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REVIEW

Landslide risk management in Italy: practices, advances, and future directions

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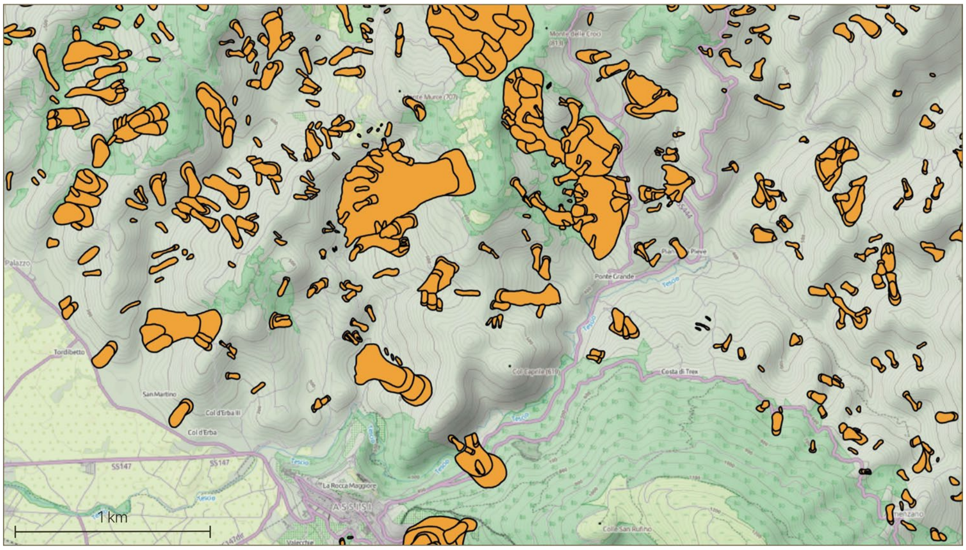
Abstract

Landslides are globally pervasive natural hazards posing growing risks under intensifying climate and land-use pressures. Italy, the most landslide-prone country in Europe, has achieved substantial progress in landslide hazard identification, mapping, modelling, forecasting, and risk reduction. Yet, critical gaps remain in inventory completeness and representativeness, medium- to long-term forecasting, monitoring coverage, vulnerability assessment, governance, and public awareness. Drawing on insights from a 2025 workshop organized by the *Accademia Nazionale dei Lincei*, this paper synthesizes current knowledge, practice, and technological capacity for landslide risk management in Italy, identifies persistent challenges, and outlines key priorities for scientific, technical, institutional, and organizational progress toward more effective risk management. We call for a coordinated strategy that integrates improved inventories, real-time monitoring, dynamic modelling, and data accessibility, supported by institutional reform and cultural change. While grounded in the Italian context, the findings and recommendations are broadly applicable to other landslide-prone countries and regions worldwide.

Graphical Abstract



Keywords Landslide · Risk management · Innovation · Italy

Extended author information available on the last page of the article

Fig. 1 Examples of recent landslides in Italy. (**a**) Large rock fall, Livergnano, Bologna. (**b**) Rock slide, Siepi di San Giovanni, Borgo di Tossignano, Bologna. (**c**) Earth flow, San Benedetto Val di Sambro, Bologna. (**d**) Soil-slips and debris avalanches, Ciola Araldi, Roncofreddo, Forlì-Cesena. (**e**) Debris flow, San Vito di Cadore, Belluno. (**f**) Rock slide, Maierato, Vibo Valentia, 15/2/2010. Arrows in the images provide an approximate visual indication of the distances. Photograph credits: a, b, c, Matteo Berti; d, Alessandro Sarretta; f, Fausto Guzzetti. For terminology see Hungr et al. (2014)

1 Introduction

A landslide is the movement of a mass of rock, soil, or debris down a slope (Cruden 1991). Landslides occur across all continents, beneath the sea, and on planets and moons. On Earth, landslides affect about 17% of the landmass (Jia et al. 2021), making them one of the most geographically widespread natural hazards. Landslides encompass a broad spectrum of movement types (Fig. 1) – falls, topples, slides, spreads, and flows (Highland and Johnson 2004; Hungr et al. 2014) – which may occur individually or in combinations, simultaneously or through successive stages of movement. The geometric and kinematic variability of landslides is vast. The areal extent of single landslides spans more than 12 orders of magnitude – from less than a square meter of a soil slip to hundreds of thousands of square kilometres of submarine landslides (Smith et al. 2004; Karstens et al. 2023). The volume of landslides spans more than 16 orders of magnitude – from less than a cubic decimetre of a small rockfall to thousands of cubic kilometres of terrestrial (Karstens et al. 2023) and submarine (Smith et al. 2004; Karstens et al. 2023) failures. The velocity of landslides ranges across 12 orders of magnitude – from less than millimetres per year to hundreds of kilometres per hour (Voight et al. 1983; Cruden and Varnes 1996). Landslides may occur as isolated slope failures, in small clusters within localized areas, or as widespread, disturbed phenomena affecting large regions during extreme triggering conditions. Landslide triggers include rainfall, snowmelt, seismic shaking, volcanic activity, and human actions, or lack of actions (Wieczorek 1996). The societal consequences of landslides are profound. Between 1995 and 2014, more than 160,000 people were killed by landslides globally (Haque et al. 2019), and more than 8% of the global population resides in areas susceptible to landslides, placing hundreds of millions at risk (Jia et al. 2021). As climate warms and land-use pressures intensify, understanding the spatial and temporal dynamics of landslides is critical for effective hazard assessment and risk management strategies. At the international level, the Kyoto Landslide Commitment 2020—KLC2020 (Sassa 2019**)** defines a strategic framework for reducing landslide disaster risk worldwide. Building on the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR. 2025), it seeks to equip governments, institutions, and practitioners across sectors with the knowledge, tools, and collaborative platforms needed to strengthen landslide risk management and foster long-term resilience at the global scale.

To mark the 42nd World Environment Day on June 5th, 2025, the *Accademia Nazionale dei Lincei* organised a workshop on landslides in Italy, bringing together around 80 landslide experts. The meeting critically examined the state of knowledge and technological capacity for landslide identification, mapping, monitoring, and forecasting, and assessed barriers to the effective application of existing and new tools for landslide risk assessment and reduction, in Italy. It also sought to identify gaps in science, technology, and governance, and to define priorities for research, innovation, and organisational improvement. This paper synthesises current knowledge and capacities, highlights key challenges in landslide risk management in Italy, and outlines directions for future research and governance, set against the backdrop of ongoing and foreseen climatic, environmental, economic, and societal change. Albeit the focus of this paper is on Italy, many of the conclusions and recommendations are general, and applicable in other regions and countries.

2 Relevance and impact of landslides in Italy

In Italy, more than 630,000 landslides have been mapped (https://idrogeo.isprambiente.it/), an average density exceeding three landslides per square kilometre, making the country the most landslide-prone in Europe. The age of the vast majority of these landslides is unknown. Recent events, however, reveal that the true number of landslides is largely underestimated (Berti et al. 2025). Between 1974 and 2023, landslides caused 1,070 fatalities and missing persons, over 1,400 injuries, and more than 138,000 displaced persons across 2,681 localities in 1,563 municipalities, affecting all Italian regions (Bianchi and Salvati 2025). Economic costs of landslides are poorly quantified, but the available estimates confirm their relevance. The Commissione De Marchi (1970) calculated a need of 429 billion Italian Lire – equivalent to approximately € 4.4 billion (2025) – for landslide and snow avalanche mitigation for the period 1970–2000. This proved to be an underestimate. Later, Catenacci (1992) estimated 33,299 billion Lire – equivalent to approximately € 350 billion (2025) – spent on geo-hydrological emergencies, including landslides, between 1944 and 1990. More recently, ANCE / CRESME (2012) estimated € 61.5 billion in damages from geo-hydrological hazards, including landslides, between 1944 and 2012. These figures exclude indirect and prevention costs that are difficult to estimate. The National Register of Interventions for Soil Defence (RENDIS, http://www.rendis.isprambiente.it/; Gallozzi et al. 2020) reported € 2.26 billion spent on landslide mitigation between 1999 and 2019.

3 Knowledge and technological capacities

In Italy, as in many other countries and regions, scientific knowledge and technological innovation have provided essential tools in advancing landslide risk assessment and mitigation. Over recent decades, a number of critical advancements have been achieved. One of the most significant is the establishment of comprehensive mapping and inventories: in Italy, the *Inventario dei Fenomeni Franosi in Italia* (IFFI, Trigila et al. 2010; https://www.progettoiffi.isprambiente.it/), which as of October 2025 contains information on more than 636,000 landslides.

This key evidence has revealed that landslides are not isolated geomorphological anomalies scattered across the landscape but rather ubiquitous processes that play a fundamental role in landscape evolution. As a result, the focus of risk management has shifted away from localized, engineering interventions toward broader strategies for regional and basin-scale planning. We emphasise that managing the risk associated with single landslides is fundamentally different from managing landslide-related processes across wider spatial and temporal scales, as the two tasks require distinct – yet complementary – forms of knowledge, methodological frameworks, and resource allocations.

Forecasting capacities have also improved, particularly in the short term (Guzzetti et al. 2020; Mondini et al. 2023): rainfall induced landslides can now be predicted hours to days in advance, and the potential for anticipating certain earthquake-induced failures has also increased. Monitoring has benefitted from rapid technological progress, including advances in sensors, ground-based and satellite remote sensing, telecommunications, computational capacity, and artificial intelligence (Casagli et al. 2023). These tools have expanded monitoring coverage and enhanced early detection, occasionally allowing the anticipation of failure onset (Intrieri et al. 2019). In parallel, modelling efforts – mechanistic, statistical, data driven, and combined – have improved, permitting more sophisticated simulations of landslide kinematics as well as susceptibility assessments from local to national scales (Reichenbach et al. 2018). Another innovation has been the production of quantitative, national-scale risk assessments for the Italian population that provide a measurable baseline of exposure and potential impact (Rossi et al. 2019) and examine the role of gender and age on fatal landslide accidents (Salvati et al. 2018). Finally, governance (Kaufmann et al. 2011) instruments have evolved: normative frameworks have strengthened early warning capabilities, contributing to a reduction in fatalities, and hazard and risk zoning maps have been developed, though their effectiveness and application remain uneven across different Regions, Provinces, and River basin authorities.

4 Challenges

Despite the remarkable progress achieved in recent decades, significant challenges persist in the field of landslide hazard and risk assessment and management.

One of the most pressing concerns is the incompleteness and lack of representativeness of landslide inventories (Guzzetti et al. 2012; Mondini et al. 2021). The catastrophic event of May 2023 in Emilia-Romagna, which produced more than 80,000 landslides across 6,000 km^2 (Berti et al. 2025), including many in areas previously unrecognized as unstable (Brath et al. 2023), exposed serious deficiencies in spatial knowledge about landslides and raised fundamental questions regarding the predictive value of geomorphological landslide inventory maps.

Landslide prediction also remains a challenge. Advances in short-term forecasting of rainfall-induced landslides – from hours to a few days – stem from the growing availability of landslide catalogues and the establishment of probabilistic rainfall thresholds (Berti et al. 2012; Peruccacci et al. 2017), recently complemented by deep learning methods (Mondini et al. 2023). Short-term forecasts form an essential component of modern early-warning systems at local to national scales (Guzzetti et al. 2020). Yet, their reliability remains difficult to assess (Guzzetti et al. 2024), and the systems struggle in predicting the number, spatial distribution, and impact of rain-triggered landslides. Seasonal landslide predictions, albeit potentially very useful, remain highly uncertain. Susceptibility modelling has improved considerably (Reichenbach et al. 2018), but the capacity for medium-term spatial–temporal prediction, measured in years or decades and essential for effective landscape and land use planning, is still in its infancy (Mondini et al. 2025) and requires significant advancements.

Monitoring remains a critical yet underdeveloped component of landslide risk management. Despite technological progress (Dei Cas et al. 2021; Casagli et al. 2023), fewer than 0.2% of known landslides listed in IFFI, the Italian landslide inventory database are instrumentally monitored, and existing systems are fragmented, rarely integrated across regions or at the national level, thereby reducing their effectiveness for risk assessment and early warning. Although supported by enhanced computing power, richer datasets, and improved understanding of physical processes, modelling efforts still face major uncertainties.

The accurate prediction of initiation location and timing, runout distances, velocities, and the number of expected failures remains elusive, largely due to the scarcity of high-quality geotechnical and hydrological data, restricting modelling at catchment to national scales, as well as the inherent complexity and heterogeneity of landslide processes. Gaps in vulnerability and risk assessments remain a major limitation. Quantitative risk estimates are available for populations (Rossi et al. 2019), but comparable evaluations for assets such as critical infrastructure, buildings, agriculture, and ecosystems – aside from a few exceptions (Caleca et al. 2025) – lacking, and information on how different elements respond to different landslide types remains scarce. This limits risk projections in the context of climate change, environmental, and socio-economic transformation. Finally, restricted access to relevant data and the lack of integrated data repositories continue to hinder scientific progress, reduce predictive capacity, and constrain the development of evidence-based decision-making in landslide risk reduction and management.

5 Necessary developments

To strengthen landslide knowledge, forecasting, and risk reduction, coordinated actions are required at scientific, technological, organizational, and cultural levels.

5.1 Landslide datasets

A first priority for advancing landslide forecasting lies in the development of more systematic, comprehensive, and representative landslide datasets, including landslide inventories (Guzzetti et al. 2012) and catalogues (Calvello and Pecoraro 2018; Peruccacci et al. 2023; Brunetti et al. 2025). Landslides should be mapped consistently and as soon as possible after their occurrence, across the entire national territory, by integrating satellite, aerial, and terrestrial technologies (Guzzetti et al. 2012; Mondini et al. 2021; Casagli et al. 2023), producing systematic and homogeneous landslide event inventories. Such event-based inventories are crucial for improving models that aim to predict not only where landslides might occur but also their number and potential impact under specific triggering conditions. Equally important is the creation of multi-temporal landslide maps and datasets capable of capturing the temporal evolution of landslide occurrence and activity. By documenting changes in activity over years or decades, these datasets provide indispensable input for medium-term, multi-decadal, spatial–temporal forecasts (Lombardo et al. 2020) and for the construction of realistic scenarios of future hazard (Mondini et al. 2025). Another critical requirement is the systematic recording of landslide initiation times, using multiple instruments and technologies, including seismic networks. Precise temporal data on landslide initiation are fundamental both for enhancing short-term predictions and for objectively evaluating the performance of early warning systems (Piciullo et al. 2018; Guzzetti et al. 2020, 2024).

5.2 Monitoring

Improving landslide monitoring requires a shift from data collection toward the production of predictive insights that can support risk management in practice. This entails the definition of shared protocols and standards for different landslide types, specifying what parameters should be measured, why those parameters are relevant, and how the resulting information should be managed. Establishing common standards would enhance comparability between monitoring systems, reduce costs, and strengthen the scientific foundation of landslide research. At the same time, responsibilities for data collection, system operation, and information management must be clarified through well-defined governance structures, ensuring consistency, integration, and accountability across institutional levels.

Monitoring coverage must also be expanded: a far greater number of landslides should be instrumented, making use of both established and emerging technologies (Dei Cas et al., 2021; Casagli et al. 2023), and each monitored site should be conceived as a dynamic forecasting system that continuously updates predictive models and bridges the gap between scientific and operational monitoring. Further, monitoring should not remain fragmented at local scales but must be progressively integrated into regional and national surveillance systems, including those operated by structure, infrastructure, and utility managers. Such integration would enhance the comparability of datasets, support real-time risk evaluation, improve early-warning performance, and ultimately advance both scientific understanding and societal protection. In parallel, it is crucial to clarify who holds responsibility for monitoring data and to establish *ad-hoc* regulations dedicated to landslide monitoring, ensuring clear governance and accountability.

5.3 Modelling

An additional priority concerns the improvement of modelling capacities at different spatial and temporal scales and their use for landslide risk management. Central to this effort is the systematic collection, organization, and dissemination of accurate large-scale datasets, including morphometric, lithological, geological, hydrological, pedological, geotechnical, seismic, land-use/land-cover, meteorological, and climatic information. Such data are indispensable for the development, calibration, and validation of both physically based (mechanistic) and data-driven models. Equally important is the integration of monitoring into modelling frameworks: high-resolution numerical models must be capable of assimilating multi-source monitoring data in real time, thereby enabling more precise and dynamic forecasts. The explicit treatment of uncertainty also requires attention. Models should not only incorporate and analyse uncertainties inherent in their structure and input data but must also communicate them transparently, thereby increasing both credibility and usability for decision-makers.

Research must deepen the understanding of geologically complex formations – such as flysch, molasse, volcanic and glacial deposits, and tectonized zones – and quantify the direct and indirect impacts of climate warming on landslides under different scenarios (Gariano and Guzzetti 2016; Gariano and Rianna 2025). These include shifts in the frequency, intensity, and spatial distribution of precipitation, temperature-driven and drought-related processes, and permafrost distribution and thawing. Attention is also needed to assess how changes in land use/land cover, and agricultural or forestry practices influence landslide activity. Another critical aspect is improving the representation and modelling of groundwater flow at the slope scale, which is often reproduced in a very simplified manner and fails to capture the actual complexity of subsurface hydrological processes. Finally, adequate access to advanced computing resources and modern analytical tools, including artificial intelligence, is essential to support the rapid development and operational application of next-generation modelling frameworks.

Predictive models underpin predictions of landslide occurrence, behaviour, and impacts across timescales from hours to centuries. Reducing landslide risk, and particularly its human toll (Bianchi and Salvati 2025), requires better early warning systems and more effective communications to relevant stakeholders, including the population. These systems require further improvement, standardized testing with independent data (Guzzetti et al. 2024), and clear, effective communication strategies tailored to different audiences (Piciullo et al. 2018; Guzzetti et al. 2020). For medium- and long-term risk reduction, from years to decades, predictive models should better account for projected climatic, environmental, and socio-economic changes, accounting for uncertainty. Although uncertainty in the prediction models will most probably persist, it must be acknowledged, quantified, and communicated to enable more informed decisions.

5.4 Vulnerability and risk

Improving the assessment of landslide risk requires progress in the evaluation of vulnerability to different landslide types, the quantification of risk (Salvati et al. 2018; Rossi et al 2019; Bianchi and Salvati 2025; Caleca et al. 2025) and of its perception (Salvati et al. 2014; Calvello et al. 2016), and the evaluation of the associated costs. At present, quantitative vulnerability functions are scarce or incomplete (Galli and Guzzetti 2007; Peduto et al. 2017; Luo et al. 2023), yet they are essential for understanding how different exposed elements – including, e.g., infrastructure, buildings, agricultural systems, ecosystems, and economic activities – respond to various types and magnitudes of landslide events and processes. Without such knowledge, it is difficult to obtain realistic and spatially explicit risk assessments.

Equally important is the development of more robust methods for quantifying landslide risk under conditions of climate warming and socio-economic and environmental transformations. More realistic risk estimates are indispensable for the design of sustainable mitigation and adaptation strategies that remain effective in future climatic, environmental, and societal contexts. Alongside this, systematic data on the direct and indirect costs of landslides – economic, social, and environmental – must be collected and analysed. Current estimates are fragmented and tend to underestimate the true burden of landslides to individuals, communities, and societies. Comprehensive cost–benefit analyses are needed to demonstrate the value of preventive measures and to raise public and political awareness of the benefits of proactive risk reduction.

Greater emphasis should be placed on the promotion and implementation of nature-based solutions (Preti et al. 2022). Ecosystem-based and sustainable approaches provide cost-effective alternatives to traditional engineering solutions and deliver multiple co-benefits, including enhanced biodiversity, improved water regulation, and increased resilience of landscapes (Capobianco et al. 2025). Their widespread adoption would represent a significant step toward an integrated and multifunctional strategy for landslide risk management.

5.5 Governance and organization

Effective landslide risk management requires strengthening governance (Kaufmann et al. 2011). The persistent fragmentation of responsibilities among different agencies and administrative levels must be addressed through the establishment of a unified national framework, as envisaged by the Commissione De Marchi (1970), 55 years ago. Such coordination must be supported by streamlined procedures for financing, design, and implementation of mitigation and adaptation measures, ensuring that institutional actions are timely and efficient. Equally important is the harmonization of regulatory frameworks: nationally consistent land-use restrictions and planning regulations must be introduced for areas affected or potentially threatened by landslides, ideally embedded within a broader European policy context to overcome current inconsistencies and gaps.

Data accessibility is also critical. Landslide inventories and catalogues, environmental datasets, and monitoring data should be standardized, openly accessible, and shared promptly to enable model validation, enhance transparency, and strengthen public trust in scientific assessments and policy decisions. The institutional capacity of technical agencies at both national and regional levels must be reinforced. This requires adequate and sustained funding, along with the recruitment and training of qualified personnel to ensure an effective territorial presence for landslide risk management. Recent landslide events (Berti et al. 2025) have exposed a digital divide, especially in small municipalities where staff struggles to manage geospatial data or collect field information with mobile tools. Closing this gap demands targeted investment in digital infrastructure, software, and training enabling authorities to exploit modern geospatial technologies more effectively in both emergency and routine contexts. Ultimately, this will improve the collective understanding of landslides and facilitate risk management and mitigation.

Improvements in governance and organizational capacity are also needed to address the growing challenges posed by climate, environmental, and economic change. Ongoing climatic shifts further complicate landslide prediction and increasingly lead to the occurrence of unforeseen crises. In this context, preparedness and prompt response are of paramount importance, together with the development of streamlined procedures for damage recovery and restoration that can be implemented rapidly and are not hindered by unnecessary bureaucracy.

5.6 Cultural and social adaptation

Effective management of landslide risk cannot be attained through scientific advancement, technological innovation, and institutional governance alone. It necessitates a parallel evolution in cultural and social dimensions. Both policymakers and the general public must be systematically informed about the complex nature of landslide hazards, their cascading impacts, and their broader environmental and socio-economic implications. Communication strategies must move beyond hazard-specific silos and adopt a multi-hazard perspective, highlighting interactions with floods, earthquakes, forest fires, volcanic activity, and other natural hazards and human activities. Equally important is the systematic, long-term monitoring of public and institutional perceptions of landslide hazard and risk. Understanding how awareness evolves over time, shaped by catastrophic events, media narratives, and policy shifts, is essential for designing adaptive communication strategies and effective risk governance frameworks. Ultimately, building lasting resilience to landslides requires improved knowledge, better forecasting tools, and enhanced emergency response systems. It also demands a cultural change. Individuals, communities, and decision makers must come to recognize landslide hazard and risk as a persistent societal challenge that requires proactive behaviour, long-term planning, and a commitment to transformative adaptation.

6 Final remarks

Landslides are widespread natural processes that shape landscapes, endanger populations, environments, and economies, and test societal resilience over the years. Italy, the most landslide-prone country in Europe, has developed advanced capabilities for mapping, forecasting, monitoring, early warning, and managing landslides and their risks. Nevertheless, significant gaps persist in spatial coverage, predictive reliability, vulnerability and risk assessment, data accessibility, and governance. In this paper we advocate a comprehensive, multi-level strategy for landslide risk management and reduction that integrates scientific and technological innovation with governance reform, institutional strengthening, and cultural adaptation. Such a holistic approach is essential to mitigating the human and economic impacts of landslides under accelerating climatic, environmental, and socio-economic change.

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Declarations

Competing interests The authors declare no competing interests.

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