Journal of the Geological Survey of Brazil

A scientometric study on Artificial Intelligence for landslide prediction: Trends, collaborations, and advances

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Abstract

This scientometric study analysed 1,834 publications (2009–2023) on artificial intelligence applications in landslide prediction, revealing rapid growth (26.66% annual citation rate) with an average of 45.80 citations per paper. Despite the increased number of publications, the citation impact has not increased proportionally. The top 25 authors contributed 50.87% of the total output, while international collaborations (42.42% of papers) drove progress, with China and Vietnam as key contributors. Funded research (1,307 papers) generated 59,863 citations. Geology dominated the discipline, although agriculture achieved the highest citation impact. Q1 journals (e.g. Catena and Landslides) outperformed Q2 venues (e.g. Remote sensing) in terms of citations. Among the 227 highly cited papers (12.38% of the total), the average citation count was 215.1. The core themes included machine learning, landslide susceptibility, and deep learning. The findings highlight AI's multidisciplinary potential of AI but underscore the need for enhanced international collaboration, explainable AI for model transparency, and strategies to mitigate citation biases to maximise research impact.

Article Information

Publication type: Research papers
Received 9 August 2025
Accepted 28 October 2025
Online pub. 6 November 2025
Editor *ad hoc*: Jessica G. Santos

Keywords:
Landslide prediction
Artificial intelligence
Machine learning
Scientometric analysis
Citation life cycle
International collaboration

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Accepted manuscript – Uncorrected pre-proof

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ISSN: 2595-1939
https://doi.org/10.29396/jgsb.2025.v8.n3.4
Open access at jgsb.sgb.gov.br

1. Introduction

Landslides are among the most frequent and devastating natural hazards worldwide, leading to severe loss of life, property, and infrastructure. Therefore, understanding and predicting landslides is vital for effective disaster management and sustainable development within geoscientific research. In recent years, Artificial Intelligence (AI) has emerged as a transformative tool in landslide studies, integrating remote sensing (RS), machine learning (ML), and Geographic Information Systems (GIS) to enhance the detection, monitoring, and risk assessment accuracy (Vaiapury & Uma, 2025). Traditional approaches are increasingly being replaced by ML and deep learning techniques, which offer improved objectivity, efficiency, and predictive precision (Ajraoui et al., 2024; Kappi & B, 2024). Parallel to these technological advancements, scientometric analyses have gained prominence for evaluating the evolving landscape of AI applications in landslide prediction. By systematically examining publication trends, citation patterns, and research collaborations, scientometric studies have revealed growing global interest and methodological diversity in this field (Ahmad et al., 2025). They also help identify influential algorithms, such as Superposable Neural Networks and conventional ML models, that have achieved predictive accuracies ranging from 75% to 95% (Korup & Stolle, 2014). Such analyses not only highlight the scientific progress made but also underscore the interdisciplinary nature of this research, where geoscience, computer science, and environmental studies converge. Continued advancements will rely on integrating climate data, real-time monitoring, and advanced computational models to improve predictive reliability. Despite the promise of AI-driven approaches, challenges related to data heterogeneity and model validation persist, thereby emphasising the need for sustained, collaborative, and evidence-driven research.

Building on this background, this study offers a comprehensive scientometric assessment of global research on the application of AI in landslide studies. Specifically, it aims to analyse publication trends and citation distributions to understand the overall growth and scholarly impact of this field. This study also seeks to identify the key research areas that define the intellectual landscape of AI-driven landslide research. In addition, it examines the most productive and influential authors, institutions, and countries that contribute to this domain, along with the journals most commonly used to disseminate related findings. Furthermore, the citation history of highly influential papers was examined to trace the evolution of foundational knowledge. This study also explores co-authorship patterns among authors, institutions, and countries, as well as journal co-citation networks, to reveal the underlying collaboration and communication structures. Finally, it aims to uncover the thematic patterns and intellectual foundations that characterise this area of enquiry.

Based on these objectives, this study provides a holistic perspective on the development, collaborative dynamics, and thematic evolution of AI applications in landslide research. Mapping the growth and structure of this emerging field contributes not only to the understanding of scientometric trends but also to advancing geoscientific knowledge in disaster prediction and risk management.

The application of AI in landslide prediction has transformed geohazard research by offering enhanced accuracy and dynamic modeling capabilities (Akanksha Sharma et al., 2024; Amol Sharma et al., 2023). Machine learning techniques, including random forests and support vector machines, have become fundamental tools for landslide susceptibility mapping (Jiang et al., 2022; Kumar et al., 2017). Deep learning models, particularly Convolutional and Recurrent Neural Networks, further improve the predictive performance by capturing complex spatial and temporal patterns (Kappi & Mallikurjuna, 2024; Lokesh et al., 2025; Thirugnanam, 2023). Recent innovations have involved hybrid approaches that combine multiple AI techniques to address data limitations and improve robustness (Blasch et al., 2021). The integration of remote sensing data, such as Synthetic Aperture Radar (SAR) and Google Earth Engine, has enabled dynamic landslide assessment by incorporating real-time environmental variables (Li et al., 2022; Nocentini et al., 2023). Furthermore, knowledge graphs and spatiotemporal models enhance generalisation across diverse geological settings (Kainthura & Sharma, 2022). Despite these advancements, challenges persist, including data scarcity, computational demands of deep learning models, and limited model transferability (Lima et al., 2022). To address the gaps in quantitative analysis, this study systematically evaluated AI applications in landslide prediction from 2009 to 2023. Assessing trends and limitations provides a foundation for future research, emphasising the need for adaptive models, improved data sharing frameworks, and computationally efficient solutions. These efforts will strengthen AI's role of AI in sustainable landslide risk management.

2. Data source and methodology

Data for this study were systematically obtained from the Web of Science (WoS) Core Collection on 18 August 2024, which offers comprehensive coverage across 229 subject categories and 21,800 journals. The search strategy used Boolean operators (AND, OR) within the TOPIC (TS) field, encompassing titles, abstracts, author keywords, and keywords, to identify publications related to AI, landslides, and predictive modelling from 2004 to 2023. All indexed documents, including research articles, reviews, conference papers, book chapters, and editorials, were included to capture the full breadth of scholarly output. Retrieved records containing bibliographic and citation information were exported in plain-text format and analyzed using VOSviewer (version 1.6.18) and Bibliometrix (version 3.1) in R Studio (version 4.2.1). The citation impact was normalised using the Journal Citation Indicator (JCI) to ensure comparability across disciplines and publication years. The analysis comprised three main phases: (i) performance analysis to assess publication growth, citation impact, and leading contributors; (ii) science mapping to visualise collaboration and co-citation networks; and (iii) thematic and cluster analysis to identify key research trends and conceptual structures. The results from both software tools were cross-validated to enhance the analytical reliability and interpretive robustness. Although the WoS Core Collection offers extensive and high-quality coverage, this study was limited by its reliance on a single database, which may have excluded relevant publications indexed elsewhere. In addition, citation-based metrics are subject to temporal and disciplinary biases. Despite these constraints, the methodological framework provides a reliable and reproducible foundation for evaluating global research trends in AI-driven landslide studies.

3. Results and interpretation

Figure 1 presents key information on AI applications in landslide prediction research (2009-2023), revealing 1,834 documents across 326 sources that generated 89,242 citations with a significant annual growth rate of 26.66%. These publications, with an average age of 3.92 years and citation impact of 46.57 CPP, draw upon 56,016 references and are indexed through 3,994 author keywords and 2,133 Keywords Plus. Funding from 1,381 agencies supported 1,307 documents (71.3%), yielding 59,863 citations (average 45.80 CPP). The research community comprises 5,540 authors, with limited single-authored contributions (39 papers) and substantial collaborative patterns (average 5.12 co-authors per document), including significant international collaborations (42.42%). The corpus predominantly consisted of articles (96.3%), with smaller proportions of reviews, conference papers, and other formats. Notably, 12.4% of publications (227) achieved highly cited status, indicating their considerable influence within the field.

Figure 1: Main information about the data

3.1 Trends in publications, citation distribution, and funding agencies

Figure 2 and Table 1 present a year-wise analysis of AI research on landslide prediction, revealing a consistent upward trend in publication volume from 2009 (n = 14) to a peak in 2022 (n = 400), followed by a slight decline in 2023 (n = 383). Despite this output growth, the average CPP shows a declining trend, falling from over 100 in the early years, peaking at 155.04 in 2012 and falling to just 7.32 in 2023. This decrease reflects the time-dependent nature of citation accumulation because newer publications have had less opportunity to garner citations. Total citations peaked in 2020 at 14,529 but declined thereafter, even as publication numbers continued to rise, indicating that recent research has not yet achieved a substantial citation impact. Although highly cited papers represent only 12.4% of the total publications, they account for a disproportionate 54.7% of all citations, underscoring their significant role in advancing the field. In contrast, uncited papers (NCPs) emerged only after 2015, reaching a high of 39 in 2023 (10.2%), which may indicate challenges in visibility, dissemination, or relevance. However, usage metrics indicate increasing engagement with the literature: 2023 recorded the highest 180-day usage count (5,315) and contributed 12.5% to the total usage count (127,177) since 2013. This suggests that while recent publications may not yet reflect strong citation performance, they are attracting considerable reader interest, signaling their emerging importance in the scholarly community. The citation distribution (Table 2) further revealed a pronounced disparity in the influence of research. While 2.89% of papers (n = 53) remain uncited, a significant portion (29.66%; n = 544) has received only 1 to 9 citations, indicating limited academic impact. Conversely, papers with 50–99 citations (14.94%; n = 274) accounted for 19,693 citations, whereas those cited 100–499 times (11.78%; n = 216) accumulated 41,212 citations. Notably, 11 papers (0.60%) received between 500 and 1,118 citations, collectively contributing 7,614 total citations.

Of the 1,834 research papers, 1,307 (71.26%) received support from 1,381 funding agencies worldwide, with 59,863 citations and an average of 45.80 CPP. A total of 1,381 funding agencies supported 1,307 publications that received 59,863 citations with an average CPP of 45.80. Among them, the top 20 agencies (Table 3) funded 1,028 papers, indicating that most research in this field was supported by a few major funders. Most of these agencies are located in East Asia, especially China, Korea, and Japan. The National Natural Science Foundation of China (NSFC) leads with 437 papers and 14,839 citations (CPP = 33.96), reflecting its central role in promoting this research area. Other key Chinese funders, including the National Key Research and Development Program of China (n=157, CPP = 37.10), Fundamental Research Funds for Central Universities (n=59, CPP = 38.34), and China Postdoctoral Science Foundation (n=53, CPP = 77.42), also show strong support and impact. The Chinese Academy of Sciences stands out with a smaller output of 31 papers but a high CPP of 89.03, showing the influence of its funded work. Outside China, the National Research Foundation of Korea (n=30, CPP = 52.03) and the Ministry of Science and ICT, Korea (n=24, CPP = 58.21), highlight Korea's growing role in this area. The University of Technology Malaysia achieved the highest CPP (153.47), with only 19 papers indicating exceptional impact. European and international funders, such as the Austrian Science Fund (CPP = 100.06) and UK Research Innovation (CPP = 61.29), contributed fewer papers, but with high citation rates. The top 20 funding agencies together produced 47,417 citations with an average CPP of 46.13, slightly above the global average, showing that major funders not only support more research, but also help increase its visibility and impact.

Figure 2: Year-wise performance of publications and citation trends

Table 1: Year-wise performance of publications with various indicators

Table 2: Distribution of citations

Table 3: Top 20 funding agencies

3.2 Major Research Areas

Figure 3 illustrates the disciplinary variations in productivity and impact within the research field. Geology emerged as the dominant field, producing 991 publications that accumulated 55,824 citations, yielding the highest average citation rate (CPP=56.33) among major disciplines. This demonstrates the established centrality of geology in landslide research. Environmental science and ecology followed with 639 publications and 26,720 citations (CPP=41.82), reflecting a substantial but comparatively lower impact. Engineering (508 publications, CPP=49.12) and Water Resources (426 publications, CPP=51.07) maintained strong representation, highlighting their technical contributions to prediction methodologies. Notably, Agriculture exhibits an exceptional citation impact (CPP=115.08) despite limited productivity (77 publications), suggesting that its specialised research generates a disproportionate influence. Conversely, specialised fields such as Telecommunications, Forestry, and Public Environmental Occupational Health demonstrated minimal contributions to both output and impact. Peripheral disciplines, such as Astronomy and Construction, show negligible involvement, with both low publication counts and citation metrics.

Figure 3: Major research areas

3.3 Most productive and impactful authors

A total of 5,333 authors contributed 1,834 papers on AI-based landslide prediction, reflecting the broad and growing research community. However, authorship distribution indicates a strong concentration of contributions among a relatively small group of prolific researchers. The majority, 4,056 authors (76.05%), authored only one paper, while 1,107 authors (20.76%) contributed to 2-5 papers. A small group of 106 authors (1.99%) produced 6-10 papers, 39 (0.73%) published 11-19, and only 25 authors (0.47%) contributed 20-27 papers. The top 25 most productive authors (Table 4) collectively accounted for 933 papers, representing over half of the total output (50.87%) and accumulating 88,890 citations (20.40%), underscoring their substantial influence in this domain. Among them, Pradhan Biswajeet (University of Technology Sydney) ranked first with 77 papers, 31 HCPs, 10,612 citations, and h- and g-indices of 46 and 77, respectively, yielding a CPP of 137.82. He is closely followed by Dieu Tien Bui (University of South-Eastern Norway), with 70 papers, including 38 HCPs, 10,048 citations, and the highest CPP of 143.54, reflecting the exceptional impact of his research. Other prominent contributors include Binh Thai Pham (Gujarat Technological University) and Chen Wei (Xi'an University of Science and Technology), each with more than 65 papers and over 6,000 citations. Pourghasemi Hamid Reza (Shiraz University) produced 56 papers with a CPP of 113.29, while Shahabi Himan (University of Kurdistan Hewler) authored 52 papers, garnering 6,176 citations. Collectively, these authors represent diverse international cohorts from Australia, Norway, India, China, Iran, and South Korea, emphasising the global nature of AI-driven landslide research. Together, they produced 315 HCPs, with an average CPP of 95.27, highlighting their pivotal role in advancing the development, visibility, and intellectual foundation of research on AI-based landslide predictions.

Table 4: Top 25 most productive and impactful authors

3.4 Most productive and impactful institutions

A total of 1,855 institutions contributed to 1,834 publications in this study. Of these, 1,178 institutions (63.50%) authored a single paper, 513 (27.65%) published between two and five, 71 (3.83%) produced six to ten, and 68 (3.66%) published 11 to 30 papers. Only 25 institutions (1.35%) contributed between 30 and 131 publications each. Notably, the top 25 institutions accounted for 1,424 publications (77.64%) and 98,905 citations (31.77%) (Figure 4). China and Vietnam dominate this group. The China University of Geosciences led with 131 publications and 6,835 citations (CPP: 52.18), followed by the Chinese Academy of Sciences with 110 publications and a CPP of 34.37. Some institutions exhibit a high impact despite a low output. For instance, the University of Kurdistan (Iraq) achieved a CPP of 111.18 with 61 publications, whereas Hanoi University of Mining and Geology (Vietnam) recorded the highest CPP of 137.55 from 29 publications. Ton Duc Thang University and Duy Tan University, also in Vietnam, reported strong CPPs of 91.53 and 85.90, respectively. Nanjing Normal University (China) further exemplifies the high impact with a CPP of 119.74. Conversely, high publication volume does not guarantee influence; for example, Southwest Jiaotong University (China) published 32 papers but recorded a low CPP of 19.16, suggesting limited scholarly impact despite high productivity.

Figure 4: Top 25 most productive and impactful institutions

3.5 Most productive and impactful countries

A total of 96 countries contributed to 1,834 publications on AI-based landslide prediction. Of these, 23 countries (23.96%) published only one paper, 24 (25%) contributed 2–5, 14 (14.58%) produced 6–10, and 10 (10.42%) published 11–20 papers. The top 26 countries (27.08%) each contributed between 21 and 820 publications, and together accounted for 3,080 publications and 182,856 citations, exceeding 100% of the total, owing to international co-authorship (Table 5). China led in productivity with 820 publications but had a low international collaboration rate (5.98%), resulting in 30,977 citations and a CPP of 37.78. Vietnam, despite a smaller output (204), achieved a high CPP of 89.25 and a higher ICP rate (22.06%). Iran (290, CPP 78.08, ICP 17.59%) and India (248, CPP 48.84, ICP 19.35%) also made strong contributions. Malaysia, with 114 publications, achieved the highest CPP (113.95) and a notable ICP rate (27.19%), indicating high-quality collaborative research. Norway recorded the highest CPP (132.11) and 50% ICP rate, underscoring the value of international partnerships. Conversely, Pakistan and Bangladesh, despite their high ICP rates (87.10% and 113.04%, respectively), had lower CPPs (15.48 and 34.74, respectively), suggesting limited research impact. Similarly, Switzerland's moderate CPP (31.00), despite its high ICP (65.22%), suggests that collaboration quality or focus influences impact more than partnership frequency alone.

Table 5: Top 26 most productive and impactful countries

3.6 Most preferred journals

The Journal Citation Indicator (JCI) enables the normalised evaluation of research impact across fields, accounting for variations in discipline, document type, and publication year. A JCI of 1.0 denotes average impact, with values above or below indicating a higher or lower influence, respectively. Although valuable, JCI alone is insufficient; combining it with other citation metrics offers a more comprehensive understanding of scholarly influence, especially considering field-specific citation practices (Collection, 2023). A total of 1,834 documents were published across 326 sources. The majority (272 journals, 83.44%) published only 1–5 papers each, accumulating 13,519 total citations. A smaller segment included 18 journals (5.52%) with 6–10 papers (9,144 citations), 14 journals (4.29%) with 11–20 papers (7,324 citations), and 16 journals (4.91%) with 21–50 papers (27,809 citations). Only six journals published between 51 and 89 papers, contributing 26,013 citations. Remote sensing led with 172 papers and 5,433 citations.

The top 25 journals published 1,146 papers (62.49%) and received 59,929 citations (67.15%) with an average CPP of 52.29 (Table 6). Notably, Remote Sensing (Q2, MDPI) and Natural Hazards (Q2, Springer) were prolific, whereas Q1 journals such as Catena (CPP: 124.05, 8,187 citations) and Landslides (CPP: 78.27, h-index: 33) showed a higher citation impact. Even Q3 journals, such as Environmental Earth Sciences (3,819 citations, CPP = 50.25), demonstrated a significant influence. Other Q2 and Q3 journals, including Geocarto International and Bulletin of Engineering Geology and the Environment, also exhibit strong citation metrics. Specialised Q1 journals, such as Geomatics, Natural Hazards & Risk, and Engineering Geology, reflected high CPPs, emphasising their relevance in landslide-focused geomatics and engineering research. In addition, multidisciplinary journals, such as Scientific Reports and Science of the Total Environment, showed substantial impact, reinforcing the interdisciplinary nature of AI-driven landslide studies. Journals like Sustainability and Sensors (Q2) also contributed significantly to both output and citation performance.

Table 6: Top 25 most preferred sources

3.7 Highly cited papers

Among the 1,834 research papers, 227 (12.38%) were identified as highly cited, defined as those receiving 100 or more citations. These included 215 articles, 11 reviews, and one conference paper each. Citation data were retrieved from the Web of Science Core Collection, covering the period from the year of publication to the end of August 2024. Collectively, these 227 papers, published across 63 journals by 1,179 authors, including eight single-author publications, accumulated 48,826 citations, with an average of 215.1 CPP. Of these, 149 papers received between 100 and 200 citations, 68 received between 201 and 500 citations, and 10 were cited between 501 and 1,051. Notably, 151 of these papers were supported by various funding agencies. Figure 5 shows the citation beauty of the top 10 HCPs, revealing diverse patterns of influence. Reichenbach (2018) achieved a remarkable impact with 1,051 TC, peaking at 259 citations in 2023 before declining slightly to 150 in 2024. Bui's 2016 paper (TC = 889) experienced a steady rise in citations, peaking at 139 in 2020, before declining to 81 in 2024. Pourghasemi (2012) achieved 696 citations, with notable growth from 2014 and a peak of 83 in 2019, followed by a stabilisation. Liu's 2015 paper (TC = 688) exhibited rapid growth, peaking at 129 in 2020 but dropping sharply to 8 citations by 2024.

Similarly, Pradhan (2010) and Yilmaz (2009), with 683 and 656 citations, respectively, demonstrated consistent growth, peaking around 2020. Pradhan's paper reached 75 citations in 2019, while Yilmaz's paper peaked at 72 citations the same year, followed by gradual declines. Were's 2015 paper (TC = 545) also showed a steady rise, peaking at 88 citations in 2020. Yalcin (2011) and Stumpf (2011) garnered 522 and 511 citations, respectively, both peaking at 63 citations in 2019–2020 before plateauing. Goetz's 2015 paper (TC = 516) displayed a gradual upward trend, peaking at 99 citations in 2022, and subsequently declining to 52 in 2024.

Figure 5: Citations beauty of the top 10 HCPs

4. Visualisation of collaborations among countries, authors, institutions, and journals using VOSviewer and co-occurrence networks

VOSviewer is a useful tool to understand scientific collaboration by visually mapping co-authorship, institutional links, Country Collaboration, and citation patterns. This helps identify how researchers work together, which institutions are the most active, and which studies are the most frequently cited. These visualisations reveal key trends, highlight influential contributors, and show that knowledge spreads across various fields. By examining these networks, VOSviewer provides a better understanding of scientific trends and influential connections

Figure 6 shows the co-authorship network among the top 50 authors, which reveals four distinct clusters (Red, Green, Blue, and Yellow) with 459 collaborative links and a TLS of 1,930, indicating an extensive collaborative ecosystem. Cluster 1 Red, comprising 17 authors, is anchored by prolific contributors such as Saro Lee (n=40, TC=3,490, 31 links, 119 TLS) and Biswajeet Pradhan (n=76, TC=10,565, 25 links, 94 TLS), who are central to this network. Supporting figures in this group include Saeid Janizadeh, Fatemeh Rezaie, and Alireza Arabameri, all of whom exhibit robust publication and citation records with notable link strengths in the literature. Cluster 2 Green, with 13 authors, is dominated by Binh Thai Pham (n=70, TC=7,762, 32 links, 270 TLS), whose extensive international collaboration is reflected in his high TLS. This cluster also includes well-cited authors such as Nadhir Al-Ansari, Indra Prakash, and Romulus Costache. In the Blue cluster (Cluster 3), comprising 12 authors, Dieu Tien Bui (n=70, TC=10,048) and Ataollah Shirzadi (n=45, TC=4,639) demonstrated both high productivity and collaborative engagement, with TLS values of 193 and 237, respectively. The Yellow (cluster 4), although smaller with 8 authors, features influential researchers like Wei Chen (n=65, TC=6,460) and Haoyuan Hong (n=42, TC=4,992), indicating significant impact despite fewer collaborative ties.

Figure 6: Top 50 most collaborative authors

Figure 7 shows that the Country Collaboration network includes 96 countries, 51 of which meet the threshold of at least five publications, distributed across seven clusters with 517 collaborative links and a TLS of 2,941. China emerged as the leading contributor (n= 820 and TC= 30,977), indicating its dominance in the field. The United States, although ranking lower in terms of TP (n= 175), shows strong international collaboration with 42 links and a TLS of 320, reflecting its strategic partnerships. Vietnam's impact is notable, with (n=204 and TC= 18,207) supported by 40 links and a high TLS of 621, indicating both research productivity and collaborative intensity. Iran had the highest TLS (695), despite producing 290 papers, showcasing its broad and active collaboration network. India (n=248, TC=12,112) maintains a significant presence with 39 links and a TLS of 460. Countries such as South Korea (TLS 284), Italy (TLS 141), Japan, Norway, and Malaysia, demonstrated varying degrees of influence. Although they contribute fewer publications, their participation in high-impact research through established collaborations reflects a globally integrated research landscape.

Figure 7: Top 51 most collaborative countries

Figure 8 Institutional Collaboration Map visualises contributions from 1,855 institutions, of which 210 met the minimum threshold of five publications each. The top 50 institutions, distributed across five clusters, were connected through 628 links and a combined TLS of 2,645. Duy Tan University emerged as the most central institution with (n=108 and TC=9,277), 47 links, and the highest TLS of 429, reflecting its leadership in the domain. Ton Duc Thang University followed with (n=77 publications and TC=7,048), 42 links, and a TLS of 300, highlighting its significant research output and network. Institutions such as the Agricultural Research, Education, and Extension Organization (AREEO) and the University of Transport Technology demonstrated high collaboration efficiency, achieving TLS values of 152 and 220, respectively, despite moderate publication counts. The Korea Institute of Geoscience and Mineral Resources (KIGAM) also maintained an active profile (n=44, TC=3,365), 39 links, and a TLS of 173. Tarbiat Modares University and Sejong University further enriched the collaborative framework, with the former contributing (n=76) and a TLS of 223. The University of Kurdistan (n= 61, TC=6,782, TLS= 266) underscores the significance of regional institutions in global research. Institutions like Korea University and Shiraz University maintain considerable influence through strategic partnerships despite a comparatively lower volume of publications.

Figure 8: Top 50 most collaborative institutions

Figure 9 Journal Co-Citation Network Map comprises 326 journals, of which 38 met the inclusion threshold of at least 10 publications, distributed across four clusters with 643 links and a cumulative TLS of 13,901. Cluster 1 features leading journals such as Remote Sensing (n=172, TLS= 2,623) and Landslides (n=67, TLS= 1,611), which play a central role in disseminating key findings. Engineering Geology, Sensors, and Scientific Reports also contributed significantly, with strong co-citation links, reflecting their multidisciplinary relevance. Cluster 2 is dominated by Catena, which, despite having 66 publications, holds the highest (TLS= 2,792) highlighting its key role in shaping the intellectual structure of the field. Cluster 3 includes Natural Hazards (n= 89, TLS= 1,787) and Geomatics, Natural Hazards, and Risk (n= 45, TLS= 1,016), indicating a sustained focus on risk modeling and hazard assessment. Cluster 4 features Science of the Total Environment (n= 30, TLS= 1,346), reflecting the journal's relevance in interdisciplinary research. The co-citation patterns underscore the dominance of geoscience and environmental science journals in AI-driven landslide research, indicating cross-pollination of techniques and theories from remote sensing, geology, and data science.

Figure 9: Top 38 most co-cited journals

Figure 10 shows the Keyword Co-occurrence network resulting from 1,834 publications, which identified 3,994 author keywords, with 78.62% (3,140 keywords) appearing only once, 653 keywords (16.35%) appearing 2–5 times, 104 keywords (2.60%) appearing 6–10 times, 64 keywords (1.60%) appearing 11–20 times, and 33 keywords (0.83%) appearing between 21 and 423 times. The analysis resulted in eight thematic clusters, encompassing 513 links and a TLS of 1,947 links. Cluster 1 is characterised by high-frequency terms like "machine learning" (423 occurrences, TLS 517) and "landslide susceptibility" (243 times, TLS 270), indicating a strong focus on predictive modeling and spatial analysis. Cluster 2 is centred on modeling tools, with keywords such as "support vector machine" (71 times, TLS 127) and "geographic information system" (31 times, TLS 47), highlighting the role of GIS in susceptibility mapping. Cluster 3 reflects the integration of AI techniques, with terms like "artificial neural network" (49 times, TLS 78) and "artificial intelligence" (40 times, TLS 57). Cluster 4 highlights advanced imaging and computational techniques, notably "deep learning" (166 times, TLS 208) and "remote sensing" (113 times, TLS 234). Cluster 5 underscores algorithmic diversity, featuring "random forest" (141 times, TLS 229) and "logistic regression" (82 times, TLS 145). Cluster 6 is focused on "landslide susceptibility mapping" (91 times, TLS 114), while Clusters 7 and 8 explore statistical modeling and risk evaluation (Table 7).

Figure 10: 60 Most occurred Author keywords

Table 7: Top 60 Most Occurred Author keywords

5. Discussion

AI research on landslide prediction has seen significant growth from 2009 to 2023, with 1,834 publications generating 89,242 citations. This increase is largely driven by advances in machine learning (ML) and Explainable AI (XAI), which have improved both model accuracy and interpretability. An annual growth rate of 26.66%, with 42.42% of studies involving international collaboration, reflects a concerted global effort to mitigate landslide risk. (Binu et al., 2024; Cheung et al., 2023). Despite this, the surge in publications, especially in 2022, coupled with a declining CPP, suggests a tradeoff between rapid research expansion and immediate impact, with newer studies still accumulating citations (Kappi et al., 2024).

Authorship analysis revealed a concentration of productivity among a small group of researchers, with 76.05% of the 5,333 authors contributing only one publication. By contrast, the top 25 authors produced 50.87% of the total output and garnered 88,890 citations, averaging 95.27 citations per publication (Meho & Akl, 2024). This trend of hyperprolific authorship is accompanied by significant international collaboration, underscoring the growing global network in AI research on landslide prediction (Jakab et al., 2024; Serpa et al., 2024).

Institutionally, a small number of institutions, mainly in China and Vietnam, dominate the field. The top 25 institutions accounted for 77.64% of the total publications but only 31.77% of the total citations, indicating a skewed distribution of research influence. For instance, the China University of Geosciences leads with 131 publications and a CPP of 52.18, whereas the University of Kurdistan, despite fewer publications, boasts a CPP of 111.18 (He et al., 2024). This shows that institutional output does not always correlate with citation impact.

International collaboration data reveal significant disparities in output and influence across different countries. China has 820 publications and 30,977 citations, but only 5.98% of its work involves international collaboration, reflecting high output but relatively low international engagement (AlShebli et al., 2024). In contrast, countries like Vietnam, with a higher CPP of 89.25 and 22.06% international collaborations, demonstrate a greater research impact despite a lower output. Meanwhile, Malaysia and Norway, with CPPs of 113.95 and 132.11, respectively, illustrate the role of collaboration in enhancing research impact, although collaboration alone is not a guarantee of influence, as seen in the lower CPPs of Pakistan and Bangladesh (Alamah et al., 2023).

A few high-impact journals dominate the field regarding publication venues. The top 25 journals accounted for 62.49% of publications and 67.15% of citations, with "Remote Sensing" and "Natural Hazards" contributing significantly despite being in Q2. Higher-impact Q1 journals, such as "Catena" and "Landslides”, show even stronger citation metrics, with "Catena" achieving a CPP of 124.05 (Gould, 2023). Multidisciplinary and specialised journals like "Scientific Reports" and "Engineering Geology" also demonstrate their importance in bridging interdisciplinary research with practical applications in AI-driven landslide prediction (Moustafa, 2024).

In terms of funding, China's dominance is clear, with the National Natural Science Foundation of China leading the contributions (23.83%), followed by the National Key Research and Development Program (4.63%). International support, such as that from the National Research Foundation of Korea highlights global investment in AI-driven landslide risk assessment, contributing to advancements in machine learning and XAI techniques for early warning systems (Kappi et al., 2021; Vaishya, Kappi, et al., 2024).

The analysis of keyword trends further emphasises the focus on AI techniques like "machine learning" and "landslide susceptibility," along with advanced methodologies such as "support vector machine" and "deep learning." However, the integration of XAI remains crucial for ensuring that these models are interpretable and applicable to real-world challenges (Mallikarjuna et al., 2024; Vaishya, Gupta, et al., 2024).

6. Conclusion

This comprehensive analysis yields three principal recommendations for advancing AI-driven landslide-prediction research. First, the field must prioritise quality over quantity by establishing standardised validation frameworks for machine learning applications in geohazard assessments, particularly for models claiming operational readiness (Singha et al., 2024). The current imbalance between methodological sophistication (evident in the ‘deep learning’ and ‘support vector machine’ keyword clusters) and practical implementation (the smaller ‘risk assessment’ cluster) suggests the need for stronger collaboration between computer scientists and geotechnical practitioners. Second, Vietnam's research growth pattern demonstrates how international collaboration serves as an impact multiplier, as evidenced by its elevated citation performance despite a moderate publication output. This success underscores the potential benefits of expanding collaborative networks through structured North–South and South–South cooperation frameworks. Such strategic alliances would counterbalance the current geographic concentration of research influence in dominant regions and enhance context-sensitive solutions for localised landslide challenges.

Third, the growing emphasis on explainable AI (XAI) in keyword trends must translate into concrete practices, as model interpretability remains critical for stakeholder adoption and ethical deployment. Future research should employ mixed-methods approaches to complement bibliometric insights with qualitative data from policymakers and practitioners, particularly in under-represented high-risk regions. As climate change amplifies landslide frequency and severity (IPCC, 2023), the future of this field depends on its ability to balance technical innovation with practical deployability. Addressing this challenge will require sustained investment in interdisciplinary training, open data sharing and equitable collaboration frameworks. While this study provides a robust foundation for understanding the evolution of the field, future work should address its limitations by incorporating broader data sources, particularly patent databases, and conducting more nuanced analyses of citation dynamics.

Authorship credits

Author	A	B	C	D	E	F
MK						
GNMN						
MB						
SJ						

A - Study design/ Conceptualization **B** - Investigation/ Data acquisition
C - Data Interpretation/ Validation **D** - Writing
E - Review/Editing **F** - Supervision/Project administration

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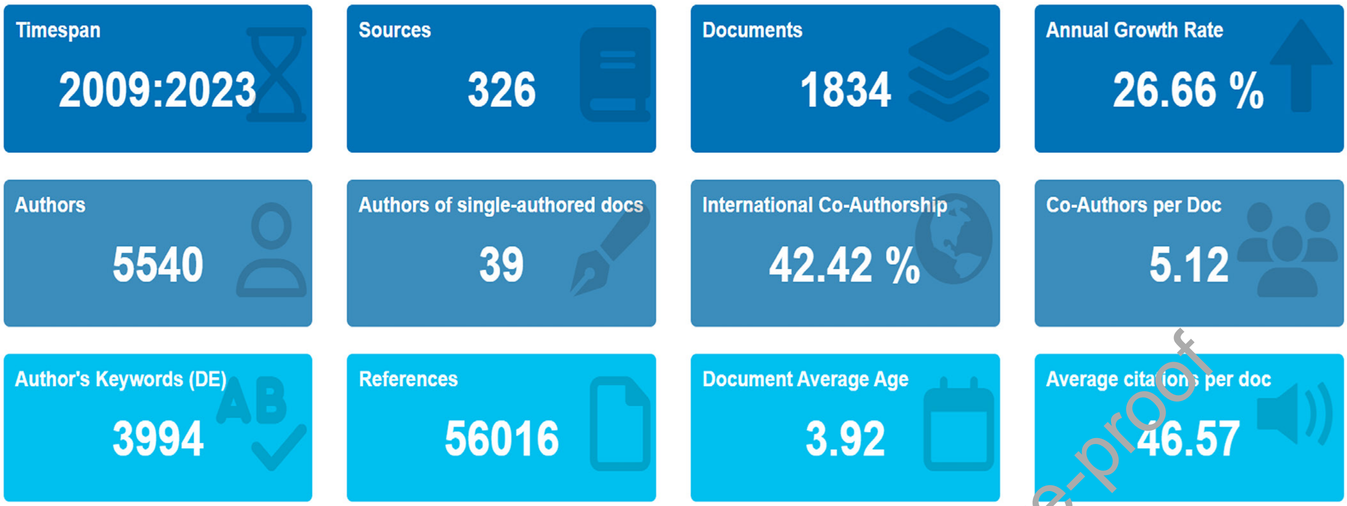

FIGURE 1. Main information about the data.

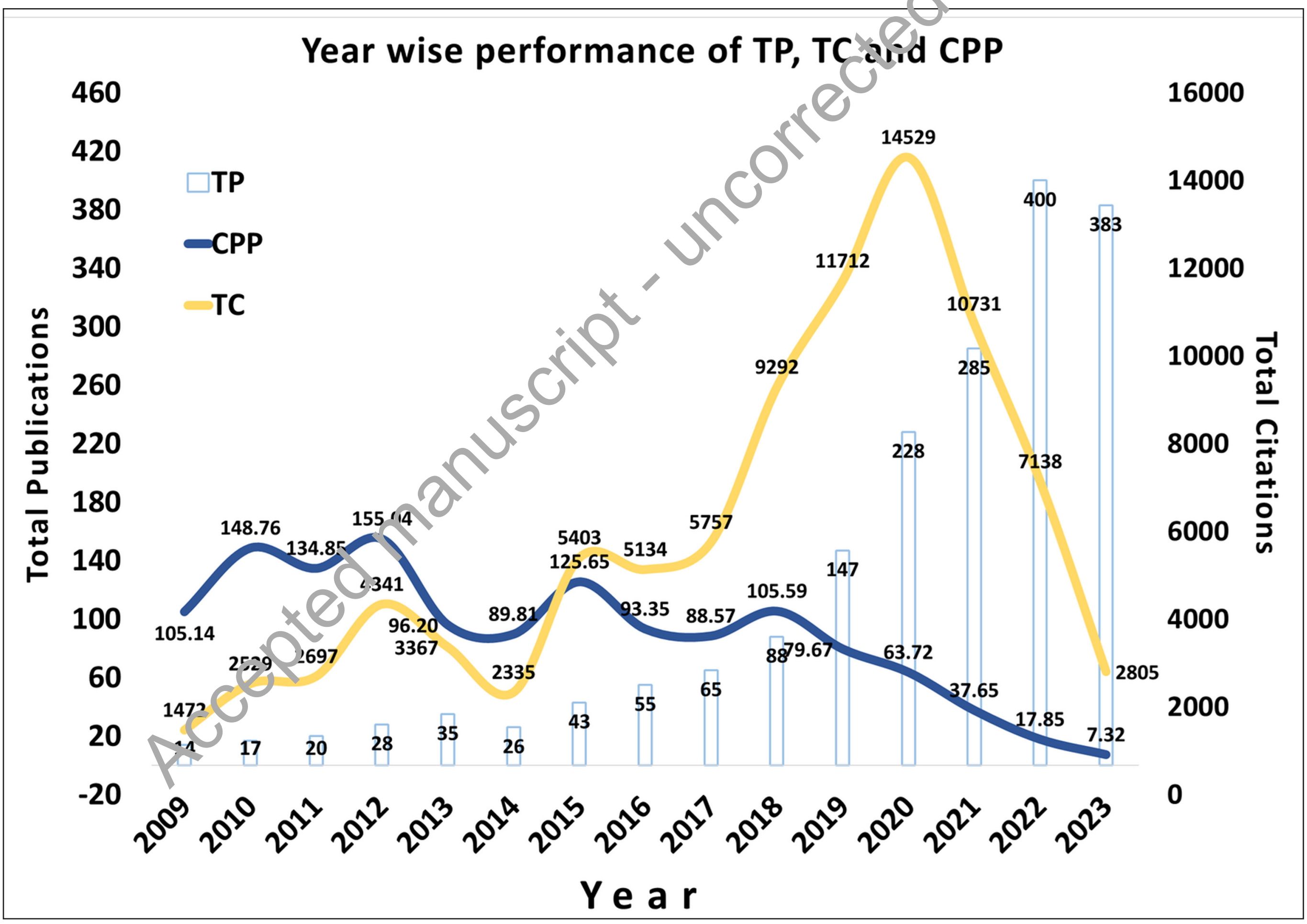

FIGURE 2. Year-wise performance of publications and citation trends.

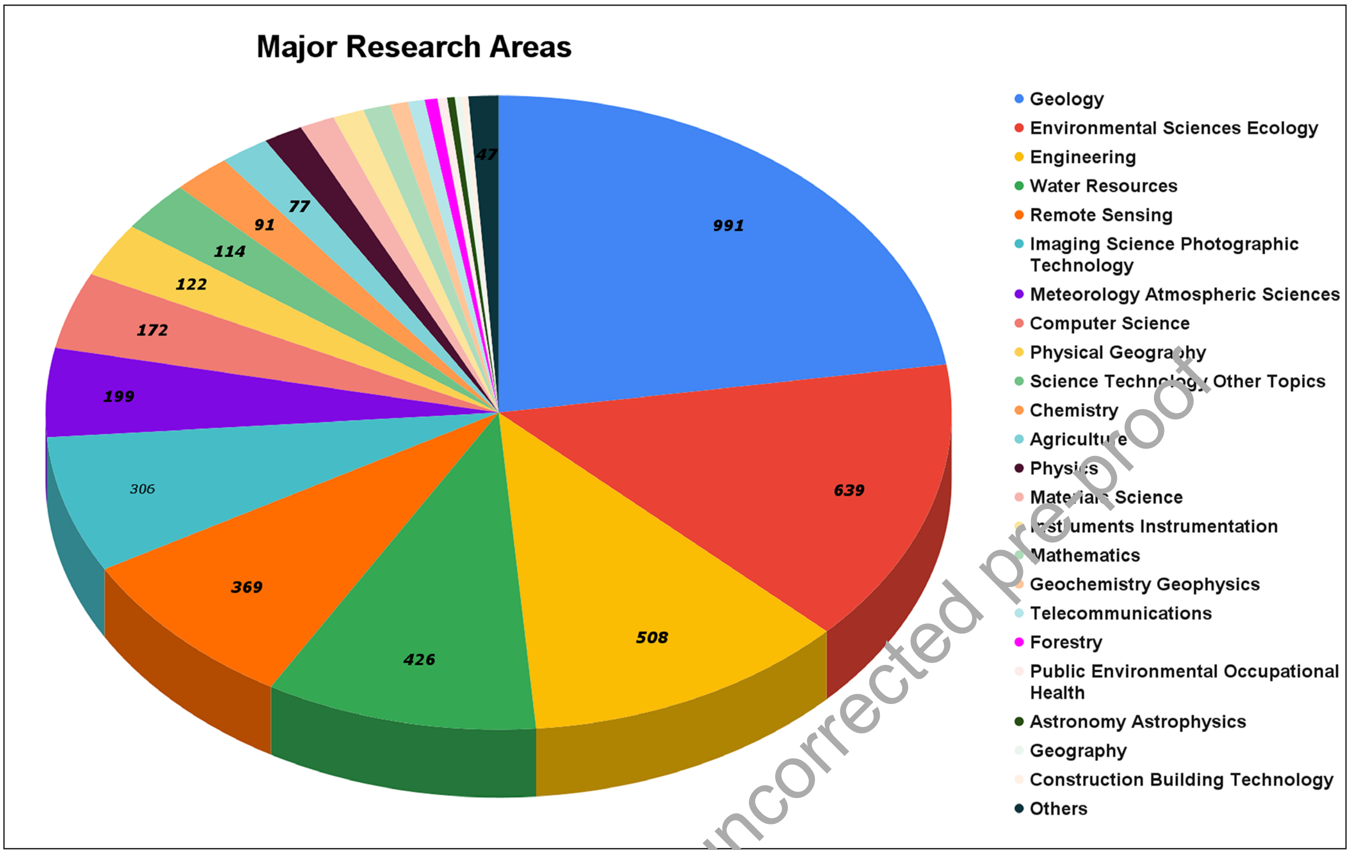

FIGURE 3. Major research areas

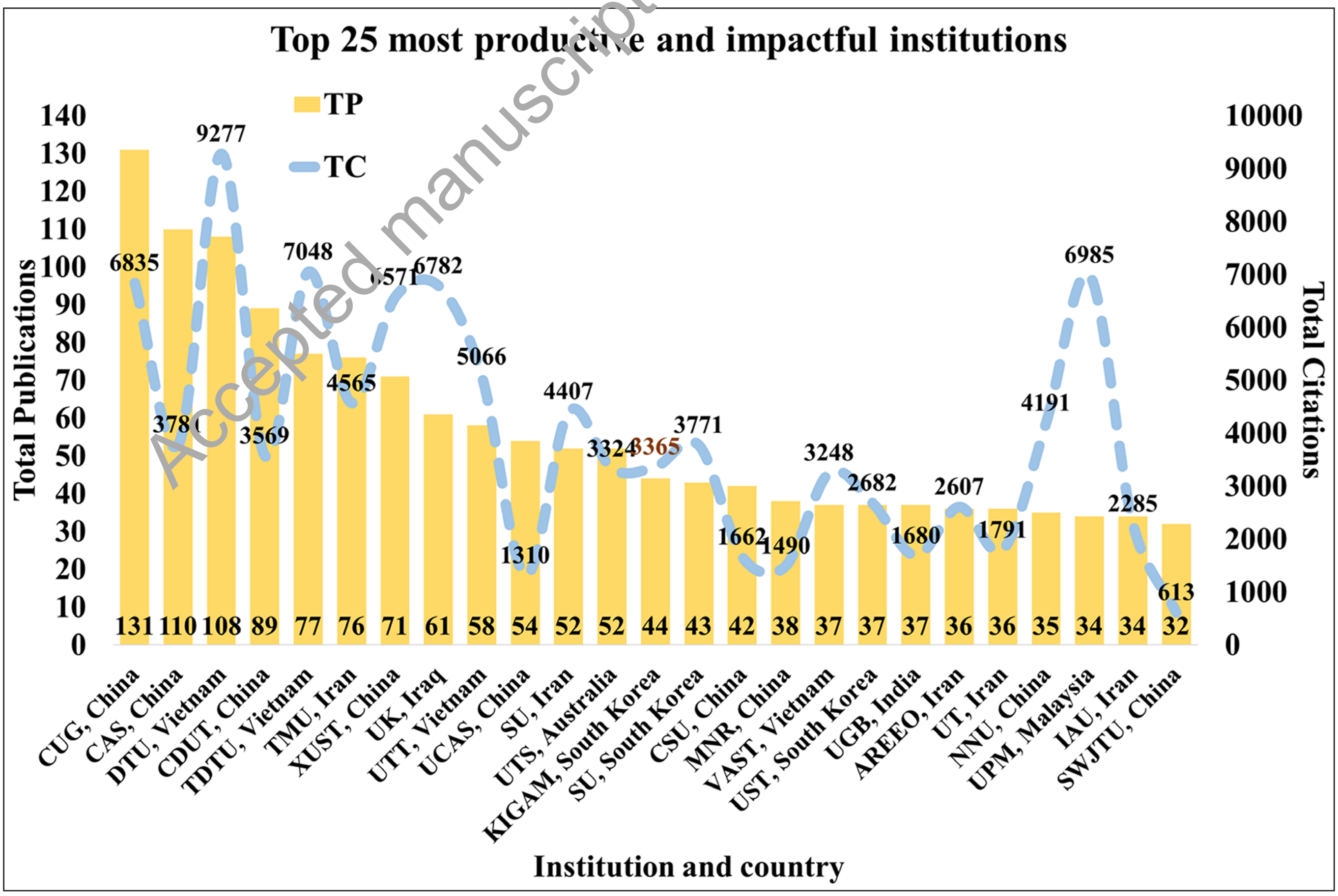

FIGURE 4. Top 25 most productive and impactful institutions

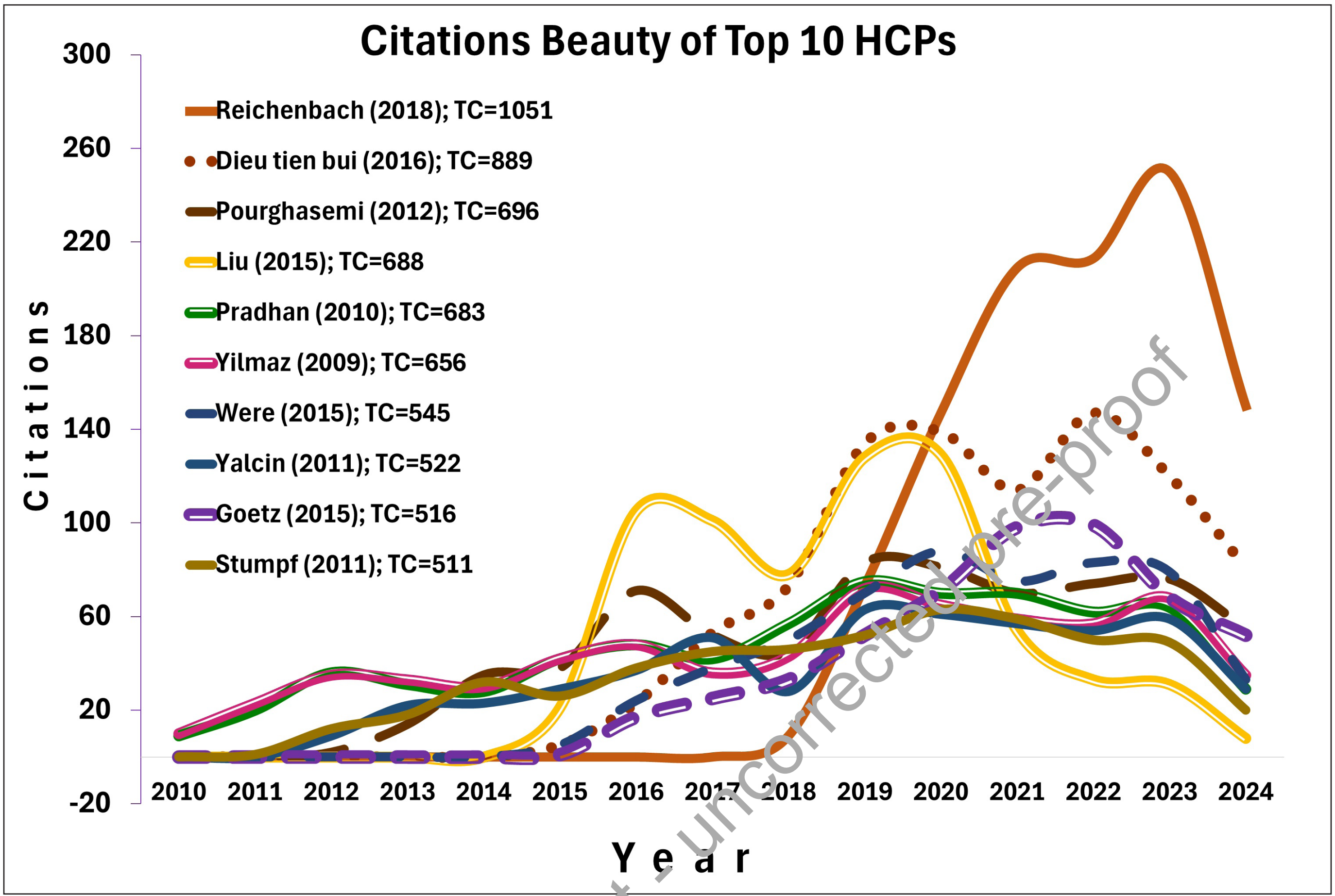

FIGURE 5. Citations beauty of the top 10 HCPs

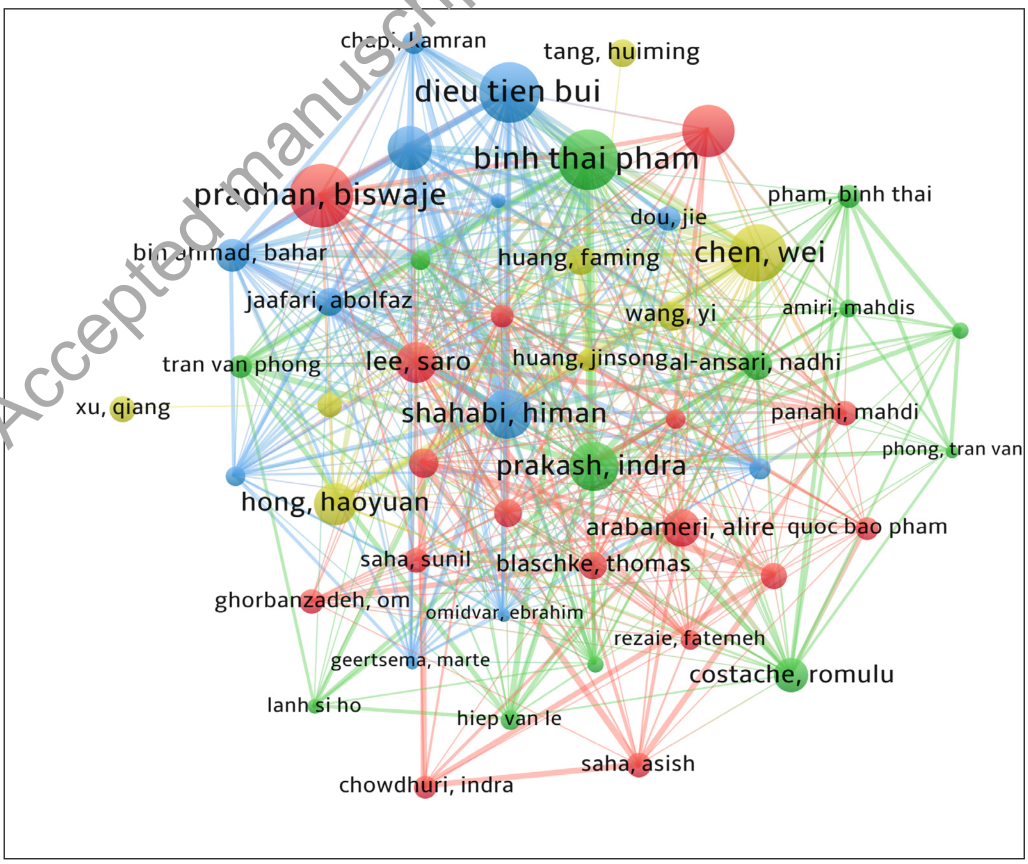

FIGURE 6: Top 50 most collaborative authors

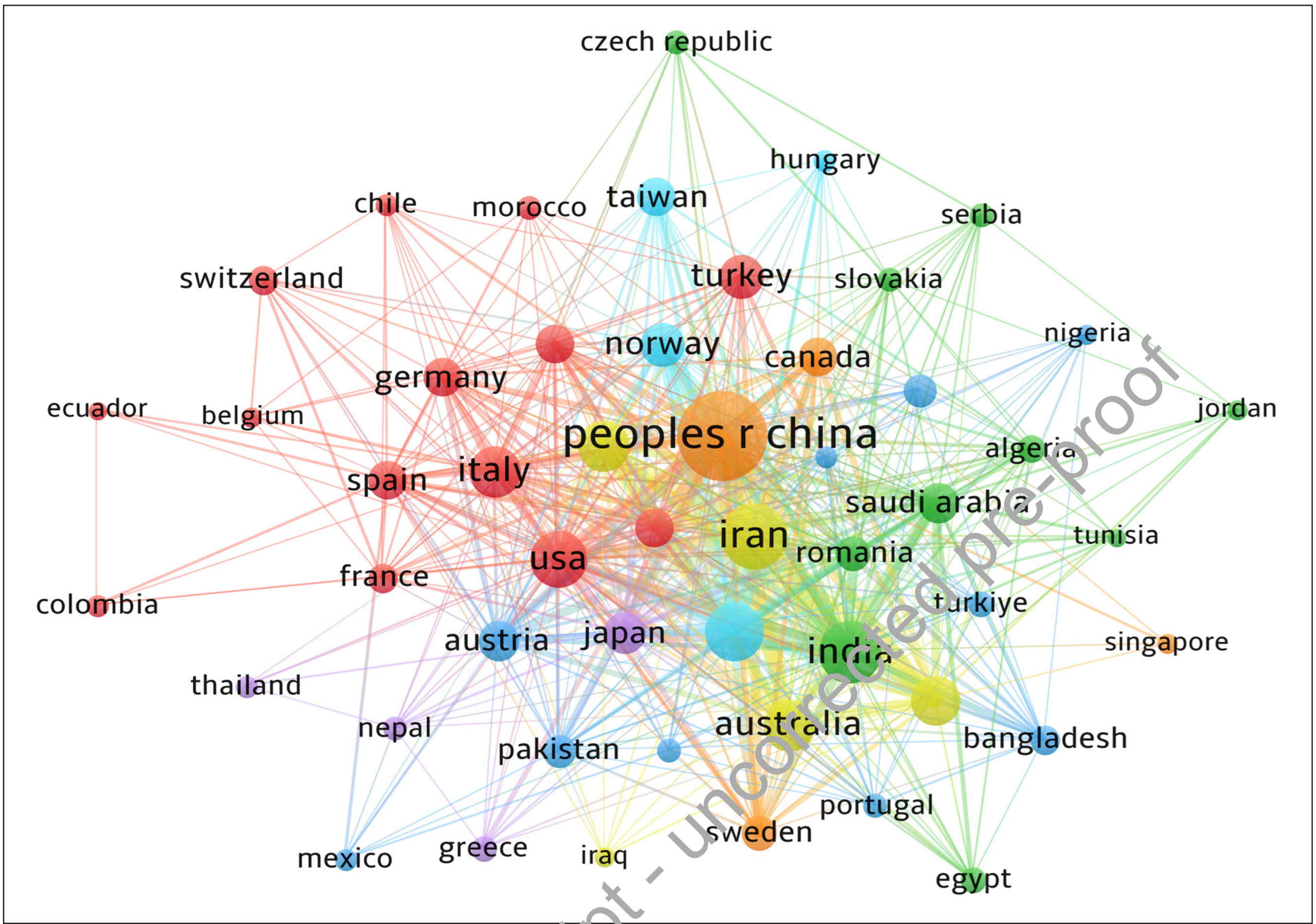

FIGURE 7. Top 51 most collaborative countries

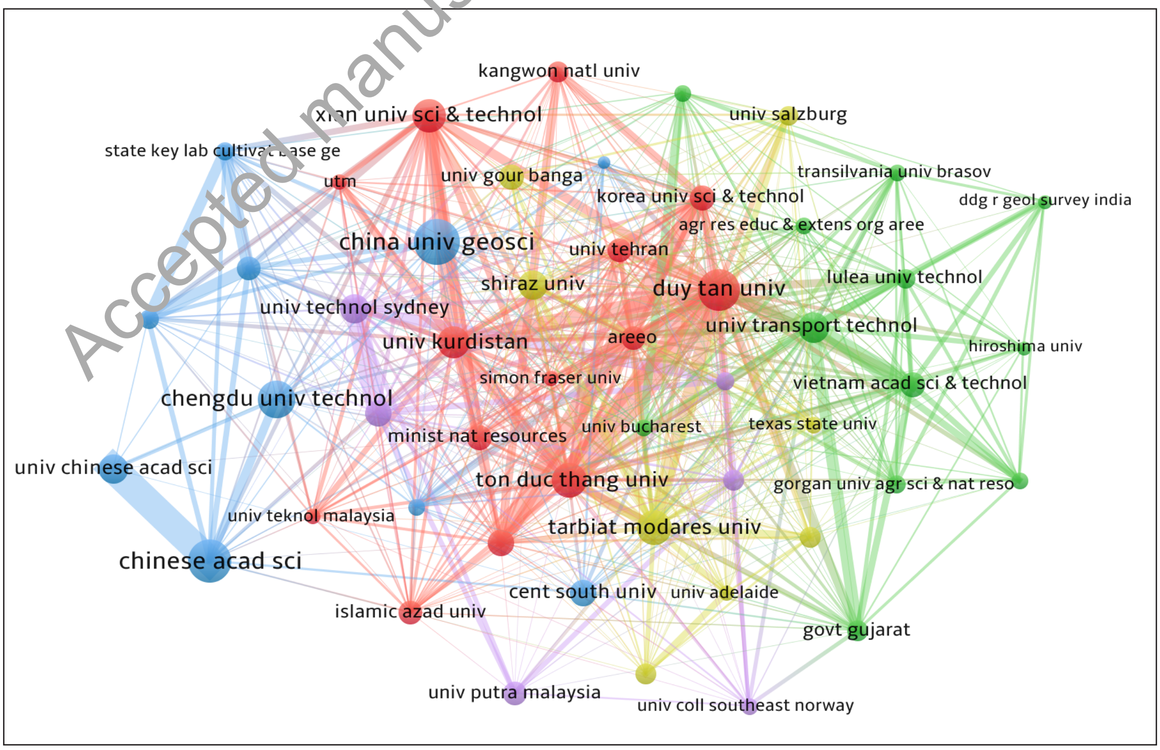

FIGURE 8. Top 50 most collaborative institutions

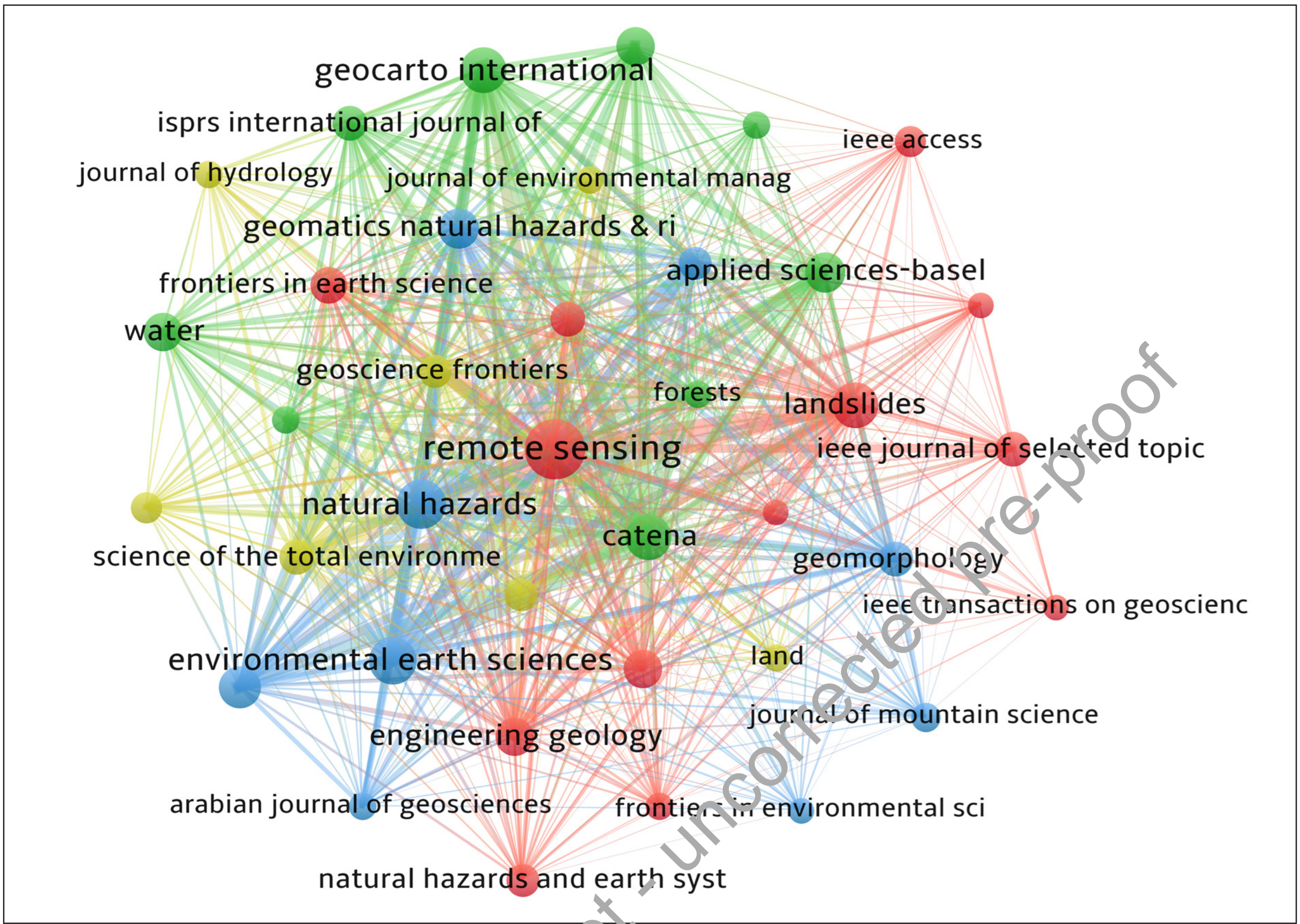

FIGURE 9. Top 38 most co-cited journals

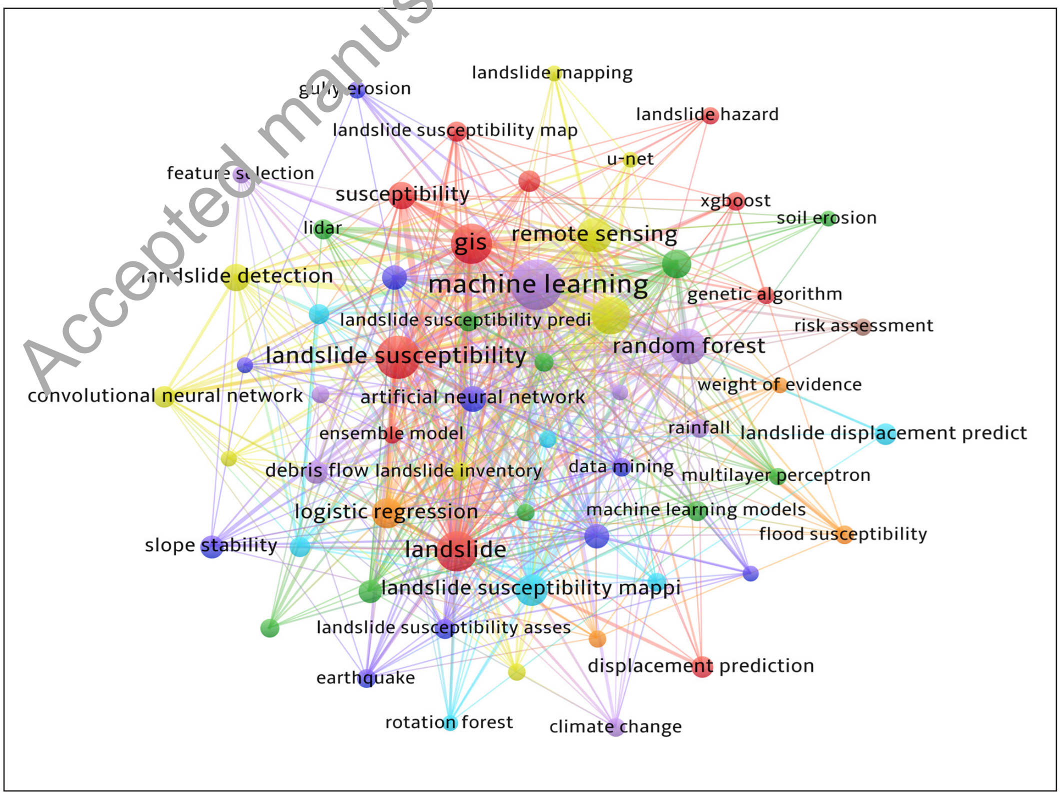

FIGURE 10. 60 Most occurred Author keywords

TABLE 1. Year-wise performance of publications with various indicators.

Year	TP	TC	CPP	NCP	HCP	HCP TC	Usage Count (180 Days)	Usage Count (Since 2013)
2009	14	1472	105.14	0	3	986	15	483
2010	17	2529	148.76	0	6	2118	41	1217
2011	20	2697	134.85	0	7	2203	53	1411
2012	28	4341	155.04	0	13	3892	49	2292
2013	35	3367	96.20	0	10	2529	115	2806
2014	26	2335	89.81	0	6	1403	97	2595
2015	43	5403	125.65	2	16	4457	233	3976
2016	55	5134	93.35	1	17	3702	225	4177
2017	65	5757	88.57	0	20	3719	258	5080
2018	88	9292	105.59	0	29	6788	770	9329
2019	147	11712	79.67	1	41	6774	965	13182
2020	228	14529	63.72	1	35	6492	1921	19022
2021	285	10731	37.65	1	23	3627	2790	22356
2022	400	7138	17.85	8	1	136	3718	23302
2023	383	2805	7.32	39	0	0	5315	15949
Total	**1834**	**89242**	**48.66**	**53**	**227**	**48826**	**16565**	**127177**

TP= Total Publications; TC= Total Citations; CPP= Citations per Papers; NCP= Uncited Papers; HCP= Highly Cited Papers; HCP TC= Highly Cited Papers

TABLE 2. Distribution of citations

Number of Citations	Number of Papers (%)	Total Citations
Uncited	53 (2.89)	0
1-9	544 (29.66)	2577
10-19	298 (16.25)	4166
20-29	200 (10.91)	4894
30-39	137 (7.47)	4674
40-49	101 (5.51)	4412
50-99	274 (14.94)	19693
100-499	216 (11.78)	41212
500-1118	11 (0.60)	7614
Total	**1834 (100)**	**89242**

TABLE 3. Top 20 funding agencies

Funding Agency	TP	TC	CPP
National Natural Science Foundation of China	437	14839	33.96
National Key Research Development Program of China	157	5825	37.10
Fundamental Research Funds for The Central Universities	59	2262	38.34
China Postdoctoral Science Foundation	53	4103	77.42
Chinese Academy of Sciences	31	2760	89.03
National Research Foundation of Korea	30	1561	52.03
National Basic Research Program of China	29	1936	66.76
China Scholarship Council	27	1898	70.30
Ministry of Science and ICT, Korea	24	1397	58.21
University of Technology Malaysia	19	2916	153.47
Austrian Science Fund	18	1801	100.06
Ministry of Education, Culture, Sports, Science and Technology, Japan	17	1203	70.76
UK Research Innovation	17	1042	61.29
Hong Kong Research Grants Council	17	670	39.41
Natural Science Foundation of Hunan Province	17	148	8.71
National Science Foundation	16	593	37.06
European Union	16	372	23.25
Japan Society for The Promotion of Science	15	798	53.20
Vietnam National Foundation for Science and Technology Development	15	798	53.20
King Saud University	14	495	35.36
Total of 20 Funding Agencies	**1028**	**47417**	**46.13**
Total of 1381 Funding Agencies	**1307**	**59863**	**45.80**

TP= Total Publications; TC= Total Citations; CPP= Citations per Papers

TABLE 4. Top 25 most productive and impactful authors

Author	Affiliation	TP	HCP	TC	CPP	h_index	g_index
Pradhan Biswajeet	University of Technology Sydney, Australia	77	31	10612	137.82	46	77
Dieu Tien Bui	University of South-Eastern Norway, Norway	70	38	10048	143.54	58	70
Binh Thai Pham	Gujarat Technological University, India	70	29	7762	110.89	52	70
Chen Wei	Xi'an University of Science and Technology, China	65	28	6460	99.38	46	65
Pourghasemi Hamid Reza	Shiraz University, Iran	56	21	6344	113.29	37	56
Shahabi Himan	University of Kurdistan Hewler, Iraq	52	25	6176	118.77	44	52
Prakash Indra	Bhaskaracharya Institute for Space Applications and Geo-Informatics, India	51	16	4667	91.51	35	51
Shirzadi Ataollah	University of Kurdistan Hewler, Iraq	46	20	4686	101.87	41	46
Hong Haoyuan	Nanjing Normal University, China	42	21	4992	118.86	35	42
Lee Saro	Korea Institute of Geoscience and Mineral Resources (KIGAM), South Korea	41	9	3537	86.27	30	41
Arabameri Alireza	Tarbiat Modares University, Iran	34	5	1510	44.41	21	34
Costache Romulus	Transilvania University of Brasov, Romania	30	2	1236	41.20	17	30
Bin Ahmad Baharin	University of Technology Malaysia, Malaysia	28	17	3540	126.43	27	28
Pal Subodh Chandra	University of Burdwan, India	25	1	829	33.16	18	25
Wang Yi	China University of Geosciences, China	24	7	1766	73.58	17	24
Rahmati Omid	Ton Duc Thang University, Vietnam	24	7	1762	73.42	19	24
Huang Faming	Nanchang University, China	24	6	2101	87.54	21	24
Al-Ansari Nadhir	Lulea University of Technology, Sweden	24	4	1441	60.04	15	24
Jaafari Abolfazl	AREEO, Research Institute of Forests and Rangelands, Iran	23	7	1903	82.74	19	23
Blaschke Thomas	University of Salzburg, Austria	23	6	1997	86.83	22	23
Tang Huiming	China University of Geosciences, China	22	1	977	44.41	17	22
Xu Chong	Institute of Geology China Earthquake Administration, China	21	6	1549	73.76	15	21
Xu Qiang	China Geological Survey, China	21	1	835	39.76	15	21
Panahi Mahdi	Kangwon National University, South Korea	20	6	1348	67.40	14	20
Chakrabortty Rabin	University of Burdwan, India	20	1	812	40.60	16	20
Total of 25 authors		**933**	**315**	**88890**	**95.27**		

TP= Total Publications; HCP= Highly Cited Papers; TC= Total Citations; CPP= Citations per Papers

TABLE 5. Top 26 most productive and impactful countries

Country	TP	ICP	% ICP	TC	CPP
China	820	49	5.98	30977	37.78
Iran	290	51	17.59	22644	78.08
India	248	48	19.35	12112	48.84
Vietnam	204	45	22.06	18207	89.25
USA	175	52	29.71	7672	43.84
South Korea	138	42	30.43	9275	67.21
Italy	132	44	33.33	7901	59.86
Australia	131	32	24.43	8464	64.61
Malaysia	114	31	27.19	12990	113.95
Turkey	79	24	30.38	7639	96.70
Norway	74	37	50.00	9776	132.11
Japan	69	36	52.17	4551	65.96
Saudi Arabia	63	39	61.90	2765	43.89
Austria	59	31	52.54	4679	79.31
England	54	29	53.70	4047	74.94
Spain	53	33	62.26	2194	41.40
Germany	52	32	61.54	3454	66.42
Netherlands	50	37	74.00	2817	56.34
Canada	49	24	48.98	2488	50.78
Taiwan	49	16	32.65	1957	39.94
Sweden	36	25	69.44	2025	56.25
Romania	35	30	85.71	1451	41.46
Pakistan	31	27	87.10	480	15.48
Brazil	29	14	48.28	779	26.86
Bangladesh	23	26	113.04	799	34.74
Switzerland	23	15	65.22	713	31.00

TP= Total Publications; ICP= International Collaborative Papers; TC= Total Citations; CPP= Citations per Papers

TABLE 6. Top 25 most preferred sources

Source Name	JCI (2023)	Publisher	Quartile	TP	TC	CPP	h_index	g_index
Remote Sensing	0.97	MDPI	Q2	172	5433	31.59	35	64
Natural Hazards	0.82	Springer	Q2	89	4426	49.73	34	64
Environmental Earth Sciences	0.63	Springer	Q3	76	3819	50.25	29	60
Geocarto International	0.74	Taylor & Francis	Q2	69	2199	31.87	26	45
Landslides	1.63	Springer	Q1	67	5244	78.27	33	67
Catena	1.47	Elsevier	Q1	66	8187	124.05	44	66
Bulletin of Engineering Geology and the Environment	0.86	Springer	Q3	55	2138	38.87	24	45
Geomatics Natural Hazards & Risk	1.1	Taylor & Francis	Q1	45	1914	42.53	22	43
Applied Sciences-Basel	0.56	MDPI	Q2	45	1555	34.56	22	38
Engineering Geology	1.85	Elsevier	Q1	42	3399	80.93	31	42
Sustainability	0.68	MDPI	Q2	41	949	23.15	14	30
Sensors	0.87	MDPI	Q2	40	1169	29.23	18	33
Water	0.67	MDPI	Q2	39	816	20.92	14	27
Frontiers In Earth Science	0.58	Frontiers Media	Q3	34	353	10.38	10	17
Science of the Total Environment	1.62	Elsevier	Q1	30	4540	151.33	26	30
Scientific Reports	1.05	Nature Portfolio	Q1	29	1408	48.55	17	29
ISPRS International Journal of Geo-Information	0.77	MDPI	Q2	23	553	24.04	15	27
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	1.13	IEEE-Inst Electrical Electronics Engineers Inc	Q1	28	794	28.36	16	27
Geomorphology	0.98	Elsevier	Q2	27	2930	108.52	24	27
Geoscience Frontiers	2.41	China University of Geosciences	Q1	25	2399	95.96	22	25
Natural Hazards and Earth System Sciences	0.98	Copernicus Gesellschaft	Q1	23	930	40.43	14	23
Computers & Geosciences	0.83	Elsevier	Q1	22	3207	145.77	21	22
Stochastic Environmental Research and Risk Assessment	1.07	Springer	Q1	22	893	40.59	15	22
IEEE Access	0.87	IEEE-Inst Electrical Electronics Engineers Inc	Q2	19	456	24.00	10	19
Environmental Science and Pollution Research	0.99	Springer	NA	18	218	12.11	8	14

JCI= Journal Citation Indicator; TP= Total Publications; TC= Total Citations; CPP= Citations per Papers

TABLE 7. Top 60 Most occurring Author keywords

Keyword	Occ	Cluster	Links	TLS	Keyword	Occ	Cluster	Links	TLS
Landslide Susceptibility	243	1	37	270	Deep Learning	166	4	40	208
Landslide	210	1	47	290	Remote Sensing	113	4	43	234
GIS	210	1	41	331	Landslide Detection	54	4	19	78
Susceptibility	59	1	24	97	Convolutional Neural Network	29	4	15	51
Displacement Prediction	26	1	7	15	Landslide Inventory	18	4	18	35
Machine Learning Algorithms	24	1	16	25	Transfer Learning	13	4	13	20
Landslide Susceptibility Map	21	1	14	25	Geohazards	11	4	10	15
Xgboost	15	1	10	20	U-Net	10	4	7	21
Ensemble Model	13	1	12	15	Landslide Mapping	10	4	7	12
Genetic Algorithm	12	1	9	15	Machine Learning	423	5	54	517
Landslide Hazard	12	1	8	8	Random Forest	141	5	39	229
Support Vector Machine	71	2	29	127	Debris Flow	35	5	15	43
Geographic Information System	31	2	22	47	Rainfall	16	5	13	23
Lidar	22	2	14	42	Climate Change	15	5	12	22
Landslide Susceptibility Prediction	20	2	12	27	Feature Selection	14	5	12	22
Machine Learning Models	20	2	12	19	Susceptibility Assessment	12	5	11	15
Spatial Modeling	17	2	16	30	Hazard Assessment	10	5	8	16
Shallow Landslide	15	2	9	21	Landslide Susceptibility Mapping	91	6	26	114
Multilayer Perceptron	14	2	16	26	Landslide Displacement Prediction	24	6	4	8
Landslide Prediction	12	2	9	14	Feature Extraction	22	6	14	44
Soil Erosion	10	2	9	10	Terrain Factors	20	6	13	47
Artificial Neural Network	49	3	26	78	Neural Network	15	6	11	17
Artificial Intelligence	40	3	26	57	Ensemble Learning	12	6	11	19
Susceptibility Mapping	36	3	21	61	Rotation Forest	11	6	10	25
Slope Stability	32	3	12	27	Logistic Regression	82	7	31	145
Landslide Susceptibility Assessment	20	3	17	37	Flood Susceptibility	16	7	11	23
Data Mining	18	3	16	31	Fuzzy Logic	13	7	13	17
Earthquake	17	3	14	30	Weight Of Evidence	11	7	8	18
Gully Erosion	13	3	6	17	Risk Assessment	13	8	7	11
Natural Disasters	11	3	11	21					
Soft Computing	10	3	11	12					

Occ.= Occurrences; TLS= Total Link Strengths