Landslides
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Towards an understanding of landslide risk assessment and its economic losses: a scientometric analysis

Abstract This scientometric analysis significantly advances the understanding of landslide risk assessment and economic losses, focusing on scientometric insights. This study aims at analyzing the global trends and structures of landslide risk and economic loss research from 2002 to 2023 using scientometric techniques such as co-authorship, co-word, co-citation, cluster analysis, and trend topics, among others. Thus, analysis of 92 studies gathered from Scopus and Web of Science databases reveals a continuous growth in environmental, social, and quantitative research topics. Predominant contributions hail mainly from China and Italy. The research identifies critical themes, including risk analysis, vulnerability, fragility, and economic losses. The current identified research combines advanced statistical methods, including logistic regression, with climate change scenarios and susceptibility assessments to reveal intricate connections between climatic shifts, hydrogeological hazards, and their economic and environmental impacts. This study provides researchers and practitioners with a comprehensive understanding of the status quo and research trends of ontology research landslide risk and its economic losses. It also promotes further studies in this domain.

Keywords Landslide risk · Economic losses · Assessment · Quantitative analysis · Scientometric analysis

Introduction

The escalating recognition of climate change as a crisis underscores the imperative to mitigate greenhouse gas emissions, given the exacerbation of climate-induced disasters yearly (Lim and Kim 2022). Despite the unequivocal acknowledgment by the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) of the warming global climate system, the precise ramifications of global warming and associated climatic shifts on geo-hydrological hazards like landslides remain elusive (Lin et al. 2020). Climatic variability emerges as a significant contributor demanding consideration in designing risk-sensitive land policies (Puente-Sotomayor et al. 2021).

As articulated by Gariano and Guzzetti (2022), the effects of climate change profoundly influence slope stability, triggering landslides, torrential floods, debris flows, and other natural disasters, thereby amplifying economic and human losses. The intricate interplay between natural and human factors complicates the assessment of climate change impacts on natural hazards. Disturbingly, data from the World Meteorological Organization (Douris and Kim 2021) reveals a staggering 11,000 disasters attributed to weather, climate, and hydro-meteorological hazards between 1970 and 2019, culminating in over 2 million fatalities and US$ 3.64 trillion in economic losses.

The escalating toll of climate-induced disasters is evident, with the United Nations Office for Disaster Risk Reduction (UNDRR) estimating that from 2000 to 2019, 3.9 billion people were affected by 6681 climate-related disasters, resulting in 510,837 fatalities—almost double that of the preceding two decades. The economic ramifications are equally distressing, with 2021 witnessing 432 disastrous events related to natural hazards worldwide, accounting for 10,492 deaths, affecting 101.8 million people, and causing approximately US$ 252.1 billion in economic losses (Guha-Sapir et al. 2021; Douris and Kim 2021; Gariano and Guzzetti 2022).

Evidently, natural hazards pose a substantial economic burden, with economic losses escalating dramatically over the past decades. From 1980 to 1999, there were 4212 disasters resulting in economic losses exceeding US$ 1.63 trillion, surging to 7348 disasters and US$ 2.97 trillion in losses between 2000 and 2019 (CRED and UNDRR 2020). Furthermore, the onset of the twenty-first century witnessed a notable uptick in average annual economic losses from natural hazards, reaching US$ 150 billion between 2000 and 2019 and surpassing previous decades' figures by 6% in 2020 alone (CRED and UNDRR 2020).

Global warming and resultant shifts in climate patterns have substantially altered the hydrological landscape, culminating in heightened rainfall frequency and intensity. Although the IPCC reports lack a specific assessment of landslide risk, there is high confidence that changes in heavy precipitation will impact landslides in certain regions (Gariano and Guzzetti 2022). These alterations induce soil saturation, perturbing slope stability and increasing susceptibility to landslides and slope failures (Wang et al. 2021; Das et al. 2022). An accurate understanding of landslides' physical and socio-economic effects is fundamental to developing more refined risk management, mitigation strategies, and land use policies (Donnini et al. 2020).

The main objective of this research is to provide a thorough scientometric understanding of landslide risks and their associated economic implications. The study endeavors to comprehensively comprehend the existing scholarly landscape within this domain, catering to a diverse audience including market participants, researchers, policymakers, and decision-makers. Moreover, it discerns emergent trajectories in research, poised to serve as a foundational framework for driving forthcoming inquiries and innovations. Distinctive in its approach, this study introduces an innovative methodology by pioneering the application of advanced scientometric and network analysis tools, namely VOSviewer and

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Bibliometrix, to understand landslide risk assessment and its economic losses. Thus, the present research addresses the following research questions:

- What is the current state of knowledge concerning landslide risk assessment and its consequential economic losses?
- Who are the preeminent researchers exerting influence within the domain of landslide risk assessment and economic losses analysis?
- Which foundational studies provide pivotal insights for advancing our comprehension of landslide risk assessment and its interconnected economic repercussions?
- What are the predominant research trends in this field?

This study contributes substantially to the existing scholarly discourse and practical implementations through a trifold approach. Primarily, it spearheads the pioneering utilization of scientometric analysis, harnessed via advanced tools such as VOSviewer and Bibliometrix. These tools collectively provide a robust framework for elucidating and comprehending the intricacies encompassing landslide risk assessment and economic losses analysis. Secondly, this research extensively compiles and categorizes a diverse spectrum of pertinent literature concerning the consolidation of landslide risk assessment and economic losses analysis. This comprehensive compilation serves as a foundational resource, offering a comprehensive compendium on the subject matter. Lastly, the study demonstrates the potency of network mapping and thematic cluster evaluations as instrumental methodologies to unearth prospects for subsequent exploration. This mechanism facilitates identifying and investigating nascent themes emerging from both empirical and theoretical literature. In doing so, the study unearths the intellectual foundations underpinning the field and delves into emerging paradigms that beckon researchers, policymakers, and stakeholders alike.

Then, by capturing insights from the empirical and theoretical literature, this paper strives to furnish a comprehensive panorama of the contemporary state of knowledge within the domain. This panoramic view, rich in analytical depth and interpretative nuance, contributes to a broader comprehension of the multifaceted aspects of landslide risk assessment and its cascading economic consequences. As such, it is poised to guide future research endeavors, propel evidence-based decision-making, and cultivate holistic strategies for addressing the intertwined challenges presented by landslides and their financial implications.

Context of the analysis

Landslides are natural hazards defined as the downward movement of a mass of rock, debris, or earth on a slope under gravity, affecting the population and its infrastructure (Varnes 1978; Cruden 1991). Landslides represent a substantial economic burden, causing the loss of human life around the world, representing the seventh worldwide largest killer among natural hazards and producing heavy economic damages in many countries (Donnini et al. 2020) and the fourth place in terms of the number of people affected by natural hazards around the world (Hidalgo and Vega 2021).

Among the triggering factors, the occurrence of landslides is attributed to various triggering factors, including earthquakes and rainfall, with the latter being the most common, triggering torrential floods and landslides that are more lethal and destructive than those generated by other factors (Sim et al. 2022). Events caused by climate-related conditions represent severe geological hazards to human life and the natural and built environment, affecting large geographic areas because climate change has led to an unprecedented increase in the frequency and intensity of rainfall, and a more significant number of landslides are triggered by rainfall along hillsides (Ortiz-Giraldo et al. 2023). Landslides are very diversified phenomena, different climate variables control or affect landslides, and different landslide types respond differently to changes in climate. In fact, it is estimated that globally landslides triggered by rainfall are responsible for 89.6% of all landslide fatalities, 14% of all monetary losses, and 0.53% of all fatalities caused by natural hazards (Hidalgo and Vega 2021).

The World Bank data shows that about 3.7 million km^2 of the earth's landmass falls into a high landslide amenable area. It is further learned from the data that 300 million people live in these very high landslide-prone areas (Mandal et al. 2021). Previous authors have stated that losses caused by landslides increased from approximately US$ 50 billion per year in the 1980s to approximately US$ 200 billion per year in the previous decade (Albano and Sole 2018). In the twentieth century, landslides ranked fourth in casualties worldwide among natural hazards, with an estimated 60,501 deaths and 3,759,329 non-lethal victims. According to the World Health Organization, between 1998 and 2017, landslides affected an estimated 4.8 million people and caused more than 18,000 deaths worldwide (Ortiz-Giraldo et al. 2023). In the case of Latin America and the Caribbean, 611 landslides were recorded between 2004 and 2013, causing 11,631 deaths, mainly due to rainfall as a triggering factor. Rainfall-induced landslides contribute to a significant 89.6% of global landslide fatalities (Petley 2008). Additionally, according to the EM-DAT database of the Center for Research on the Epidemiology of Disasters (CRED), a global annual average of 914 deaths were reported between 2005 and 2014 due to rainfall-triggered landslides (Aristizábal and García-Aristizábal 2020). These human losses occur predominantly in developing countries, and the consequent effects on businesses and the economy can be very significant (Brabhaharan et al. 2001).

According to the CRED, in 2022, 387 natural hazards and disasters worldwide occurred, resulting in the loss of 30,704 lives and affecting 185 million individuals. Economic losses totaled around US$ 223.8 billion. The 2022 record is slightly higher than the average from 2002 to 2021 (370), and the occurrence of each type of disaster was also close to the average levels in the last two decades (CRED Crunch 2022). According to Fig. 1, between 2002 and 2022, America and Asia are the most affected continents by disasters, with economic losses amounting to 400 billion dollars (CRED 2022).

According to the scenario shown, events caused by climate-related conditions represent serious geohazards worldwide to human lives and the natural environment, affecting large geographic areas. Nevertheless, not only is affectation caused to the life of people when geohazards occur, but damage to infrastructure may also challenge the ability of emergency institutions to determine the extent and nature of the damage. Natural hazards such as landslides may damage natural resources and engineering constructions, block rivers, lose valuable watershed and grazing lands, and disrupt communication. As can be seen, the direct and indirect

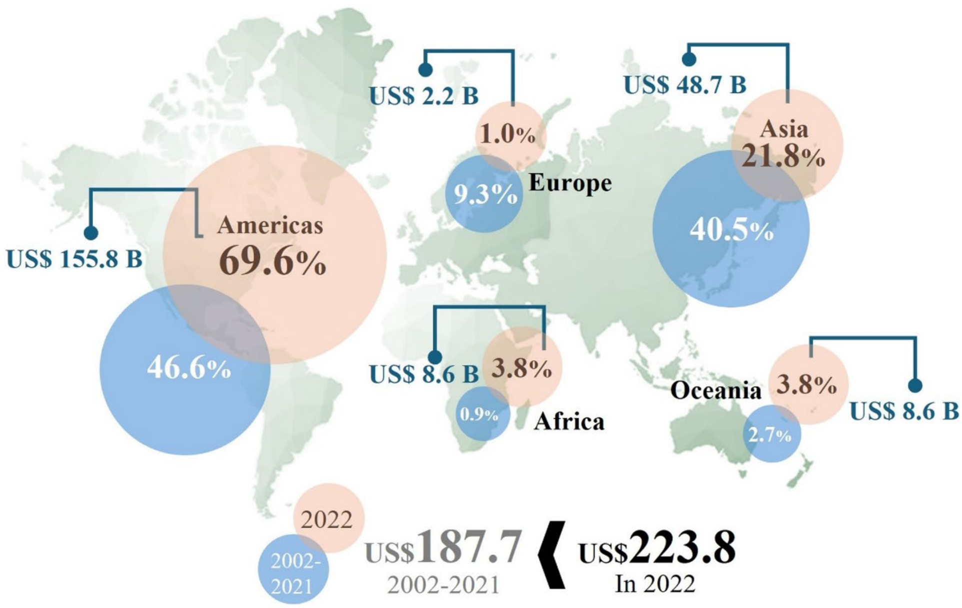


Fig. 1 Economic losses for natural hazards (billion US$) by continent. Year 2022 compared to the 2002–2021 annual average. Based on CRED (2022)

costs of landslides can be significant in terms of gross domestic product (GDP), even in developed countries.

Therefore, it is necessary to continue developing new studies that lead to the generation of new knowledge in order to establish methodological guidelines that complement what has been developed to date on the subject of landslide risk, which led to the materialization of this systematic search and analysis of landslide risk studies worldwide.

Materials and methods

This study uses essentially four scientometric techniques, such as diagrams and information maps analysis, to examine the linkage between landslide risk and economic losses research: (1) co-author, (2) co-word, (3) citation, and (4) cluster analysis. After the elimination of 40 duplicate records, a total of 92 research documents were employed to conduct scientometric analysis, employing two specialized tools: VOSviewer software version 1.6.19, developed by van Eck and Waltman (2017), and the Bibliometrix package for R conceived by Aria and Cuccurullo (2017). The idea for using this methodology is to measure the impact of scientific contributions in the analyzed topics, monitor scientific developments, identify emerging trends, and map science patterns that allow identifying the internal composition of this specific topic. Figure 2 illustrates the delineated strategy employed for the systematic literature search, including the search equation.

According to Fig. 2, four scientometric techniques were used to (i) follow the evolution of the research field through the core documents, (ii) identify the leading researchers and institutions about the topic, (iii) research keywords and co-citation clusters, and (iv) deduce the emerging research themes. Meanwhile, several journal articles, conference proceedings, books, and other documents were analyzed. Finally, the Scopus and Web of Science (WoS) databases were chosen as the most appropriate option to carry out the study. In this way, a total of 92 documents were obtained in August 2023 using the following search equation: ((TITLE-ABS-KEY ("Landslide* risk*") AND TITLE-ABS-KEY ("Economic Loss*" OR "economic impact" OR "economic evaluation")).

After these, all studies were downloaded and indexed into the Mendeley reference manager for reading and content analysis. The main research information in the databases is presented in Table 1. From the 92 documents constituting the focal point of this study, a collective of 371 distinctive authors emerged as contributors. The documented average of citations per individual publication, standing at an impressive 27.29, attests to the scholarly significance attributed within academic circles. Notably, a mean of approximately 4.7 co-authors per document underscores the collaborative ethos intrinsic to the knowledge generation process within this field.

The predominant genre of documentation within this amount is the article format, encompassing 61 instances. Further analysis reveals the existence of 537 KeyWords Plus and 272 author keywords, each contributing nuanced dimensions to the semantic scope of the discourse. For a comprehensive overview, Table 1 consolidates pertinent details encapsulating the overarching characteristics of the scrutinized papers, thereby enriching the contextual understanding of this study's scope.

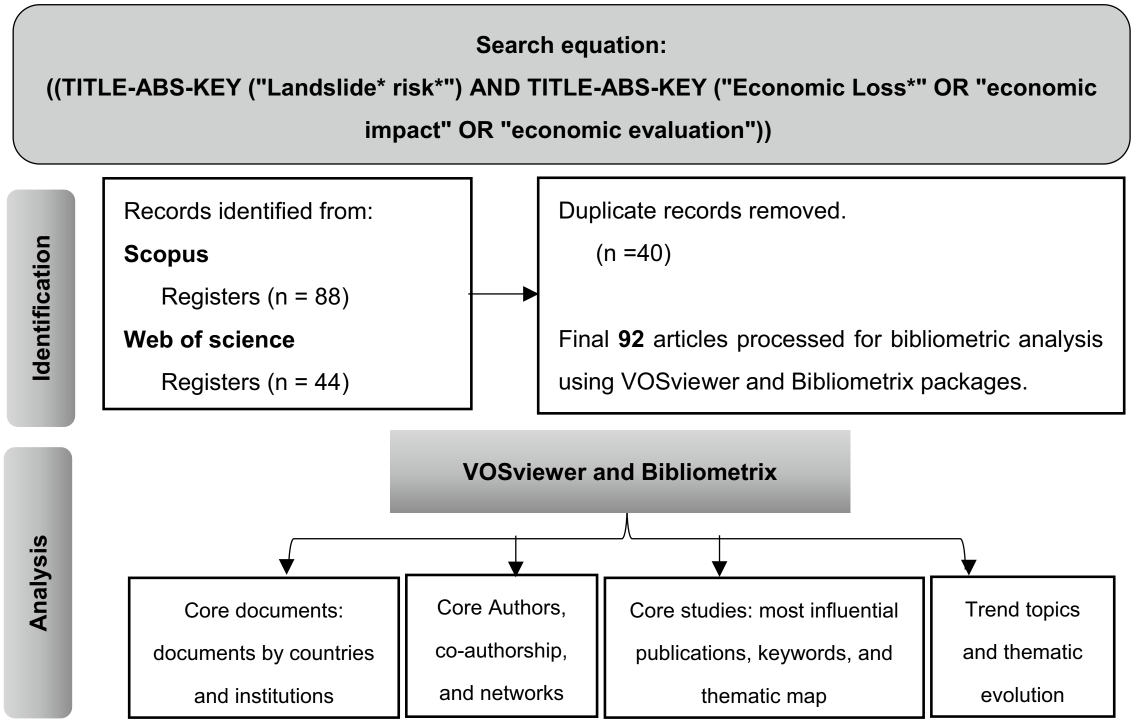


Fig. 2 Strategy employed for the systematic literature search

Scientometric analysis

Analysis of the documents

Publication output

In Fig. 3A, a temporal progression of published documents over successive years is unveiled, providing an insightful overview of the field's scholarly activity. Notably, this publication trend's peak was observed in 2014, marked by a substantial count of 13 documents. This surge in publications underscores the heightened academic attention garnered by the subject during that specific timeframe.

Moreover, Fig. 3B and Table 1 delve into the quantitative aspect by depicting the annual growth rate (%) of publications across the temporal spectrum. The discerned growth rate of approximately 5.37% per annum serves as a quantitative representation of the cumulative expansion within the field over the considered time span. This numerical insight complements the visual narrative of Fig. 3A, accentuating the enduring progression of scholarly contributions in tandem with the evolving understanding of landslide risk assessment and its economic repercussions.

Discipline-wise analysis

Figure 4A presents a discerning examination of the most pertinent sources contributing to the field's scholarly discourse. Notably, the preeminent knowledge repositories emanate from the *Landslides* and *Engineering Geology* journals, each boasting a noteworthy count of eight and five articles, respectively. Additionally, the Geoenvironmental and IOP Conference Series: Earth and Environmental Science align closely, each harboring three notable documents. A comparable triad is observed in the *Bulletin of Engineering Geology And The Environment*, *Frontiers In Earth Science*, *Geological Bulletin Of China*, *Journal Of Natural Disasters*, *Landslide Science And Practice: Social And Economic Impact And Policies*, and *Landslide Science For A Safer Geoenvironment: Volume 2: Methods Of Landslide Studies*, each hosting two documents.

Figure 4B extends the analysis by offering an illustrative representation of the distribution of the most cited sources within the domain. The *Engineering Geology* journal emerges as the predominant source through a quantitative lens, commanding a substantial 169 citations. The *Landslides* journal closely follows this ascendancy, boasting an equally noteworthy 165 citations. The realm of geomorphology occupies a consequential position, with a commendable citation count of 120. This hierarchical arrangement based on citation numbers underscores these sources' notable influence and resonance within the scholarly discourse, thereby shaping the intellectual trajectory and depth of inquiry within the landscape of landslide risk assessment and its intertwined economic dimensions.

Documents by countries and institutions

The study undertook a comprehensive analysis encompassing the world's foremost countries and institutions as integral components of the research. In the visual representation provided by Fig. 5A, China emerges as the foremost contributor in generating scholarly documents on the subject matter, displaying an impressive tally of

Table 1 Summary of the main information

Description	Results
Time span	2002:2023
Sources (Journals, Books, etc.)	65
Documents	92
Annual growth rate %	5.37
Document average age	7.28
Average citations per doc	27.29
References	3779
Document contents	
KeyWords Plus (ID)	537
Author's keywords (DE)	272
Authors	
Authors	371
Authors of single-authored docs	3
Authors collaboration	
Single-authored docs	3
Co-authors per doc	4.7
International co-authorships %	20.65
Document types	
Article	61
Article; early access	2
Article; proceedings paper	1
Book chapter	10
Conference paper	16
Review	2

Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

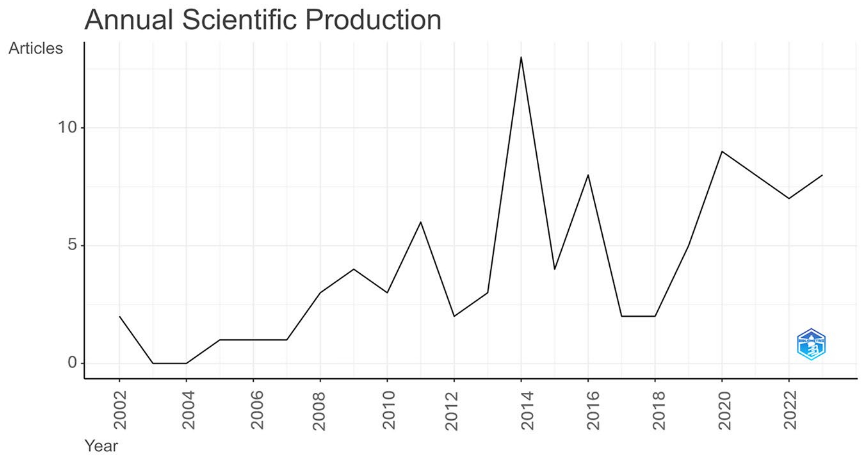
18 publications. Italy takes the second position with a commendable count of 16 documents, followed closely by Belgium, Brazil, India, the UK, and the USA, each contributing three documents apiece. Figure 5A further expounds on other prominent nations contributing to this scholarly discourse.

Turning to Fig. 5B, the research delves into the realm of top-ranking institutions. Evidently, Consiglio Nazionale delle Ricerche (CNR) in Italy secures the foremost position among the top ten institutions, exemplified by their publication of seven articles. Universidade NOVA de Lisboa in Portugal follows suit, positioning itself as a significant contributor with four articles. Other prominent institutions in the list include Central South University, Chang'an University, and China University of Geosciences in China; Research Institute Geohydrol Protect in Italy; Swedish Geotechnical Institute in Sweden; and University of Salerno and University of Twente, both contributing two articles each. This comprehensive portrayal underscores these esteemed institutions' pivotal role in shaping the intellectual landscape of landslide risk assessment and its attendant economic dimensions.

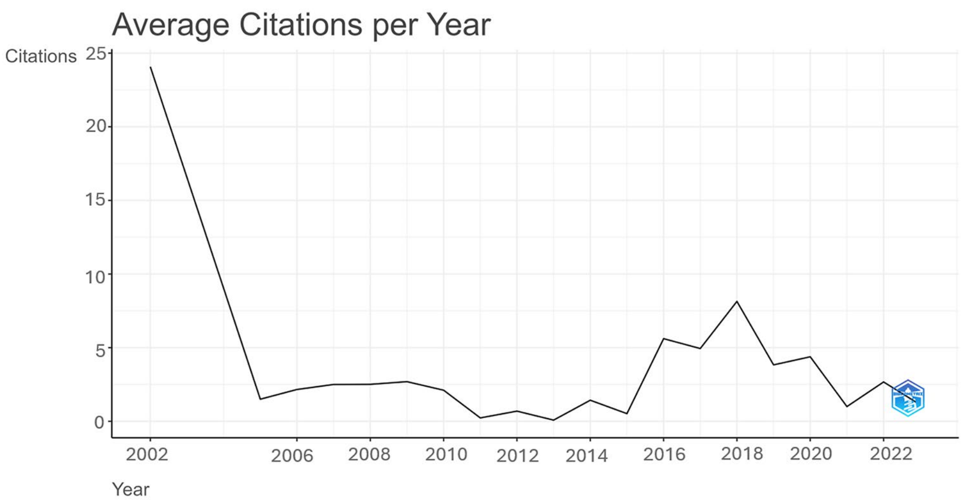
Author analysis

Most relevant authors

Figure 6A presents an overview of the primary authors of note, ranked by the quantity of published articles: (i) Ferlisi, (ii) Nicodemo, (iii) Peduto, (iv) Sterlacchini, and (v) van Westen. Moreover, Fig. 6B visually depicts the chronological progression of these authors' research output. The graphical representation employs varying color intensities to denote the publication year. At the same time, the size of each bubble corresponds to the number of publications authored by each individual within a



(A)



(B)

Fig. 3 Scientific production and citations per year: **A** Publication output and **B** average number of citations per year. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

specific year. For example, in 2016, Ferlisi, Nicodemo, and Peduto (Peduto et al. 2016) introduced their initial study in this domain. Subsequently, the same researchers contributed one additional research to this subject matter in 2017 (Peduto et al. 2017), 2019 (Ferlisi et al. 2019), and 2021 (Gullà et al. 2021).

Ferlisi, Nicodemo, and Peduto (and other authors) discuss various aspects of slow-moving landslides, their economic impact, vulnerability assessment, and risk management strategies. Then, Peduto et al. (2016), Peduto et al. (2017), Ferlisi et al. (2019), and Gullà et al. (2021) collectively provide information on the significance of slow-moving landslides in terms of economic losses and disruption of activities, the importance of vulnerability analysis and consequence assessment in landslide risk management, the use of satellite data for intensity determination and risk assessment, the challenges posed by slow-moving landslides to urban areas, and the proposed methodologies for risk assessment and mitigation. Each research contributes to the overall understanding of the issues related to slow-moving landslides and the strategies proposed to manage and mitigate their impacts.

Co-authorship network

In the analysis of co-authorship (Fig. 7), a crucial factor to consider is the frequency of collaborative efforts among researchers, indicated by the number of documents they jointly contribute to. The visualization of this network is achieved through a map where connections between researchers are represented as color-coded lines linking various items. The significance of the identified network is portrayed through the weight attributes, determining each item's size. The quantity of lines connecting co-authors within the bibliographic data analysis indicates their relevance and prominence in the collaborative framework (Lin and Su 2020; Marín-Rodríguez et al. 2022).

Figure 7 presents the connections between researchers according to the conjointly elaborating documents. Thus, this figure allows us to examine the existence and characteristics of collaboration networks and possible established groups of authors that center

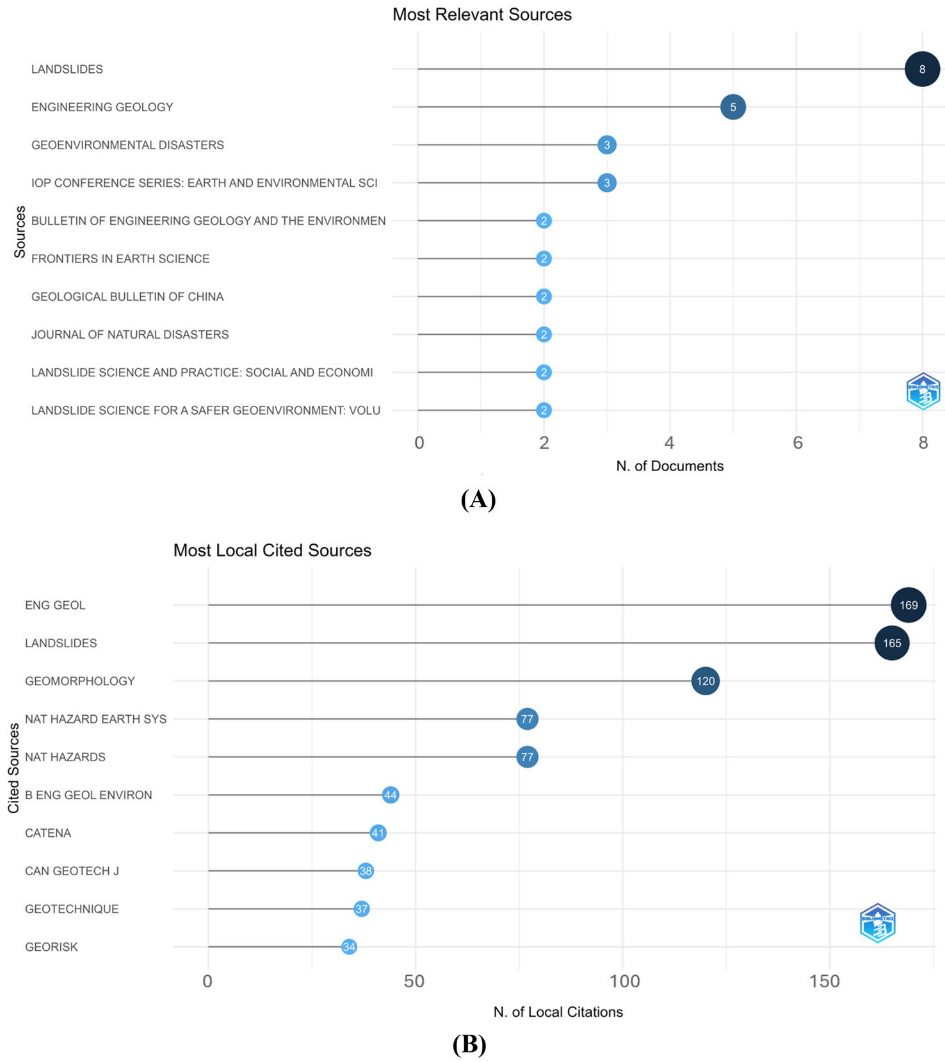


Fig. 4 Discipline-wise analysis: **A** Most relevant sources and **B** most local cited sources. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

on studying landslide risk assessment and its economic losses. The network obtained reveals the existence of 325 authors and 49 links that are formed in four clusters. These clusters are very dispersed, but several research co-authorships can be identified. For example, in the blue cluster are van Puissant, Van Den Eeckhaut, and Maquaire (Puissant et al. 2014). In the yellow cluster are Ivanov, Dobrev, Berov, Frantzova, and Krastanov, among others (Ivanov et al. 2022). In the green cluster are Halkia, Gaprindashvili, Engström, Keellings, and Chalov, among others (Haque et al. 2016). Finally, in the red cluster are Haque, Blum, Da Silva, and Pilz, among others (Haque et al. 2016) and Bukhari, Da Silva, Pilz, Istanbulluoglu, Görüm, Lee, Karamehic-Muratovic, Urmi, and Soltani, among others (Bukhari et al. 2023).

Network of countries and regions

The utilization of co-authorship analysis serves as a method to discern the distribution of leading countries' contributions to knowledge production and collaborative networks within the examined research field. This approach sheds light on the interplay of nations and regions, revealing a network encompassing 57 countries and 47 links and forming five distinct clusters. This detailed representation is presented in Fig. 8, wherein the predominant clusters are denoted by red, green, yellow, blue, and purple colors.

The highlighted clusters within the network carry distinct nations. The red cluster, for instance, encompasses countries like Italy, Norway, Cyprus, and Belgium, among others. The red cluster further includes France, Germany, Switzerland, Austria,

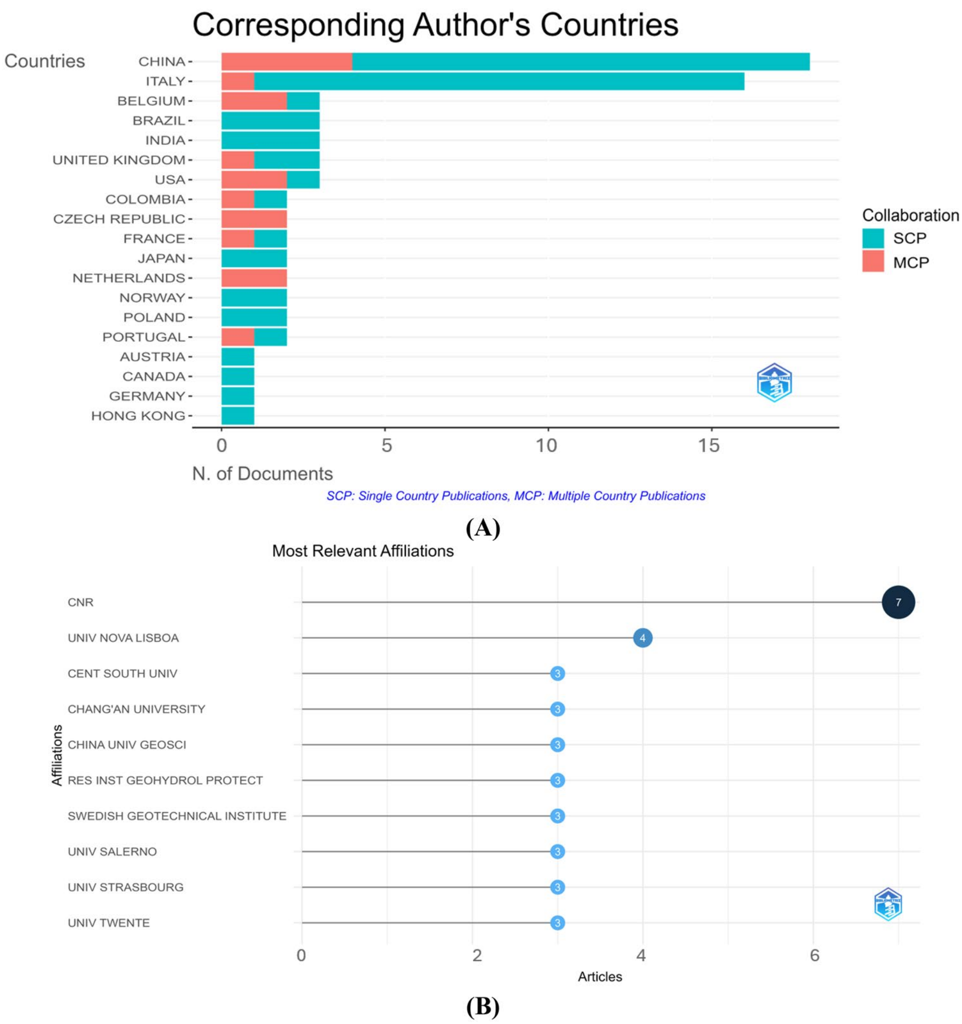


Fig. 5 Documents by countries and institutions: **A** Most relevant countries and **B** most relevant affiliations. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

Bulgaria, and Georgia, among its constituents. Meanwhile, the blue cluster prominently features China, which exhibits numerous connections with other countries, including the Netherlands, India, Canada, and Indonesia, among others. Lastly, the purple cluster is comprised of the UK and Poland.

Core studies

Most influential publications

Table 2 provides an overview of the ten most widely cited studies globally. These studies' outcomes primarily focus on landslide risk assessment and its associated economic ramifications across three pivotal dimensions. In the first place, the importance of understanding landslide risk assessment, its impact on societies, and the methods used to manage these risks. The need for new methodologies, the challenge of quantifying casualties, and the socio-economic impacts of landslides emphasize the urgency of accurate assessment and effective management strategies (Dai et al. 2002; Kjekstad and Highland 2009; Haque et al. 2016).

In the second place, the studies delve into specific case studies and methodologies for assessing landslide vulnerability and risk (Philpott et al. 2008; Frigerio and De Amicis 2016; Arabameri and Rezaei 2019). These studies highlight the vulnerability of agricultural systems, social vulnerability assessment, and the need for a common legal framework in Europe. They provide real-world examples and techniques for evaluating and addressing landslide risks. Finally, in the third place, the studies discuss comprehensive approaches to assessing and mitigating landslide risk (van Westen et al. 2006; Pellicani et al. 2014; Peduto et al. 2017; Herrera et al. 2018). These studies introduce methods for vulnerability assessment, qualitative exposure analysis, and Bayesian modeling for prediction. They showcase a range of strategies to improve our understanding of landslide hazards, their spatial distribution, and their implications. For example, van Westen et al. (2006) highlight the increasing importance of quantifying

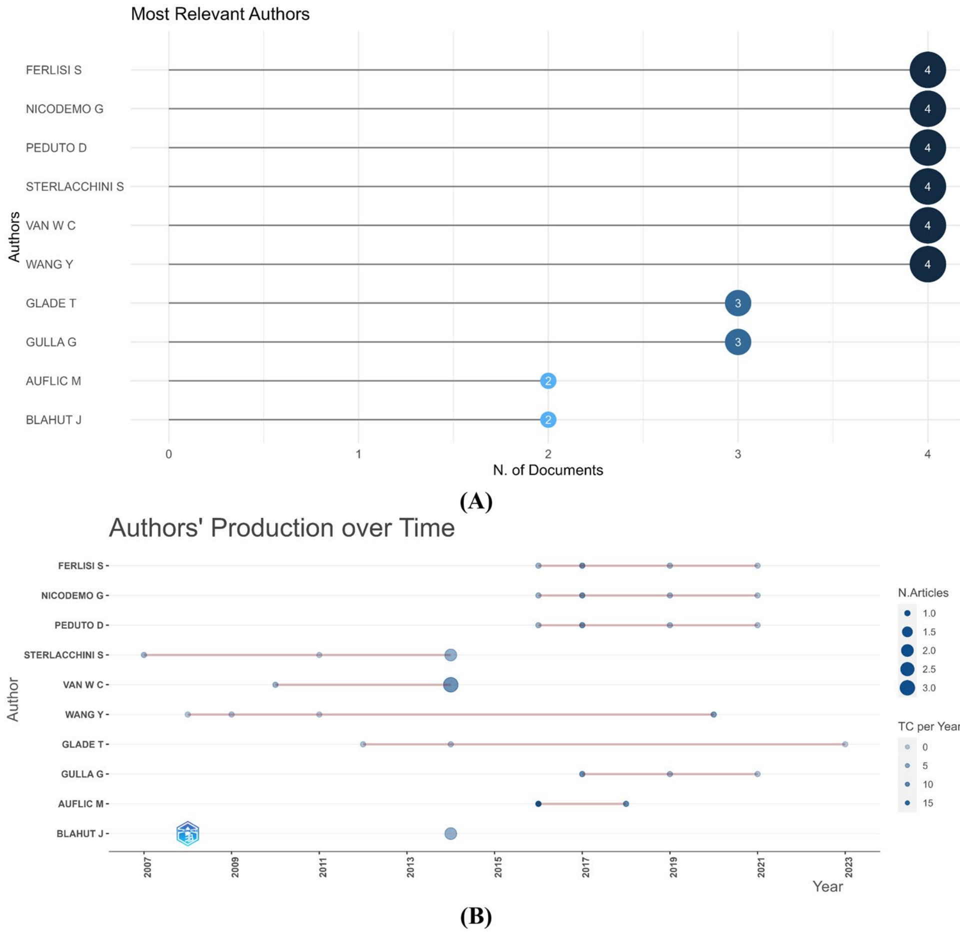


Fig. 6 Most relevant authors. **A** Number of publications by authors and **B** authors' production over time. Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases

risk in landslide studies and discuss the challenges of extending quantitative risk assessment to larger areas. It emphasizes the need for detailed topographic data, event-based inventory maps, and consideration of land use and climatic change scenarios for comprehensive landslide risk assessment.

Collectively, the studies contribute to a holistic view of landslide risk assessment and economic losses. They emphasize the complexity of the issue, the importance of accurate assessment, the role of various methodologies, and the need for international collaboration and advanced modeling techniques to manage these risks effectively and reduce their impact on society and the economy.

Most frequent keywords

Co-occurring keyword analysis is employed to identify the key terms prevalent in the scrutinized bibliographic records. This process aids in ascertaining the most pertinent categories of research within the realm of study, with larger sizes indicating higher frequencies (Fig. 9). This analytical approach proves valuable as it enables researchers to concentrate on the most significant terms highlighted in the research outcomes. In Fig. 9A, the author's keywords such as "landslides," "landslide risk," "vulnerability," "debris flow," "risk," and "climate change" stand out as the primary focal points in the context of research on landslide risk assessment and its associated economic implications. On the other hand, the KeyWords Plus section (Fig. 9B) emphasizes terms such as "landslides," "risk assessment," "hazard," "susceptibility," and "logistic regression" as crucial keywords in the analysis.

Thematic map

The Bibliometrix package allows for constructing word networks, determining their relationships, and grouping them by subject areas based on centrality and density. Then, the conducted analysis yields a thematic map, wherein the map is partitioned into four distinct topic quadrants predicated on the density (development degree) and centrality (relevance degree) of the subject matters (Fig. 10). Given their pronounced concentration and significance, it is imperative to undertake more comprehensive and in-depth research of the themes in the upper right quadrant (Herrera et al. 2018; Ferlisi et al. 2019). Then, the most promising areas for further research in analyzing landslide risk assessment and its economic losses are represented by the following four groups keywords: (i)

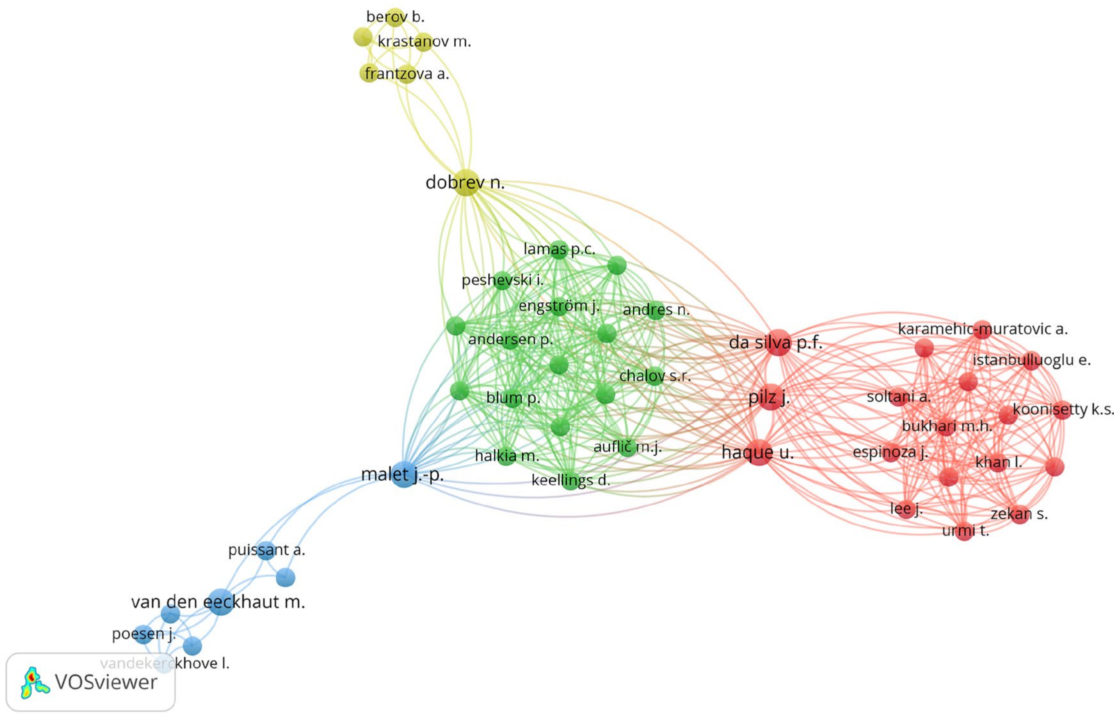


Fig. 7 Co-authorship network. Source: Author's own research using VOSviewer and Scopus database

hazard assessment, vulnerability, and economic impact; (ii) landslides, risk assessment, and losses; (iii) hazard, GIS (Geographic Information System), and climate change; and (iv) logistic-regression, area, and frequency ratio.

In the first group of keywords, further research should delve into the comprehensive assessment of hazards, evaluating their potential impacts on various communities and regions over extended periods. This inquiry should also explore the intricate interplay between socio-economic factors, hazard vulnerability, and the subsequent economic repercussions. Additionally, in the second group of keywords, further research should aim to advance the field of landslide risk assessment by exploring innovative techniques for

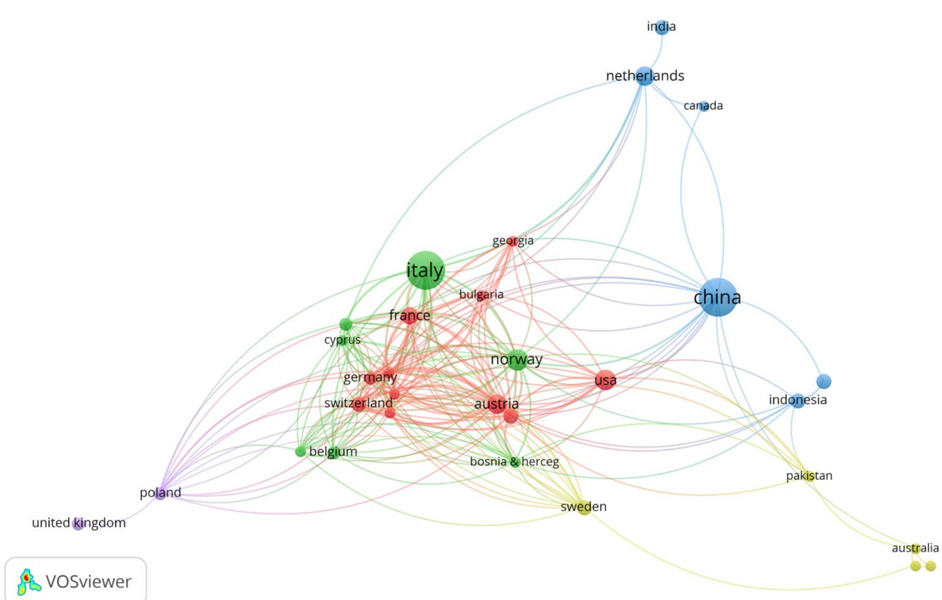


Fig. 8 Network of countries. Source: Author's own research using VOSviewer and Scopus database

Table 2 Top ten most globally cited studies exploring the linkage between landslide risk and economic losses

	Author	Source	Total citations	TC per year	Normalized TC
1	Dai et al. (2002)	*Engineering Geology*	887	40.32	2.00
2	van Westen et al. (2006)	*Bulletin of Engineering Geology and the Environment*	784	43.55	3.56
3	Haque et al. (2016)	*Landslides*	169	21.13	3.61
4	Kjekstad and Highland (2009)	*Landslides - Disaster Risk Reduction*	137	9.13	3.49
5	Philpott et al. (2008)	*Agriculture, Ecosystems & Environment*	117	7.31	2.81
6	Frigerio and De Amicis (2016)	*Environmental Science & Policy*	107	13.38	2.29
7	Arabameri and Rezaei (2019)	*Remote Sensing*	78	15.60	3.86
8	Peduto et al. (2017)	*Landslides*	72	10.29	1.97
9	Herrera et al. (2018)	*Landslides*	67	11.17	1.99
10	Pellicani et al. (2014)	*Landslides*	63	6.30	4.22

Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

advanced landslide hazard mapping, developing more robust early warning systems explicitly tailored for landslides, and enhancing the effectiveness of land use planning strategies to mitigate potential losses caused by these natural phenomena.

In the third group of keywords, further research endeavors should focus on leveraging the capabilities of Geographic Information Systems (GIS) to develop comprehensive hazard mapping strategies that effectively incorporate the influence of climate change, providing insights into the spatial distribution and temporal variations of climate-driven hazards. Furthermore, investigating the potential shifts in hazard frequency and intensity due to climate-induced changes will contribute to a more accurate understanding of evolving risks in dynamic environments. Finally, in the fourth group of keywords, further research explores the synergistic potential of machine learning techniques and logistic regression to enhance landslide prediction models. Additionally, investigating the application of logistic regression for predictive modeling of landslide-affected areas could offer valuable insights into optimizing strategies for practical risk assessment and mitigation.

Trend topics

The citation analysis determines the relationship between the items based on the number of times an item within the sample cites another. For these purposes, the software is indifferent if the citation is from A to B or vice versa. This analysis allows to examine which studies impact the academic community most. Thus, by identifying the most cited documents, it is recognized which are the base articles within the field of study, which serve as references for current researchers, and which should be considered in future research. Within the applicable units of analysis are the source, author, and document.

Fig. 9 Word cloud. **A** Author keywords and **B** KeyWords Plus. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

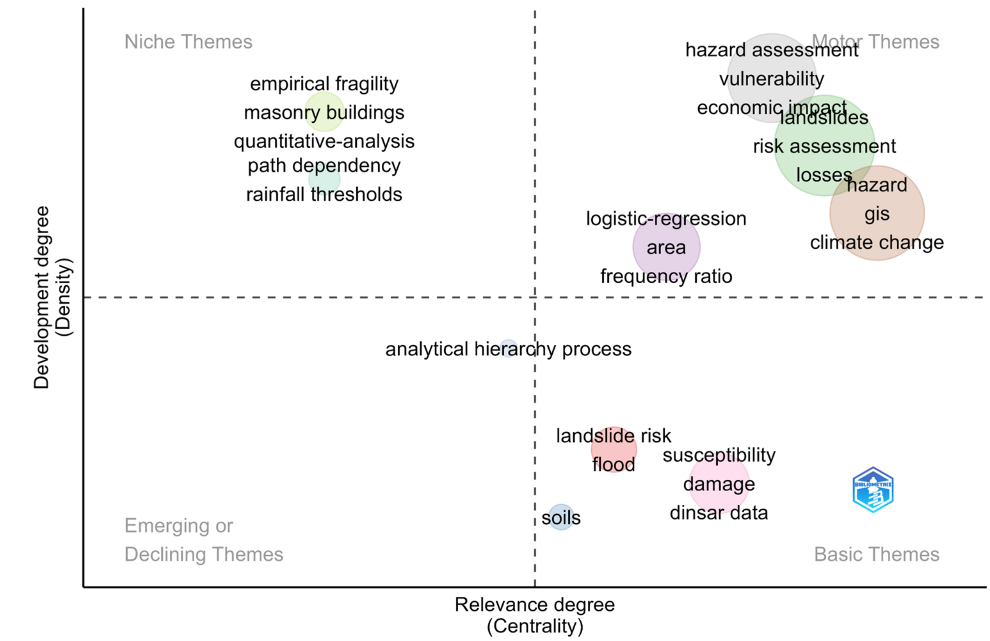


Fig. 10 Thematic map. Source: Authors' own research using Bibliometrix tool, as well as Scopus and WoS databases

Trend topics over the years

Conducting a trending topic analysis holds significant value as a mapping instrument to illustrate the dynamic evolution of scholarly discourse. Figure 11 shows the discerned themes derived from KeyWords Plus, considering a minimum occurrence of five words per article in three distinct timeframes annually.

The analysis of the KeyWords Plus reveals the prominent themes that have emerged between 2010 and 2023, including logistic regression, susceptibility, management, losses, climate change, risk analysis, hazard, and landslide risk. This scenario suggests that the recent trend in conducting comprehensive research encompassing logistic regression modeling, susceptibility assessment, risk analysis, and management strategies is paramount in addressing the multifaceted challenges of climate change–induced landslide risks. This imperative research trend endeavor facilitates quantifying potential losses and provides a robust framework for devising effective hazard management measures. By integrating advanced statistical techniques, such as logistic regression, with climate change scenarios and susceptibility assessments, this recent research has the potential to illuminate the complex relationships between climatic shifts, hydrogeological hazards, and their corresponding economic and environmental consequences. Ultimately, this interdisciplinary

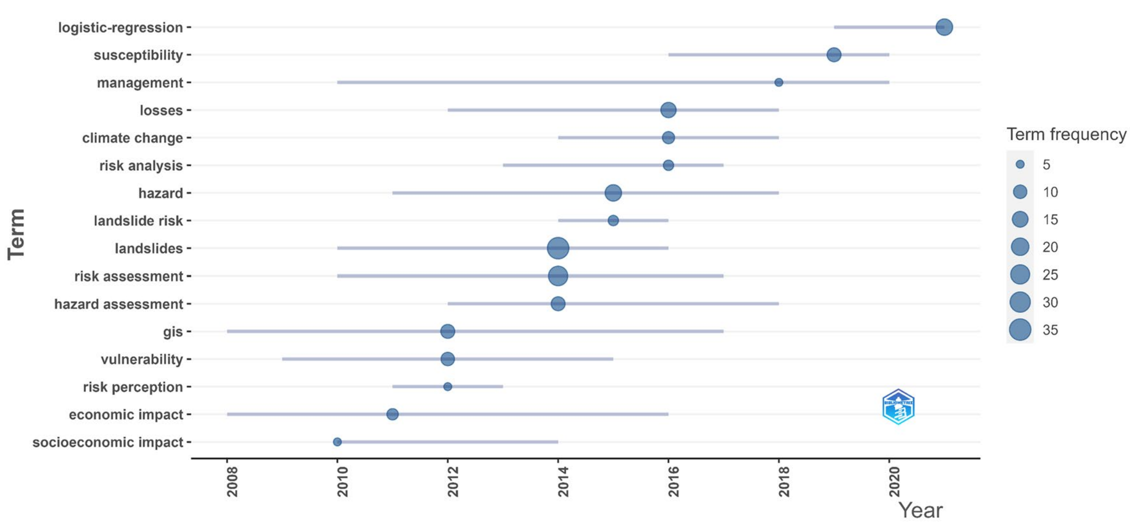


Fig. 11 Trend topics over the years. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

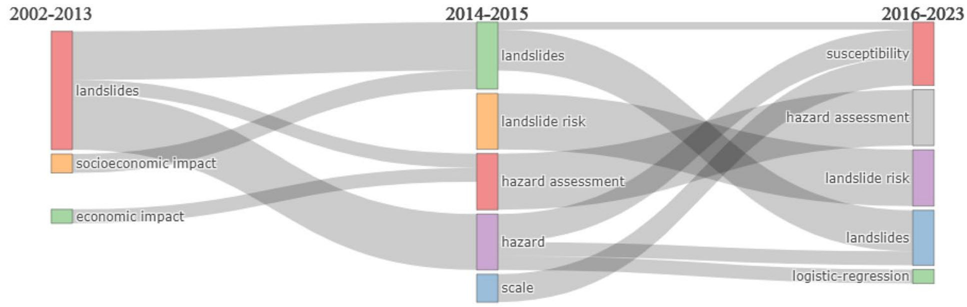


Fig. 12 Thematic evolution of KeyWords Plus. Source: Authors' own research using the Bibliometrix tool, as well as Scopus and WoS databases

approach promises to refine existing risk mitigation strategies, enhance preparedness efforts, and promote sustainable land use policies in the face of escalating landslide risk scenarios.

Thematic evolution

Thematic evolution, a bibliometric technique, is a pivotal tool for imbuing historical research with a historical perspective and engendering a science-driven paradigm to steer forthcoming research trajectories (Moral-Munoz et al. 2018). It accentuates the salient research themes that have evolved, thereby offering illuminating insights into the prospective course of the field (Chen et al. 2019). The visual representation in Fig. 12 delineates the temporal progression of frequently employed terms in investigating landslide risk assessment and its economic losses, as inferred from the co-occurrence network spanning 2002 to 2023. A longitudinal perspective was employed to analyze thematic evolution, dividing the analysis into significant periods from our study: 2002–2013, 2014–2015, and 2016–2023. These worldly anchors encompass pivotal junctures such as the first articles written on this topic (2002–2013), the explosion of research on this topic in 2014–2015, and the more recent times spanning 2016–2023 (August), encapsulating a holistic representation of evolving dynamics of the issue.

From 2002 to 2013, the most popular keywords were landslides, socio-economic impact, and economic impact. In that period, the explorations were directed towards the macroeconomic effects caused by landslides. These three topics were merged into the next time slice (2014–2015) as landslides, landslide risk, hazard assessment, hazard, and scale. It is essential to mention that the term "hazard" is divided into three branches in the next time slice (2016–2023): susceptibility, landslides, and logistic regression. These terms have appeared as a joint research topic in recent times when a study of landslides and their impacts has been made holistically.

Discussion

Scientometric reviews conducted on landslide risk assessment and its economic losses offer a comprehensive understanding of its impact in different areas such as social, environmental, political, and economic. The review of the existing literature on landslide risk assessment and its economic losses analysis has been increasing in recent years. The review conducted by Carrión-Mero et al. (2021) analyzed various landslides documented by the United States Geological Survey (USGS). Their study emphasizes the multifaceted nature of landslides, the causes, the resultant geomorphological changes, and socio-economic consequences. The emphasis on techniques for vulnerability reduction, sector-specific susceptibility, and slope stability improvement carries significance for disaster mitigation. In the context of the paper, this sentence provides contextualization for the relevance of landslide research, outlining its interdisciplinary nature and societal impacts. In addition, Wu et al. (2015) present a bibliometric analysis encompassing a specific period and data sources. It illuminates the growth trajectory of landslide research, major science categories, active journals, and geographic distribution. It establishes the paper's connection with previous research efforts and contributes empirical evidence to understanding the evolution of landslide research.

Furthermore, Yang et al. (2019) conducted a bibliometric analysis of the evolution of landslide research and research encompassing a broader timeframe and different countries. The mention of specific research trends, such as landslide susceptibility analysis and machine learning methods, aligns with the overarching theme of understanding landslide risk assessment and its economic consequences. Overall, this scientometric analysis from review articles contributes to understanding landslide risk assessment and its financial losses by offering a foundation for the study's context and highlighting the global growth of landslide research, its interdisciplinary nature, evolving trends, and geographic patterns. Finally, Gokceoglu and Sezer (2009) offer a perspective on the scarcity of statistical assessments within landslide literature and highlight the complexity of landslides' natural phenomena. This view contributes to the paper's overarching aims by indicating the gap in comprehensive bibliometric analysis and setting the stage for the significance of the scientometric analysis carried out in the paper. The presented reviews of the topic underscore the importance of techniques for vulnerability reduction, indicate how research foci vary in different countries, and provide a solid empirical basis for comparison and analysis within the scientometric framework of the study. However, literature review studies on landslide risk assessment and economic losses are unavailable. Nevertheless, recent studies highlight the importance of incorporating the economic assessment of landslides from a holistic perspective to measure the global impact of a disaster.

Compared to the literature reviews, this study examines recent trends and new researches concerning the integration of landslide risk assessment and its economic losses—an aspect overlooked in prior analyses. Employing innovative tools like VOSviewer and Bibliometrix, this research identifies and contributes to current trends, serving as a foundation for future studies. Based on the scientometric analysis, the study expands the knowledge frontier in the analysis of landslide risk assessment and its economic losses. Ultimately, this work aims to offer valuable insights to researchers, policymakers, and decision-makers, enhancing the understanding of landslide risks and their economic implications.

Additionally, researchers have identified several key issues in the domain of global landslide risk assessment.

Global biases in natural hazard research

The analysis highlights the challenges in generalizing findings and estimating global economic losses due to variations in landslide occurrences worldwide. Biases in research funding and priorities often concentrate on specific regions with higher landslide activity, neglecting many countries and leading to inadequate examinations of landslide occurrences and knowledge disparities. Addressing these gaps is crucial for a comprehensive and unbiased global understanding of global landslide risks (Kahn 2005; Substance Abuse and Mental Health Services Administration 2017; Qi et al. 2023; Stein et al. 2024).

Absence of depurated, reliable, and comprehensive databases with data on direct costs

The topic discusses the importance of comprehensive and reliable data on landslide occurrences, impacts, and economic losses for accurate assessments and effective disaster preparedness. However, existing disaster databases suffer from missingness and fragmentation, hindering global assessments and data utilization. Standardized and complete databases are essential for effective risk assessment and mitigation policies (Petley 2012; Sepúlveda and Petley 2015; Kirschbaum et al. 2015; Froude and Petley 2018; Jones et al. 2022; Gómez et al. 2023).

Standardized data on the vulnerability assessment of exposed elements

Vulnerability assessment, critical for understanding landslide risks, faces challenges due to the lack of standardized data and methodologies. Variations in vulnerability across regions and the dynamic nature of vulnerability necessitate continuous monitoring and data updating. Inconsistent terminology and methodologies hamper the generation of reliable data on the vulnerability of exposed elements, leading to difficulties in estimating economic losses (Eidsvig et al. 2011; Field 2012; Pellicani et al. 2017; United Nations Development Programme (UNDP) and United Nations Office for Disaster Risk Reduction (UNDRR) 2022; Tyagi et al. 2022).

Standardized methods for estimating economic losses in risk studies according to the level of quantification

The topic emphasizes the need for standardized methods for estimating economic losses post-disaster in landslide risk studies. Challenges include the lack of consensus on terminology, difficulties in quantifying indirect costs, and the dynamic nature of vulnerability. The study concludes by stressing the importance of universally accepted methodologies to enhance the accuracy and reliability of economic loss estimates (Hallegatte and Przyluski 2010; Quan Luna et al. 2013; Vega et al. 2017, 2019, 2023; Kreibich et al. 2022).

Addressing these issues requires research collaboration, enhanced data sharing and standardization, and resource allocation for comprehensive research. By considering regional variations, improving data availability and accessibility, and incorporating local contexts, more accurate assessments of economic losses associated with landslide disasters can be achieved on a global scale.

Conclusions

Scientometric reviews are crucial in enhancing our comprehensive understanding of landslide risk assessment and economic losses, shedding light on their impact across various areas while highlighting the interdisciplinary nature of landslide research. Additionally, recent bibliometric analyses have yielded valuable empirical evidence, uncovering the growth and evolution of landslide research. The current research has the potential to explain the complex connections between climatic shifts, hydrogeological hazards, and their economic and environmental consequences by integrating advanced statistical techniques like logistic regression with climate change scenarios and susceptibility assessments. These analyses have helped identify emerging trends, active journals at the forefront of this field, and geographic patterns, further enriching our knowledge of the subject matter. Such insights from literature reviews and bibliometric analyses collectively contribute to advancing landslide research and provide a solid foundation for further research.

This scientific study employs advanced scientometric methods, including VOSviewer and Bibliometrix, to comprehensively analyze the landscape of landslide risk assessment and its economic losses research. Examining 92 studies from 2002 to August 2023 using sources like Scopus and Web of Science, we uncover trends and avenues for further exploration. The author's keywords like "landslides," "landslide risk," "vulnerability," "debris flow," "risk," and "climate change" emerge as significant focal points. Similarly, KeyWords Plus highlights terms like "landslides," "risk assessment," "hazard," "susceptibility," and "logistic regression" as essential in this research context.

The study outcomes are subject to bias due to the dynamic evolution of research trends, the emergence of novel methodologies and technologies, and evolving disaster events that could impact the pertinence and significance of specific themes, potentially impacting the precision of conclusions drawn from the analysis. Moreover, the study's concentration on particular regions or countries within the reviewed literature may constrain the broader applicability of findings to a global perspective. Nevertheless, this study presents an inclusive survey of the research panorama encompassing landslide risk assessment and its economic implications. By discerning influential authors, institutions, and prevailing research trajectories, the analysis guides researchers in navigating this domain and facilitates their contributions. The revelation of nascent themes and evolving trends in the research provides essential foresight into the prospective course of research. Moreover, the study fosters a connection between scientific inquiry and real-world policies and practices.

The integration of landslide risk assessment and its economic losses has been overlooked in prior analyses, making the current study significant in addressing this gap and identifying recent research trends. Further research is essential to comprehensively assess hazards and their impacts, explore innovative approaches in landslide risk assessment, leverage GIS for climate-influenced hazard mapping, and synergize machine learning and logistic regression techniques for improved prediction models and risk assessment. Considering the evolving global landscape, cross-disciplinary collaborations could offer fresh perspectives on comprehensive risk management strategies encompassing environmental, socio-economic, and policy dimensions. Additionally, longitudinal studies assessing the effectiveness of implemented mitigation measures would provide critical feedback for refining existing practices.

This scientometric analysis significantly advances the understanding of landslide risk assessment and economic losses. However, it is important to address the limitations of this study and explore further avenues for research. By doing so, it is to possible enrich the discourse surrounding this pressing issue, enhance methodologies, and empower decision-makers in effectively tackling landslide risks. Furthermore, this study's insights are valuable to researchers, policymakers, and decision-makers. The study enhances our understanding of landslides' economic implications and offers data collection strategies. By expanding the knowledge frontier in this field, we can continue to deepen our understanding of landslide risks and develop more effective approaches to mitigate them.

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Declarations

Conflict of interest The authors declare no competing interests.

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