide is:

$$P(L|H \text{ or } \theta) = \frac{P(H \text{ or } \theta|L) \times P(L)}{P(H \text{ or } \theta)}$$

where $P(H \text{ or } \theta|L)$ is the conditional probability of variable H or θ given the landslide events, $P(L)$ is the prior probability of landslide events, and $P(H \text{ or } \theta)$ is the marginal probability of variable H or θ. The terms involved in above equation were estimated as;

$$P(H \text{ or } \theta\,|L) = \frac{\text{No. of Landslide Events with Given H or } \theta}{\text{Total No. of Landslide Events}}$$

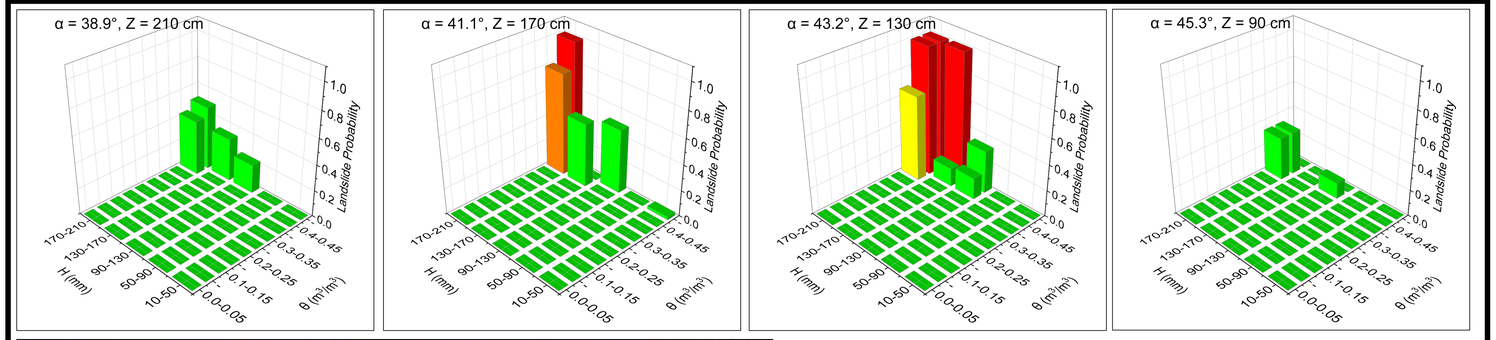
$$P(L) = \frac{\text{No. of Landslide Events}}{\text{Total No. of Events}}$$

$$P(H \text{ or } \theta) = \frac{\text{Total No. of Events with Given H or } \theta}{\text{Total No. of Events}}$$

Sharing is encouraged

ONSITE ATTENDEE

Dynamic Probability of Landslide for combined effect of triggering and antecedent conditions



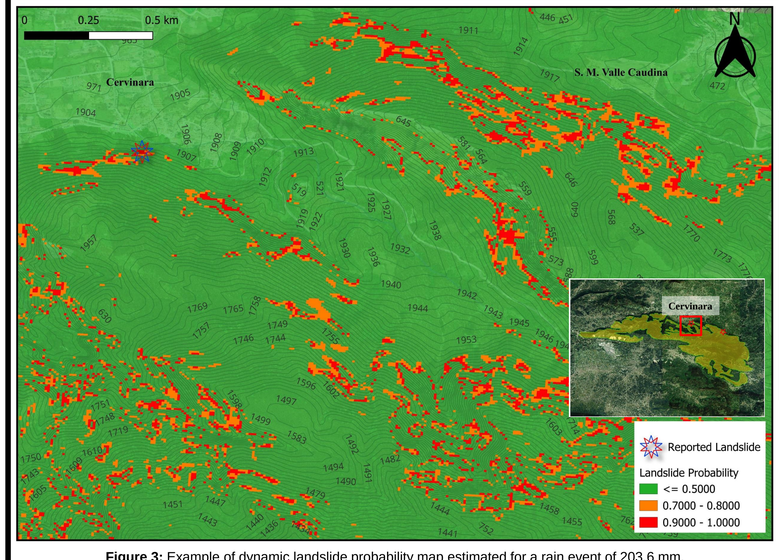


Figure 3: Example of dynamic landslide probability map estimated for a rain event of 203.6 mm.

Here, the conditional probability of landslide was assessed by considering the combined effects of rainfall and the antecedent soil moisture. The Bayes theorem equation can be expressed as:

$$P(L|H \cap \theta) = \frac{P(H \cap \theta|L) \times P(L)}{P(H \cap \theta)}$$

Results

- Out of 822 rainfall events in 18 years, 19 rainfall events triggered landslides.
- All the landslide events occurred with antecedent soil moisture ≥ 0.3.
- The rainfall-induced landslide catalogue reports 13 landslides for our study area in 18 years (Peruccacci et al., 2023). Out of which 7 landslides were correctly matched with landslides from simulations.
- The probability for landslide occurrence is zero in mild slopes (<37°), and it is small in very steep slopes (>44°).
- In the considered geomorphological context, rainfall is the major factor controlling landslide triggering, compared to antecedent soil moisture. The maximum probability in case of rainfall ≈ 0.9 while it is ≈ 0.1 for antecedent soil moisture.
- However, the combined effect of triggering rainfall and antecedent soil moisture acts as a probability enhancer, allowing the assessment of the most probable locations of landslide occurrence.

The rain event of 203.6 mm, started on 01.01.2009 (04:00) and ended on 03.01.2009 (21:00), caused following two landslides:

- In Cervinara (Avellino) on 03.01.2009
- In Pannarano (Benvento) on 10.01.2009

(Figure 3)

References

1. De Vita, P., Agrello, D., & Ambrosino, F. (2006). Landslide susceptibility assessment in ash-fall pyroclastic deposits surrounding Mount Somma-Vesuvius: Application of geophysical surveys for soil thickness mapping. Journal of Applied Geophysics, 59(2), 126-139.
2. Greco R, Marino P, Santonastaso GF, Damiano E. Interaction between perched epikarst aquifer and unsaturated soil cover in the initiation of shallow landslides in pyroclastic soils. Water 2018, 10, 948.
3. Marino P, Comegna L, Damiano E, Olivares L, Greco R (2020). Monitoring the Hydrological Balance of a Landslide-Prone Slope Covered by Pyroclastic Deposits over Limestone Fractured Bedrock. Water 12(12): 3309.
4. Peruccacci, S., Gariano, S. L., Melillo, M., Solimano, M., Guzzetti, F., & Brunetti, M. T. (2023). ITALICA, an extensive and accurate spatio-temporal catalogue of rainfall-induced landslides in Italy. Earth System Science Data Discussions, 2023, 1-24.
5. Zhao, B., Dai, Q., Zhuo, L., Zhu, S., Shen, Q., & Han, D. (2021). Assessing the potential of different satellite soil moisture products in landslide hazard assessment. Remote Sensing of Environment, 264, 112583.