TYPE Editorial
PUBLISHED 10 February 2025
DOI 10.3389/feart.2025.1556839

Editorial: Environmental processes driving to slope failures: investigations, monitoring, and modelling through natural field laboratories

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KEYWORDS

landslides, slope stability, environmental forcings, weathering, temperature changes, rainfalls, climate actions

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RECEIVED 07 January 2025
ACCEPTED 27 January 2025
PUBLISHED 10 February 2025

CITATION
Marmoni GM, Blahůt J, Martino S and Bakun-Mazor D (2025) Editorial: Environmental processes driving to slope failures: investigations, monitoring, and modelling through natural field laboratories. *Front. Earth Sci.* 13:1556839. doi: 10.3389/feart.2025.1556839

Editorial on the Research Topic
Environmental processes driving to slope failures: investigations, monitoring, and modelling through natural field laboratories

Geological and meteo-climatic factors significantly contribute to landslides, as they can drive the slopes to failures, gradually or abruptly changing, over medium-to long-term timescales, and pre-existing conditions. These factors have been categorised in the literature as predisposing, preparatory, and triggering ones (Gunzburger et al., 2005) which are generally studied separately due to a lack of comprehensive datasets that could connect causal relationships among them. More properly, predisposing factors can be related to time-independent conditions and/or parameters that control the geological, geomorphological and geomechanical framework where the landslide process can evolve, i.e., the overall compatibility. Moreover, in an intrinsically stable slope system, the anthropic actions (e.g., a slope cut) can newly predispose and play a destabilising role when they dive to failures, in case of external acting forces (Figure 1). More in particular, preparatory actions belong to processes that evolve or change their intensity over time (e.g., weathering or mechanical fatigue), leading the slopes to progressive unstable conditions. On the other hand, triggers correspond to sudden actions at the timescale of the landslide phenomena able to equalise acting and resisting forces or making the system progressively more unstable (Popescu, 2002), up to reaching the ultimate failure condition (Figure 1). In this sense low magnitude triggers, which represent the most frequent and therefore the most hazardous ones, can become more effective if the system has evolved and is adequately prepared.

In this framework, to reliably model future landslide scenarios, it is thus essential to systematically investigate the above-mentioned preparatory processes through extensive, multi-parametric monitoring at natural sites or field or in-house laboratories. If informed on data from monitored parameters, advanced numerical models can represent reliable tools for future previsional analysis. Understanding the influence of time-dependent processes

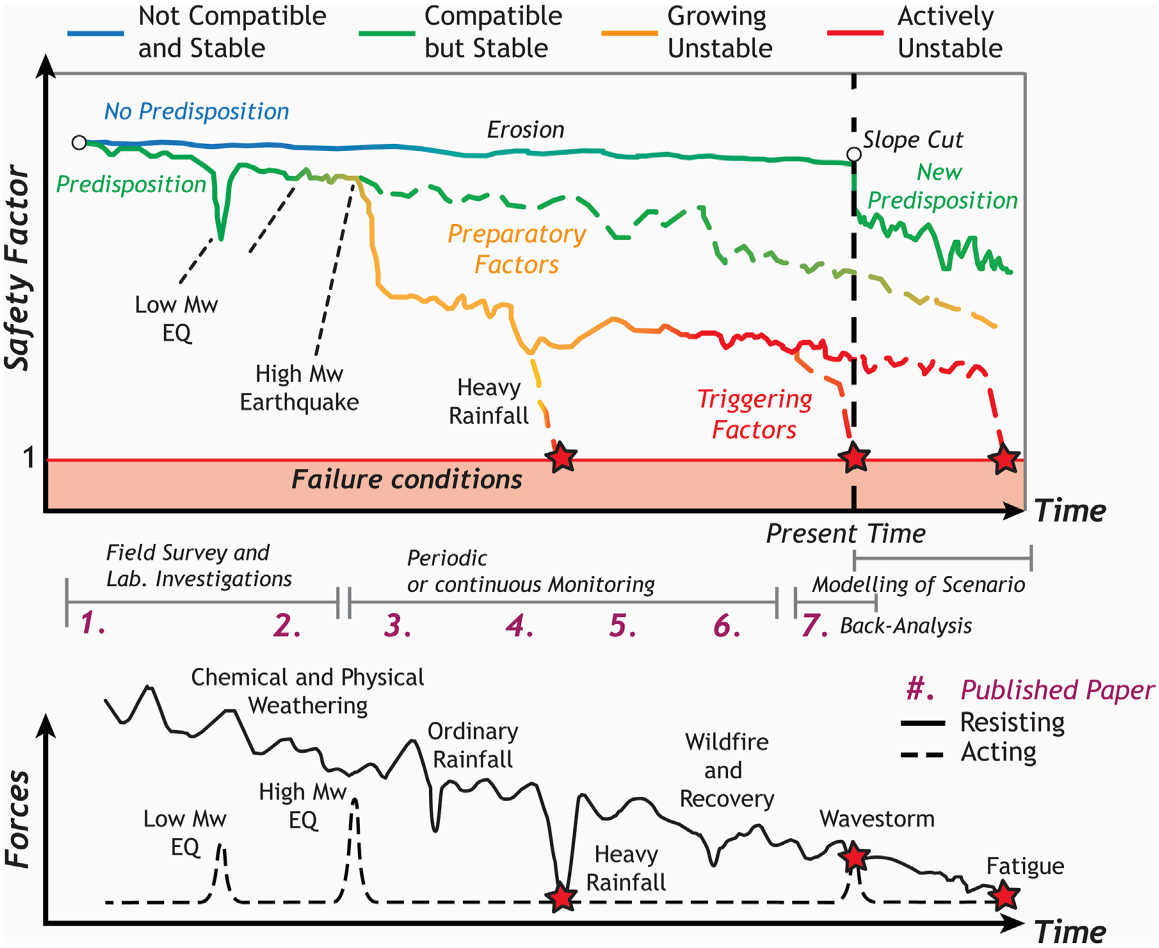

FIGURE 1
Conceptual scheme of landslide evolution, as influenced by predisposing, preparatory, and triggering factors (modified from Gunzburger et al., 2005; Popescu, 2002). The sequence highlights how various methods and approaches can contribute to monitoring and understanding the process, ultimately aiming to predict future scenarios. The research papers published in this Research Topic are cited in the scheme according to the methods and approaches they adopt and the causative factors they address.

operating in a time frame of hundreds or thousands of years as mechanical fatigue — such as temperature oscillations, changes in the ordinary and intense rainfall regimes, sea level rise, or sea wave impacts – is critical to assess the landslide risks in a changing climate context accurately.

Within this conceptual framework, a deeper understanding of damage propagation within rock matrices or joint networks provides a more constrained interpretation of the time-dependent effects that lead to mechanical degradation and weakening of natural systems and that anticipate failure. This would support the deepening of principles of a subcritical and progressive rock mass failure, enabling its reproduction through numerical approaches and proper digital twins. The scientific community that deals with landslides and associated risk has in the last decade been particularly committed to shifting the focus of research from analytical approaches, aimed at hazard definition, towards quantitative analyses of scenarios, which are more markedly functional for the adoption of risk mitigation and resilience strategies of the exposed communities.

From this perspective, several studies demonstrated that the connection between laboratory practices, monitoring, and modelling represents a significant tool for understanding the mechanical behaviour of geomaterials across different scales and is crucial for projecting the future evolution of natural processes, including landslides, in a forward-scenario perspective.

To this end, creating and training learning systems based on data-informed approaches that find their best expression in multiparametric monitoring and machine and deep learning methods is necessary. The application of artificial intelligence to landslide risk assessment is a promising and reliable tool for future advancements in risk mitigation studies.

In this Research Topic, we collect articles covering different approaches, including laboratory and advanced field surveys. Articles are numbered and reported in the sketch of Figure 1.

- Laboratory (laboratory to a rock-slope scale)

The study on the Lanniqing landslide in Southwest China by Xu et al. (#1 in Figure 1) examined particle size characteristics using various preprocessing methods and a laser particle size analyser. The research revealed that the coarsening of particles and increased clay content in the sliding zone indicate multiple shear and compression events. The study concluded that traffic load, slope cutting, and rainfall contribute to landslide occurrence, with high clay content and low permeability leading to excessive pore water pressure and mineral lubrication.

The study on Ili loess in China by Lai et al. (#2 in Figure 1) investigated the effects of wet and dry cycles on soil properties using direct shear tests, triaxial shear tests, and scanning electron microscopy. The study found that shear strength decreased with wet-dry cycles, with triaxial tests showing higher shear strength and cohesion but lower internal friction angles than direct shear tests. Microstructural changes were identified as the primary cause of shear strength deterioration, providing valuable insights for engineering in Central Asia.

- Monitoring (from real testbed towards digital twins)

Three papers report studies on monitoring environmental processes driving slope failures, focusing on temperature fluctuations and their effects on rock weathering and landslide dynamics. A year-long study in Hamilton, Canada by Gage et al. (#3 in Figure 1), examined thermomechanical weathering in temperate climates, revealing minute-scale temperature oscillations that magnify over time and produce significant thermal stress. Seasonality and site-specific characteristics influence the rock thermal regime, with thermomechanical weathering potential highest in spring.

Fiorucci et al. (#4 in Figure 1) carried out research in the Cinque Terre National Park, Italy, over 2 years to investigate hydrological dynamics in terraced landscapes. Results showed that coarse-grained, anthropically remoulded soils favour rapid rainwater infiltration, causing sharp changes in soil volumetric water content and pore water pressure. Seasonal trends of alternating slow drying and fast wetting were observed.

The study by Narcisi et al. (#5 in Figure 1) in the western Alps of Piemonte, Italy, discusses the relationship between climatic factors and displacement rates of three slow-moving landslides over 30 years (1991–2020). This research combined *in situ* monitoring and remote sensing techniques, demonstrating correlations between significant meteorological events and variations in displacement time series.

- Modelling (Numerical models towards the analysis of scenarios)

The paper by Chicco et al. (Paper #6 in Figure 1) analyses the impact of wildfires on soil properties in the Susa Valley, Italy. Through controlled fire simulations and numerical modelling, they found that significant temperature increases in the soil are limited to a shallow depth. Field tests showed that at 2 cm below the surface, temperatures never exceeded 70°C, suggesting minimal impact on soil components and properties at greater depths.

The second paper, by Jensen et al. (#7 in Figure 1), investigates the use of seismic resonance and surface displacement measurements for landslide monitoring at Courthouse Mesa, Utah. Over 3 years, researchers observed crack aperture increases of 2–4 mm/year, with significant seasonal variations in modal parameters driven primarily by temperature changes. This study suggests a thermal wedging-ratcheting mechanism and demonstrates the value of combining seismic resonance and crack aperture data for improved rock slope instability characterisation and monitoring.

The editors hope that this volume provides valuable scientific insights and serves as a source of inspiration for future research. We extend our best wishes to readers for a thought-provoking and enriching experience.

Author contributions

GM: Conceptualization, Data curation, Project administration, Supervision, Writing–original draft, Writing–review and editing. JB: Conceptualization, Data curation, Writing–original draft, Writing–review and editing. SM: Conceptualization, Data curation, Writing–original draft, Writing–review and editing. DB-M: Conceptualization, Data curation, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

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