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Landslide science for sustainable development



Introduction

Landslide science plays a critical role in sustainable development by contributing to risk assessment, disaster risk reduction, and the protection of communities, infrastructure, and ecosystems.

Landslide risk reduction is a key objective of the UN Sendai Framework for Disaster Risk Reduction 2015–2030 and contributes significantly to the United Nations Sustainable Development Goals (SDGs) (Alcántara-Ayala and Sassa 2021; 2023).

The impact of landslides is often underestimated as they are usually associated with several other natural hazards such as heavy rainfall and flooding, earthquakes, volcanic activity, coastal erosion and tsunamis, forest fires, and glacial and permafrost melt.

Understanding the processes and mechanisms of landslides contributes to sustainable development by providing insights into the causes, effects, and prevention of landslides. It helps us to understand the geological, hydrological, and meteorological factors that contribute to landslides. This understanding can help us identify areas that are prone to landslides and develop measures to mitigate the risks.

Landslide science and technologies can help us develop early warning systems that can alert communities to the risk of landslides. These systems can include monitoring rainfall, ground movement, and other indicators of landslide activity.

Landslide experts can help design sustainable, landslide-resistant infrastructure. This includes constructing roads, bridges, and buildings that are resilient to ground movement and slope movement. They can also help with land use planning by identifying areas that are susceptible to landslides and helping to develop guidelines for safe land use in these areas.

Landslide risk reduction policies can support the development of sustainable land management practices that can help prevent landslides. These include measures such as reforestation, erosion control, and soil stabilization.

Landslide risk reduction can benefit from the knowledge and expertise of local communities, who often have a deep understanding of the landscape and the risks of landslides. Collaborating with local communities can help ensure that measures to mitigate the risks of landslides are effective and sustainable, by sharing knowledge and best practices with other disciplines and stakeholders, sharing information on the causes and mechanisms of landslides, as well as successful landslide risk prevention and mitigation strategies.

Landslide risk reduction can benefit from technological advances and innovations, such as remote sensing, artificial intelligence, and machine learning. These tools can help improve our understanding of landslides and develop more effective measures to prevent and mitigate their risks.

Overall, landslide science can play an important role in promoting sustainable development by helping to mitigate the landslide

risk and minimizing their impacts on communities and the environment.

WLF6 and key themes

Landslide science for sustainable development is the theme of the 6th World Landslide Forum (WLF6; <https://wlf6.org>) that was held from November 14–17, 2023, in Florence at the Palazzo dei Congressi.

The 6th World Landslide Forum, gathered experts, researchers, practitioners, and policymakers from around the globe to address one of the pressing natural hazards of our time: landslides. This forum served as a crucial platform for knowledge exchange, collaboration, and innovation in the field of landslide research and mitigation.

The forum was a direct contribution to the Kyoto 2020 Commitment for global promotion of understanding and reducing landslide disaster risk (KLC2020) (Sassa 2021), a commitment to the Sendai Landslide Partnerships 2015–2025 (Sassa 2015), the Sendai Framework for Disaster Risk Reduction 2015–2030, the 2030 Agenda Sustainable Development Goals, the New Urban Agenda, and the Paris Agreement (Casagli et al. 2022, 2023).

The forum addressed key aspects related to landslide analysis, landslide monitoring and early warning, landslide modeling, landslide hazard and risk assessment, mitigation techniques, landslide triggering mechanism, and climate change.

The 6th World Landslide Forum was attended by a broad international audience interested in landslide disaster risk reduction: research and academic institutions, UN organizations, EU institutions and agencies, national governments and local authorities, non-governmental organizations with an interest in and activities related to disaster risk reduction, international and national civil protection and disaster relief organizations and agencies, and the private sector engaged in research, development and practical application of landslide risk reduction technologies and solutions. In particular, the WLF6 was attended by more than 1200 participants from 61 countries. A total of 853 abstracts were submitted, 643 oral presentations, and 210 e-posters (Casagli et al. 2023).

One of the central themes of the forum was the impact of climate change on landslide incidence and severity. Participants highlighted the increasing frequency of extreme weather events, such as heavy rainfall and rapid snowmelt, which exacerbate slope instability. Innovative research presentations showcased advances in remote sensing technology and geospatial analysis, offering new tools for early warning systems that could significantly improve landslide preparedness and response.

The forum also featured discussions on community engagement and the importance of incorporating local knowledge into landslide risk management strategies. Case studies from various regions illustrated successful community-led initiatives that have fostered resilience against landslides. This grassroots approach not

only empowers communities but also enhances the effectiveness of risk reduction measures.

Furthermore, the role of policy in landslide risk management emerged as a critical point of discussion. Experts advocated for stronger legislative frameworks that promote sustainable land-use practices and enforce strict building codes in landslide-prone areas. The importance of integrating landslide risk assessments into urban planning was emphasized, as cities worldwide grapple with increasing development pressures in vulnerable landscapes.

The forum also served as a launchpad for innovative technologies in landslide monitoring and risk assessment. Participants were introduced to cutting-edge tools such as remote sensing, drones, and machine learning algorithms useful in analyzing historical landslide data, improving predictive modeling, and identifying potential hazard zones. Presentations highlighted successful implementations of these technologies in various countries, demonstrating how they can provide real-time data and improve predictive capabilities. These technological advancements promise to enhance our understanding of landslide dynamics and aid in the development of more effective mitigation strategies.

One of the forum's most valuable aspects was the opportunity for networking and collaboration. Participants engaged in lively discussions, forging partnerships that promise to drive future research and initiatives. The interdisciplinary nature of the forum facilitated rich exchanges of ideas among geologists, engineers, urban planners, environmental scientists, and community leaders.

The papers gathered in this thematic issue are a relevant showcase of the different case studies and methodological approaches presented during the Forum, dealing with landslide hazard and risk management, remote sensing, and early warning.

Two papers focus on specific types of landslides. The work by Šegina et al. (2024) investigated the triggering mechanisms of more than 2100 small rockfalls that occurred in 2021 in Slovenia, Europe, along the 51,000 km national road network. They analyzed the spatial and temporal characteristics of rockfalls as well as the triggering mechanisms of their occurrence based on different weather scenarios. Among the scenarios tested, the winter scenario, which includes a combination of antecedent precipitation, snowmelt, and freeze–thaw cycles a few days before the event, was able to predict 72% of the events in the cold season. In Veloso et al. (2024), the triggering and dynamics of a debris flow in the Toque-Toque Grande catchment are analyzed instead. The analysis is based on numerical modeling and the risk that debris flows pose to pipeline crossings using the Debris-flow Hazard Index method. Computational modeling helped to visualize the flow dynamics and provided a crucial understanding of the dynamics of the flow.

The interaction of landslides with other natural hazards such as earthquakes, volcanoes, and tsunamis is an important issue for the landslide community. The work of Pouth Nkoma et al. (2024) deals with landslide hazard and risk assessment in volcanic areas. The methodological multi-hazard approach is based on the combination of numerical modelling, remote sensing, and field data to identify the areas with the highest risk to population and activities. Li et al. (2024) propose a framework based on quantitative risk analysis to effectively and sustainably manage the risk of landslide–tsunami hazard chains (LTHC). Landslide-triggered tsunamis in reservoirs often pose a greater risk than landslides themselves. More than 5000 landslides have occurred on the banks of the Three

Gorges Reservoir in China, some of which can trigger tsunamis. The framework includes decision-making based on risk characteristics and local economics, a strategy to select an optimal plan to control risk through cost–benefit analyses that consider long-term effectiveness and negative impacts, and dynamic management through iterative cycles to reassess and control risk.

Three papers refer to specific case studies on landslides. Kerverdo et al. (2024) investigate the sediment dynamics after the extreme storm Alex in October 2020 in the Roya Valley and its tributaries in the Alpes-Maritimes region, France. This event led to unprecedented rainfall and caused extensive flooding and erosion in the region. The study uses aerial and satellite imagery, digital elevation models, and field surveys to quantify sediment mobilization and its impact on the Viévol alluvial fan in the Roya Valley. Elkharrat et al. (2024) investigate several complex paleo-landslides on the Larzac Plateau in the Occitanie region (southern France), which involved the failure of Jurassic carbonate series overlying Triassic clays. The study, which was carried out using field and remote sensing surveys, revealed a complex mode of failure; toppling and spreading of the rock combined with creep deformation of the underlying clay layer. The dating of two of the studied landslides indicates triggering in the mid-Holocene when climatic variations were responsible for the heavy rainfall that may have triggered the investigated landslides. Mulaya et al. (2024) conducted an analysis of the catastrophic landslide of December 3, 2023, which claimed 89 lives in the town of Hanang in northern Tanzania. An integrated approach based on geological fieldwork, structural measurements, and SRTM-DEM data made it possible to reconstruct the geological and geomorphological features of the landslide. Understanding the complex interactions between geological, seismic, hydrological, and topographical factors that trigger catastrophic landslides is crucial for the formulation of effective monitoring and mitigation strategies.

Bozzolan et al. (2024a, b) showed the potential of using huge libraries of synthetic landslide simulations representing different topographies, soil properties, rainfall factors, and housing characteristics to identify slope failure “hotspots,” synthetic rainfall thresholds, and the environmental factors that most strongly influence landslide occurrence under different topographies and land covers.

Liu et al. (2024) use artificial intelligence, and particularly a neural network with short-term memory (LSTM) neural network to predict slope displacement taking into account precipitation, snow, and slope movements. The parameters of snow accumulation are determined by image processing algorithms. The method was tested on a deep-seated landslide in Italy. The detection of snow and its inclusion in the prediction model proves to be an important aspect for considering the impact of winter snowfall on landslide movement. The authors propose an innovative strategy for other case studies at high altitudes where there are no precise instruments to record snow precipitation.

Pareek et al. (2024) address an important issue related to the usability and reliability of landslide susceptibility maps. The paper focuses on several landslide susceptibility maps produced using different methods for the same area and evaluates their posterior predictive ability. To analyze the usability, the authors conducted a literature review and interviewed end users and map producers. To evaluate the predictive capability, an independent landslide inventory was created using deep learning, followed by map validation.

The study highlights the need for purpose-oriented landslide susceptibility mapping and a subsequent assessment of the predictive capabilities of these maps to fulfill the respective purpose.

Conclusion: a call to action

The 6th World Landslide Forum was more than just a gathering of experts; it was a call to action. As we reflect on the discussions and findings presented in Florence, it becomes clear that addressing landslide risk requires a holistic and integrated approach that combines scientific research, technological innovation, policy reform, and community engagement.

For this reason, the landslide community gathered in Florence during the WLF6 adopted the Florence Declaration (Casagli et al. 2024) which commits to:

- Foster understanding and reduce the risk of landslide disasters worldwide;
- Share information and best practices, support research and development of new technologies, and build capacity at all levels to improve preparedness and response to a landslide disaster;
- Pursue and support the further implementation of the Kyoto 2020 Commitment for Global Promotion of Understanding and Reducing Landslide Disaster Risk (KLC2020) by continuing to reduce the risk and impact of landslides on the environment and society, and working with all stakeholders to make further progress in the coming years;
- Work together to raise awareness of the risks posed by landslides and promote the implementation of effective mitigation and adaptation measures, including early warning systems, safe land use planning, sustainable land management practices, risk education, and awareness;
- Initiate and promote the process to organize the 7th World Landslide Forum (WLF7) in 2026 by mobilizing a medium and long-term global alliance to accelerate and incentivize landslide risk reduction actions as defined in KLC2020; and
- Submit the 2023 Florence Declaration on Landslide Risk Reduction to UNDRR for endorsement as a further commitment from the global landslide community to the Sendai Framework for Disaster Risk Reduction 2015–2030.

In an era marked by environmental uncertainties, the insights and collaborations fostered at this forum are essential in building a more resilient future. The urgency to act is undeniable, and the forum has provided a robust foundation for ongoing dialogue and action. As we move forward, it is imperative that we harness the collective knowledge and commitment of the global community to mitigate landslide risks and safeguard vulnerable populations.

Declarations

Competing interests The authors declare no competing interests.

References

Alcántara-Ayala I, Sassa K (2021) Contribution of the international consortium on landslides to the implementation of the Sendai framework

for disaster risk reduction: engraining to the science and technology roadmap. *Landslides* 18(1):21–29

Alcántara-Ayala I, Sassa K (2023) Landslide risk management: from hazard to disaster risk reduction. *Landslides* 20:2031–2037

Bozzolan E, Holcombe E, Pianosi F, Wagener T (2024a) Synthetic libraries of urban landslide simulations to identify slope failure hotspots and drivers across spatial scales and landscapes. *Landslides*. <https://doi.org/10.1007/s10346-024-02327-4>

Bozzolan E, Holcombe E, Pianosi F, Wagener T (2024b) Correction to: synthetic libraries of urban landslide simulations to identify slope failure hotspots and drivers across spatial scales and landscapes. *Landslides*. <https://doi.org/10.1007/s10346-024-02376-9>

Casagli N, Canuti P, Sassa K, Tofani V (2022) The Sixth World Landslide Forum (WLF6) on November 14–17th, 2023, Florence. *Italy Landslides* 19(10):2539–2545

Casagli N, Canuti P, Sassa K, Tofani V (2023) The Sixth World Landslide Forum (WLF6): call for abstracts. *Landslides* 20(02):707–716

Casagli N, Canuti P, Sassa K, Tofani V (2024) The Sixth World Landslide Forum (WLF6), Florence, 2023. *Landslides* 21:1161–1172

Elkharrat K, Homberg C, Lafuerza S et al (2024) Study cases of complex paleo-landslides in the south of France. *Landslides*. <https://doi.org/10.1007/s10346-024-02329-2>

Kerverdo R, Lafuerza S, Gorini C et al (2024) The impact of Storm Alex on the Vievola catchment: a quantitative analysis of sediment volume and morphological changes in the Roya River tributaries. *Landslides*. <https://doi.org/10.1007/s10346-024-02361-2>

Li Y, Xie X, Jin B et al (2024) Comprehensive risk management of reservoir landslide-tsunami hazard chains: a case study of the Liangshuijiang landslide in the Three Gorges Reservoir area. *Landslides*. <https://doi.org/10.1007/s10346-024-02283-z>

Liu Y, Brezzi L, Liang Z, Gabrieli F, Zhou Z (2024) Cola S (2024) Image analysis and LSTM methods for forecasting surficial displacements of a landslide triggered by snowfall and rainfall. *Landslides*. <https://doi.org/10.1007/s10346-024-02328-3>

Mulaya E, Gama R, Kimani C et al (2024) The triggering factors on the 3rd December 2023 catastrophic landslide in the Hanang area, northern Tanzania. *Landslides*. <https://doi.org/10.1007/s10346-024-02386-7>

Pareek T, Bhuyan K, van Westen C, Rajaneesh A, Sajinkumar KS, Lombardo L (2024) Analyzing the posterior predictive capability and usability of landslide susceptibility maps: a case of Kerala, India. *Landslides*. <https://doi.org/10.1007/s10346-024-02389-4>

PouthNkoma AM, Meli'i JL, Gweth MMA et al (2024) An approach to assess hazards in the vicinity of mountain and volcanic areas. *Landslides*. <https://doi.org/10.1007/s10346-024-02278-w>

Sassa K (2015) ISDR-ICL Sendai Partnerships 2015–2025 for global promotion of understanding and reducing landslide disaster risk. *Landslides* 12(4):631–640

Sassa K (2021) The Kyoto Landslide Commitment 2020: launched. *Landslides* 18(1):5–20

Šegina E, JemecAuflič M, Mikoš M et al (2024) A preliminary investigation of the small rockfall triggering conditions along a road network in Slovenia. *Landslides*. <https://doi.org/10.1007/s10346-024-02302-2>

VelosoVQ, Reis FAVG, Cabral V et al (2024) Application of the debris-flow hazard index for pipelines in the context of the hydrogeological disaster of February 2023 in São Sebastião, Serra do Mar, Brazil. *Landslides*. <https://doi.org/10.1007/s10346-024-02319-4>

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