https://rbgeomorfologia.org.br/
ISSN 2236-5664

Revista Brasileira de Geomorfologia

v. 27, nº 3 (2026)

http://dx.doi.org/10.20502/rbg.v27i3.2817

Review Article

Systematic literature review of debris flows in Southern Brazil

Revisão sistemática da literatura sobre fluxos de detritos no Sul do Brasil

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Received: 07/05/2026; Accepted: 12/08/2026; Published: 10/09/2026

Abstract: Debris flow is a type of mass movement with high destructive potential. This study is located on Southern Brazil, where debris flows occur mainly in mountainous regions and on steep slopes. The objective was to conduct a systematic literature review of debris flow focusing on Rio Grande do Sul, Santa Catarina, and Paraná states, using the PRISMA method. A search equation was developed and applied in Scopus, Lens, and Web of Science. A total of 372 articles, published up to the end of 2025, were identified, of which 28 met the inclusion criteria. Although the number of publications increased after 2018, no more than five articles were published in any single year, with the highest annual number occurring in 2022. The main findings of these 28 publications were summarized. It was noted that most studies had mixed (qualitative-quantitative) analysis and focused on local and regional studies. Among the states of Southern Brazil, Paraná was the most studied, particularly in the Serra do Mar region. Finally, knowledge gaps were identified due to the limited number of publications on the topic, despite the frequency of debris flows events and their socioeconomic impacts in Southern Brazil.

Keywords: Disasters; Mass movement; PRISMA method; Hazard assessment.

Resumo: Fluxo de detritos é um tipo de movimento de massa com alto poder destrutivo. A área de estudo está localizada no Sul do Brasil, onde fluxos de detritos ocorrem principalmente em regiões montanhosas e encostas íngremes. O objetivo foi realizar uma revisão sistemática da literatura sobre fluxos de detritos focada nos estados do Rio Grande do Sul, Santa Catarina e Paraná, utilizando o método PRISMA. Uma equação de busca foi desenvolvida e aplicada nas bases Scopus, Lens e Web of Science. Ao total, 372 artigos, publicados até o final de 2025, foram identificados, dos quais 28 foram selecionados por abordarem adequadamente o tema da pesquisa. Embora o número de publicações tenha aumentado após 2018, o maior número não ultrapassou cinco publicações, em 2022. Os principais achados dessas 28 publicações foram sintetizados. Observou-se que a maioria dos estudos apresentou análises qualiquantitativas e focou em estudos de escala local e regional. Entre os estados do Sul do Brasil, o Paraná foi o mais estudado, especialmente na região da Serra do Mar. Por fim, foram identificadas lacunas de conhecimento devido ao número limitado de publicações, apesar da frequência de fluxos de detritos e de seus impactos socioeconômicos no Sul do Brasil.

Palavras-chave: Desastres; Movimento de massa; Método PRISMA; Avaliação de perigo.

1. Introduction

1.1. Debris-flow definition

Debris flow is a flow of sediment and water mixture in a manner as if it was a flow of continuous fluid driven by gravity, and it attains large mobility from the enlarged void space saturated with water or slurry (Takahashi, 2014). The total impact force of a debris flow primarily consists of the dynamic pressure of the flow matrix and the collision force of large boulders (Song et al., 2019). The high mobility of debris flows is evidenced by their lower equivalent friction coefficients compared with other types of mass movements (Takahashi, 2014). Consequently, debris flows may reach velocities of up to 20 m/s (Iverson, 1997).

Geomorphologically, following Hussin (2011), a debris flow is characterized by three zones: initiation, transport, and deposition. The initiation zone is where slope failure initiates. The flow may be initiated by a slide, debris avalanche or rock fall (Hungr; Leroueil; Picarelli, 2014). The transport zone is transitional, commonly located on steep slopes, and it is where additional sediment is entrained into the flow. In the deposition zone, the sediment is deposited, often forming levees. Alvarado (2006) describes the sedimentological characteristics of debris flows which the solid phase ranges from silt-sized particles to large boulders. When silt and clay are mixed with water, a viscoplastic flow is formed; the incorporation of rock fragments into this mixture gives rise to debris flows.

The Brazilian context is characterized by woody debris flows (Kobiyama et al., 2015), driven by the high vegetation density in subtropical climate regions. In Brazil, these events are predominantly observed in mountainous regions (Paixão et al., 2023) and often occur simultaneously with floods (Hungr; Leroueil; Picarelli, 2014). Rainfall reduces the cohesion of slope materials by eliminating capillary pressure and increasing the unit weight of the soil, thereby triggering mass movement (Maciel Filho; Nummer, 2011).

Definitions of the debris-flow process have evolved over time, with several authors proposing different classification criteria (Hungr; Leroueil; Picarelli, 2014; IRDR, 2014; Imaizumi; Sidle; Kamei, 2008; Vandine; Bovis, 2002; Jan; Shen, 1996; Costa, 1988; Varnes, 1978). In Brazil, the classification of debris flows also remains challenging because of the strong hydrological influence on wet mass movements (Franck, 2024). Due to their transitional nature, there is still no universally accepted definition capable of clearly distinguishing debris flows from other types of flow.

1.2. Debris-flow effects

Debris flows are among the most catastrophic natural phenomena owing to their rapid propagation, long runout distances, and high energy (Yi et al., 2026; Thouret et al., 2020; Hungr; Leroueil; Picarelli, 2014; Takahashi, 2007; Iverson, 1997; Okuda et al., 1980). Their destructive potential is further enhanced by the transport of large volumes of debris-flow material, particularly large boulders capable of generating high-impact forces (Wang et al., 2023; Shen et al., 2018). As demonstrated by Thouret et al. (2020), the impacts of these events extend well beyond immediate physical damage and loss of life, generating substantial long-term economic and societal consequences, influenced by the immense kinetic energy of debris flow (Dowling; Santi, 2014).

More broadly, the Digital Atlas of Disasters in Brazil (SEDEC/MIDR) provides an overview of the human and economic impacts associated with disasters in the country. According to it, between 1991 and 2025, 5,535 disaster-related deaths were recorded, and more than 144 million people were directly affected. Material damage exceeded USD 155 billion, while public-sector losses exceeded USD 70 billion. Over the last decades, given the growing exposure of populations and infrastructure in susceptible areas, debris flows have increasingly become a focus of research, engineering practice, and governmental risk management efforts (Trujillo-Vela et al., 2022; Saito et al., 2019).

A recent example occurred in Rio Grande do Sul state. Between April and May 2024, a sequence of several days of intense and heavy rainfall saturated the soil, which is relatively shallow and has limited capacity to absorb large amounts of water (Paiva et al., 2024). In the escarpment region of the mountain range, rainfall was so extreme that it resulted in the largest mass movement event ever documented in the country (Andrades-Filho et al., 2025;

Andrades-Filho et al., 2024; CEMADEN, 2024). More than 16,000 scars were mapped across the state at that time, of which more than 3,000 were classified as debris flows (Andrades-Filho et al., 2025). The death toll reached 185, and 23 people remain missing (Brito, 2026). Economic losses were estimated at approximately USD 17 billion (BID, 2024).

1.3. Research gap and objectives

Despite the recurrence of debris flow events in Southern Brazil, scientific literature remains fragmented and dispersed across different disciplines, including geology, geomorphology, hydrology, and disaster risk management. Consequently, a comprehensive synthesis of existing knowledge is still lacking (Paixão et al., 2023; Trujillo-Vela et al., 2022; Paixão; Kobiyama, 2019; Kobiyama et al., 2015). Such a synthesis is necessary to identify research trends, methodological approaches, geographic distribution of such studies, and knowledge gaps.

In this context, systematic reviews provide a structured approach to evaluate existing scientific knowledge. To address these gaps, this study aims to conduct a systematic literature review of debris-flow research in Southern Brazil using the PRISMA methodology. The review was designed to answer the following research questions:

- What is the current state of knowledge on debris flows in Southern Brazil?
- What are the main research gaps limiting hazard assessment and risk management of debris flows in Southern Brazil?

2. Study area

According to the historical analysis conducted by Kobiyama et al. (2015), Southern and Southeastern Brazil contain the highest concentration of documented debris-flow events in the country. To elucidate, between 1900 and 2014, Santa Catarina alone recorded more than 200 fatalities associated with debris-flow disasters.

The states of Southern Brazil—Rio Grande do Sul, Santa Catarina, and Paraná—are predominantly located within the Paraná Sedimentary Basin, a major geological unit composed of extensive sedimentary and volcanic rock sequences. This geological setting, combined with steep topography in several areas, provides favorable conditions for debris-flow occurrence.

Hydrological conditions are among the main factors controlling the occurrence of debris flows (Paixão et al., 2023; Sidle; Lopes, 2017; Ochiai, 2006; Selby, 1993). In addition, current climate variability, influenced by climate change, is significantly altering the hydrological cycle, increasing uncertainty regarding water availability and contributing to a higher frequency of extreme weather events. In Brazil, the National Water and Sanitation Agency (ANA) has conducted assessments of climate change impacts on water resources (ANA, 2024). The results indicate increasing precipitation and streamflow, particularly in Southern Brazil, without significant increases in evapotranspiration. In summary, the Southern region shows a predominance of scenarios within increased water availability, associated with a higher frequency of floods and inundations. In contrast, projections for the rest of the country indicate reduced water availability and a marked increase in evapotranspiration.

Considering the strong influence of geological and hydrological conditions on debris-flow occurrence, combined with the projected intensification of hydrological extremes under climate change, Southern Brazil was selected as the study area for this systematic review (Figure 1).

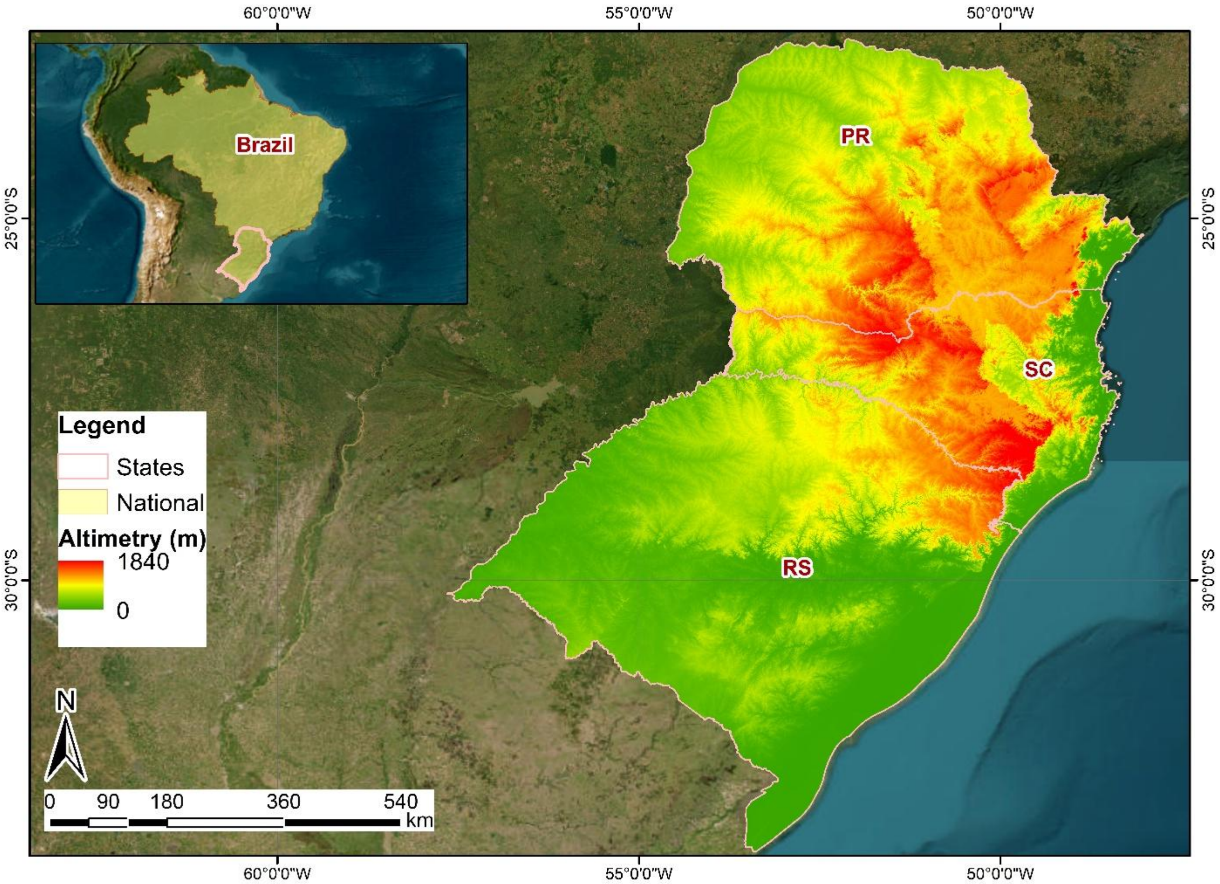

Figure 1. Study area of this systematic review.

3. Methods

Following Galvão and Pereira (2014), systematic reviews are considered secondary studies based on primary studies, such as scientific articles. In this research, the PRISMA Method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was applied to improve reporting of systematic review (PRISMA, 2020). The search and article selection process followed the steps described below:

1. Selection of databases for articles retrieval.
2. Definition of the search equation.
3. Screening of articles and exclusion of those that did not meet the research objective.
4. Compilation of the selected articles for analysis.

Three databases were used: Scopus, Lens, and Web of Science. Using the advanced search functionalities available on each platform, the search terms were applied to article titles, abstracts, and keywords.

Considering the non-standardization of this phenomena definition, the term debris flow may appear in different forms while retaining the same meaning. That is why synonyms and related terms were used in order to retrieve the largest possible number of publications. The adopted terms were: debris-flow, debris flow, debris flows, mass flow, mass flows, rapid mass movement, rapid mass movements, colluvial flow, colluvial flows, mudflow, mudflows, shallow landslide, shallow-landslide, and shallow landslides. To ensure that the primary focus of each publication was debris flows, these terms were required to appear in the title.

Focusing on Southern Brazil, this research included in the search equation the following geographic terms within the title, abstract, and keywords: Brazil, BR, Rio Grande do Sul, RS, Santa Catarina, SC, Paraná, PR, and Southern Brazil. After an initial screening, geographic terms related to other Brazilian states or regions were excluded, as they fall outside the scope of this study, such as São Paulo, SP, Rio de Janeiro, RJ, SE, Northeastern Brazil, Northeast Brazil, Southeast Brazil, and Southeastern Brazil.

Boolean operators were used as follows: AND to combine and restrict terms, OR to broaden the search by including synonyms, and NOT to exclude places that were not in the study area. Quotation marks were used to ensure retrieval of compound terms, and the parentheses were applied to organize combinations of operators. The final search equations applied in each database were presented in the Supplementary Material.

It is important to highlight that books were not included in this review. Because the study focuses on Brazilian case studies, Portuguese-language search terms were initially applied using the same search strategy and indexed databases adopted. However, they did not retrieve any additional eligible studies beyond those already identified through the English-language search, instead returning Portuguese versions of articles that were also available in English. Although relevant studies written in Portuguese may exist, particularly in conference proceedings, institutional publications, dissertations, or journals not indexed by the selected databases, these sources fall outside the scope of the systematic search strategy employed. Restricting the search to indexed databases ensured methodological consistency, reproducibility, and transparency, but may have resulted in the exclusion of relevant non-indexed literature. This limitation should therefore be considered when interpreting the findings of this review. Thus, only articles published in English were analyzed. Studies with no study areas located in Southern Brazil were removed. Duplicate articles were also excluded.

The search equation enables the identification of potentially relevant publications. After abstract screening, only articles aligned with the objective of this study were selected. Not all selected articles had full-text versions freely available; therefore, abstract information was prioritized. Nevertheless, whenever possible, full articles were also analyzed. Following the selection stage, key information extracted from the manuscripts was subjected to analyses.

The methodological workflow is presented in Figure 2. For the selected studies, the following information was extracted:

1. Title.
2. Authorship.
3. Year of publication.
4. Research approach.
5. Key findings, based on general objective, applied methodology, and main conclusions.
6. Study area within Southern Brazil.
7. Spatial scale, classified as local (single catchment, specific study area, or municipality), regional (more than one catchment, more than one municipality, or one geomorphological unit), national (more than one state), or international (Brazil and at least one other country).
8. Type of analysis, classified as qualitative, quantitative, or mixed (qualitative-quantitative).
9. Identified knowledge gaps.

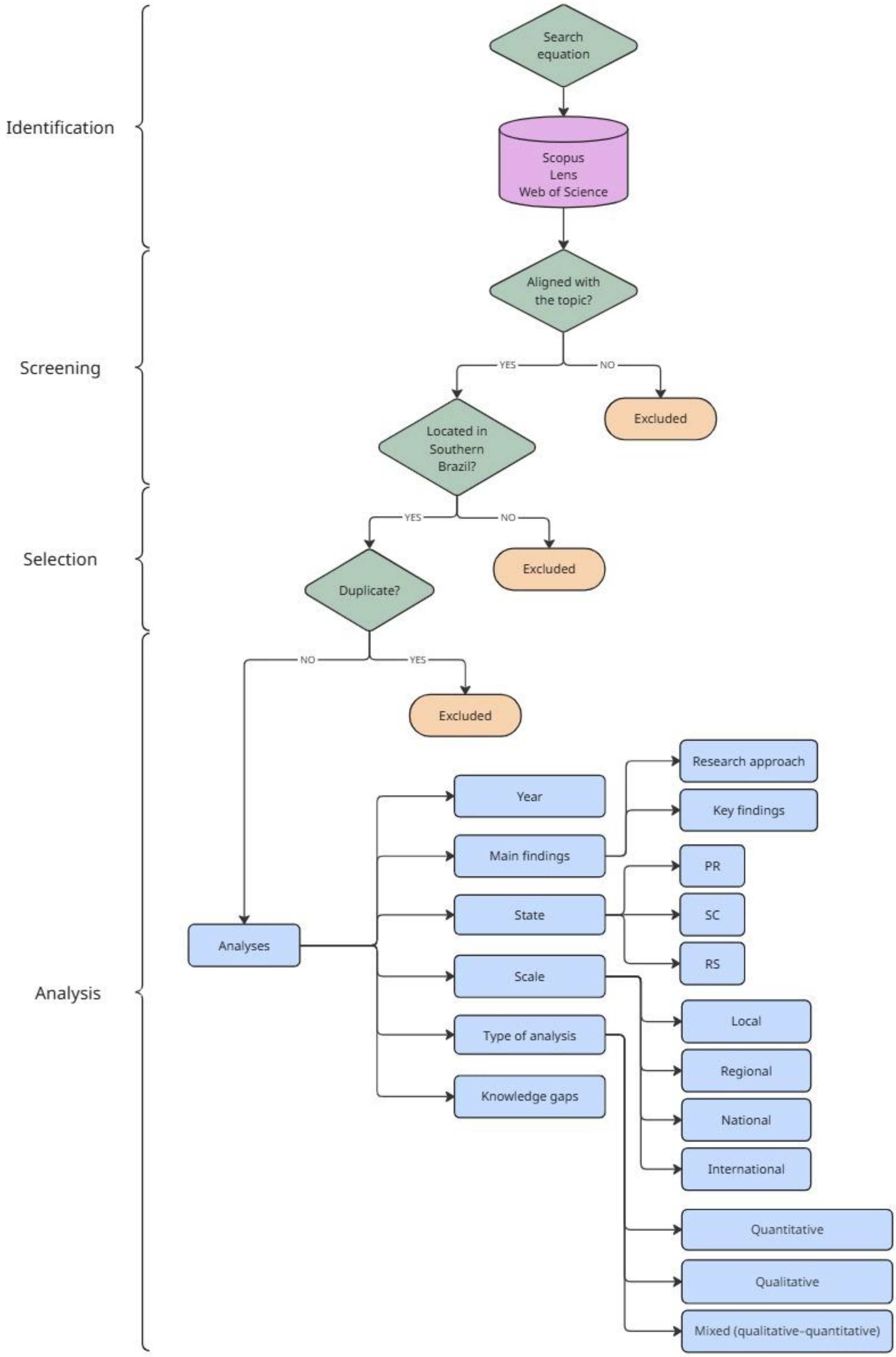

Figure 2. Methodological workflow.

4. Results

Scopus identified 95 articles, of which 15 met the eligibility criteria and were selected in the analysis. The Lens search returned 206 articles, of which 27 were included. Finally, Web of Science identified 71 articles, of which 11 were selected. A total of 53 articles were retained, and 25 duplicates were removed. After duplicate removal, 28 articles were included in this systematic literature review of debris flows in Southern Brazil. As shown in Figure 3, Scopus and Lens each retrieved unique publications that were not identified by the other databases, whereas Web of Science retrieved only records that were also found in Scopus or Lens.

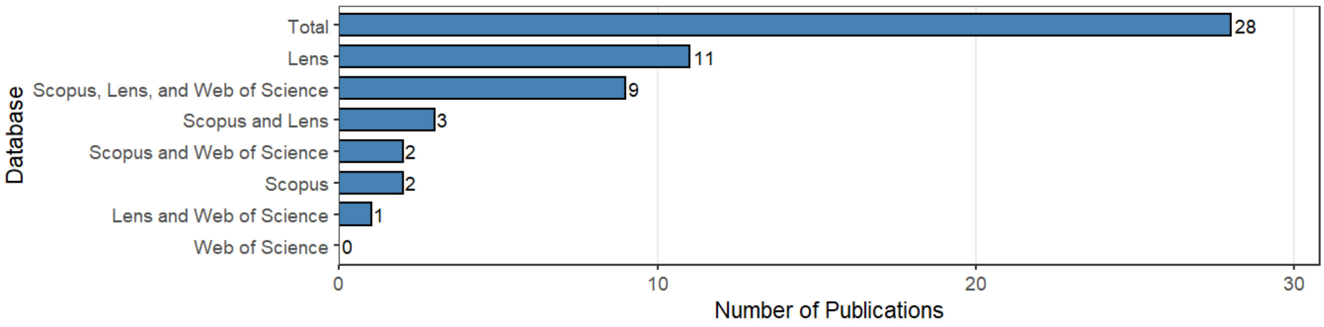

Figure 3. Number of publications by database.

The temporal distribution of publications (Figure 4) indicates that the first article was published in 2002, followed by a low publication rate with a maximum of one article per year until 2015. Since 2016, publication output has increased, beginning with three studies that year, and has shown a clear and sustained upward trend from 2018 onward, reflecting growing interest in the topic. The peak occurred in 2022, with five publications representing the year with the highest number of articles up to December 2025. Publication output subsequently declined, with no articles published in 2024. Nevertheless, one study was published in 2025, suggesting a continued interest in debris-flow research.

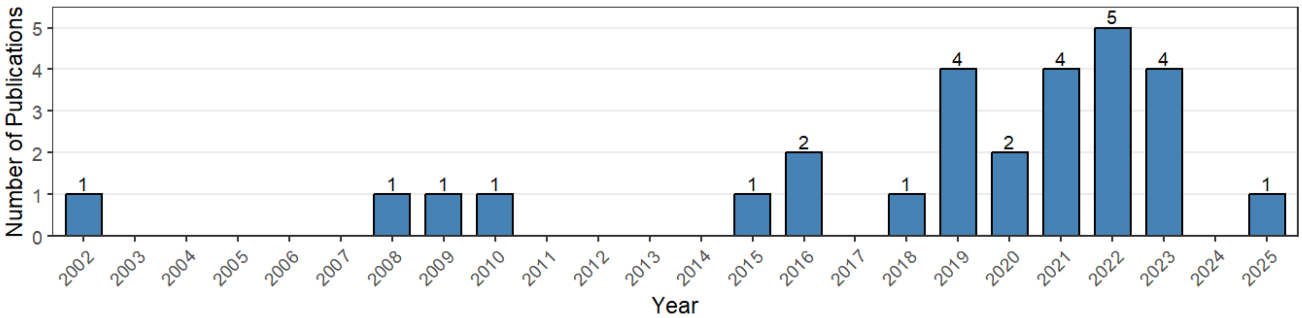

Figure 4. Number of publications by year.

The studies addressed debris flow from different perspectives. To answer the first research question, the 28 selected articles were analyzed, and their main findings are summarized in Table 1, providing an overview of the current state of knowledge on debris flows in Southern Brazil.

Table 1. Summary of the main findings of the selected articles.

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
1	Modeling the geomorphologic susceptibility to debris flow initiation with geomorphometric parameters and fuzzy logic in the mountainous region of Serra do Mar (state of Paraná, Brazil)	Silveira and Silveira (2025)	Serra da Prata, Serra do Mar (PR)	Computational modelling	Developed a model to map areas susceptible to debris-flow initiation in humid tropical mountainous regions based on the March 2011 event in the Serra do Mar.	Quantitative
2	The consequences of debris flows in Brazil: a historical analysis based on recorded events in the last 100 years	Cabral et al. (2023)	Brazil, including RS, SC, and PR	Parameter quantification	Quantified the socioeconomic consequences of debris flows that occurred in the country between 1920 and 2021, highlighting the higher fatality rates in Brazil compared to China, Japan, and Italy.	Qualitative
3	The effects of debris flow on structural sediment connectivity: case studies in the Italian Alps and in Southern Brazil	Paul et al. (2023a)	Revolver watershed (SC) and Stolla watershed (Italy)	Computational modelling	Modeled debris flows in two watersheds—one in Brazil and one in Italy—highlighting how topographic changes influence sediment connectivity and flow behavior.	Mixed
4	Debris flow susceptibility from Landscape Descriptors	Salvador and Michel (2023)	Jaguar Stream, Alto Feliz (RS)	Susceptibility mapping	Proposed a debris-flow susceptibility assessment using landscape descriptors from the TauDEM platform. Applied to the Jaguar Stream watershed, the model achieved a 94% true positive rate.	Mixed

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
5	Comparison of different rheological approaches and flow direction algorithms in a physically based debris flow model for data scarce regions	Paul et al. (2023b)	Mascarada River watershed (RS)	Computational modelling	Proposed a debris-flow simulation model for data-scarce regions and compared different flow-direction algorithms and rheological approaches. Results in Mascarada River watershed show that flow-direction algorithms have a stronger influence on the predicted affected area than rheological formulations.	Quantitative
6	Susceptibility to the Development of Debris Flows in the Territory of the Caminhos dos Cânions do Sul Geopark in Southern Brazil	Sugiyama and Gomes (2022)	Caminhos dos Cânions do Sul Geopark (RS and SC)	Susceptibility mapping	Identified high or very high susceptibility to debris-flow development in 12 of 25 watersheds within the geopark, particularly in areas containing geosites.	Quantitative
7	Geomorphic analyses of two recent debris flows in Brazil	Dias, McDougall and Vieira (2022)	Tingidor watershed (PR) and Guarda-Mão watershed (SP)	Analysis of triggering factors	Investigated and compared the triggering factors and geomorphological characteristics of two debris-flow events—one in Paraná State and one in São Paulo State in 2014— importance of sediment entrainment during flow propagation.	Mixed
8	Differences in the occurrence of debris flows in tropical and temperate environments: field observations and	Dias et al. (2022)	Tingidor watershed (PR), Guarda-Mão watershed (SP) e Lillooet (Canada),	Analysis and comparison of events	Compared the geomorphological characteristics and morphometric signatures of two debris flows—one in Brazil and one in Canada—showing	Mixed

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
	geomorphologic characteristics in Serra do Mar (Brazil) and British Columbia (Canada)		Mount Currie (Canada)		similarities despite climatic and environmental differences.	
9	Regional Scale Mapping of Debris-Flow Susceptibility in the Caminhos dos Cânions do Sul GeoPark, Southern Brazil	Sugiyama et al. (2022)	Caminhos dos Cânions do Sul Geopark (SC)	Susceptibility mapping	Compared two methodologies for regional debris-flow susceptibility mapping and showed that, when evaluated against flow inventories, both require calibration to the specific steep-slope conditions of the Serra Geral escarpment.	Quantitative
10	Alluvial plain morphostratigraphy affected by recent mud and debris flows: a study in the Jacarei River basin (southern coast of Brazil)	Paz and Paula (2022)	Jacareí River watershed (PR)	Morphostratigraphy analysis	Analyzed two morphostratigraphic units in an alluvial plain affected by mud and debris flows, identifying three depositional contexts: pre-2011, 2011 flow deposits, and post-2011.	Mixed
11	Characterization of a landslide-triggered debris flow at a rainforest-covered mountain region in Brazil	Cabral et al. (2021)	Pedra Branca watershed, Guaratuba (PR)	Analysis of triggering factors	Analyzed the meteorological and geomorphological factors triggering a debris flow in the Pedra Branca watershed, quantifying its magnitude, discharge, and velocity.	Quantitative
12	Post-glacial Permian debris flow deposits and their paleoclimatic implications (Mariana Pimentel paleovalley, southern Paraná Basin)	Coitinho et al. (2021)	Mariana Pimentel paleovalley (RS)	Fossil-record investigations	Demonstrated that diamictite deposits (sedimentary rock) from debris-flow processes in the Mariana Pimental paleovalley reflect increased	Mixed

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
					temperature and humidity during the Permian period.	
13	Evaluations and proposals for the debris flow hazard mapping method of the GIDES Project	Facuri and Picanço (2021)	Jacareí River watershed (PR)	Susceptibility mapping	Evaluated the GIDES debris-flow hazard mapping method using the 2011 event in the Jacareí River watershed. Results revealed limitations in the original model and showed that adaptations based on morphometric parameters improve hazard mapping accuracy.	Mixed
14	Relationship between sediment connectivity and debris flow in a mountain catchment	Abatti et al. (2021)	Mascarada watershed (RS)	Computational modelling	Demonstrated, through computational simulations of the 2017 Mascarada event, that sediment connectivity, assessed using the Index of Connectivity (IC), is an effective indicator for identifying areas prone to debris-flow sediment transfer in mountainous catchments.	Mixed
15	Standard Countermeasures Studies for Debris Flow Disasters in Brazil	Costa et al. (2020)	Blumenau (SC) and Nova Friburgo (RJ)	Proposal for management measures	Developed a manual for debris-flow countermeasures based on Japanese guidelines, demonstrating its feasibility through the implementation of two pilot projects.	Qualitative
16	Magnitude estimation of a landslide-triggered debris flow	Cabral et al. (2020)	Pedra Branca watershed (PR)	Parameter quantification	Estimated the magnitude of the 2017 Pedra Branca debris flow by calculating the total volume of mobilized material	Quantitative

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
	in the Serra do Mar Mountain Range, Brazil				and sediment accumulated in the riverbed, with potential for remobilization in future events.	
17	Debris flow in Serra do Mar/PR, Brazil, in 2017: Damages to right of way, recovery and protection actions	Piedade et al. (2019)	OSPAR pipeline in BR-376, Pedra Branca, Serra do Mar (PR)	Analysis and comparison of events	Described the 2017 debris-flow event affecting Petrobras' pipeline. Emergency actions successfully restored the area, and a protection structure was designed to withstand future flows without blocking or dissipating their energy.	Qualitative
18	Debris-flow hazard investigation with Kanako-2D in a rural basin, Alto Feliz municipality (Brazil)	Kobiyama and Michel (2019)	Alto Feliz (RS)	Computational modelling	Modeled debris-flow scenarios in a small rural watershed, highlighting risk to a house, typical thalweg erosion patterns, and deposition linked to slope variations.	Quantitative
19	Proposal of Debris Flow Disasters Management in Brazil Based on Historical and Legal Aspects	Kobiyama, Michel and Goerl (2019)	Brazil, including RS, SC, and PR	Proposal for management measures	Conducted a documentary study and proposed a debris-flow disaster management strategy in Brazil to mitigate future events.	Qualitative
20	Geotechnical and Mineralogical Properties of Granite Regolith Related to Nucleation Mechanisms of Debris Flows in Tropical Areas	Picanço, Mesquita and Melo (2019)	Gigante's Creek catchment in Morretes, Serra do Mar (PR)	Geotechnical and mineralogical analysis	Investigated debris-flow initiation by analyzing the geological and geotechnical characteristics of a regolith profile in the Serra do Mar, highlighting how regolith composition and weathering patterns influence landslide	Mixed

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
					initiation and the potential generation of debris flows in steep catchments.	
21	Identification and analysis of areas susceptible to debris flow in the basin Taquari-Antas river, RS	Oliveira et al. (2018)	Taquari-Antas River watershed (RS)	Computational modelling	Modeled debris-flow susceptible areas in the Rio Taquari-Antas watershed, identifying approximately 30% of the watershed as vulnerable, mainly in erosive escarpment regions.	Quantitative
22	Debris flow hazard zonation in Serra da Prata range, Paraná State, Brazil: Watershed morphometric constraints	Picanço et al. (2016)	Serra da Prata, Serra do Mar (PR)	Parameter quantification	Mapped debris-flow susceptibility in 11 watersheds in Serra da Prata using morphometric parameters, finding that only three met typical thresholds for occurrence.	Quantitative
23	Historical views and current perspective of debris flow disaster management in Brazil	Kobiyama, Michel and Goerl (2016)	Brazil, including RS, SC, and PR	Historic evolution of the theme	Analyzed the historical evolution of debris-flow management in Brazil, identifying a shortage of journal publications and proposing measures to improve risk management.	Qualitative
24	Historical analyses of debris flow disaster occurrences and of their scientific investigation in Brazil	Kobiyama et al. (2015)	Brazil, including RS, SC, and PR	Historic evolution of the theme	Historically analyzed debris-flow disasters and current scientific research in Brazil, highlighting an increase in publications since the 1990s despite a scarcity of journal papers.	Qualitative

ID	Title	Authorship	Study area	Research approach	Key findings	Type of analysis
25	Debris flow occurrences in Rio dos Cedros, Southern Brazil: Meteorological and geomorphic aspects	Kobiyama et al. (2010)	Rio dos Cedros (SC)	Analysis and comparison of events	Analyzed two debris flows in November 2008 in Rio dos Cedros, highlighting accumulated rainfall as the main trigger and topography and vegetation as influences on flow behavior and deposition.	Mixed
26	Geomorphological Controls and Land-use Effects on Rainfall Triggered Debris Flows in Brazil	Fernandes et al. (2009)	Morro do Baú (SC) and Rio de Janeiro (RJ)	Analysis of triggering factors	Analyzed geomorphological, geological, and land-use controls on rainfall-triggered debris flows in Brazil, showing that hillslope–channel interactions and land-use changes can significantly influence debris-flow initiation and magnitude.	Mixed
27	Predicting debris flow susceptible areas through GIS modelling in Aparados da Serra (Brazil)	Strieder et al. (2008)	Aparados da Serra (RS)	Computational modelling	Presented modeling results with strong correlation to real events, identifying debris-flow susceptible areas triggered by concentrated convective storms in the Aparados da Serra region.	Quantitative
28	The December 23rd 1995 floods and debris flows in Santa Catarina State (Subtropical Brazil)	Pellerin et al. (2002)	Sub-watersheds of the Figueira and Pinheirinho rivers, Serra Geral (SC)	Analysis and comparison of events	Reconstructed December 23, 1995, debris flows and floods in Santa Catarina using geomorphological mapping and field observations. Results indicate that such events are recurrent throughout the Serra do Mar and should be considered in hazard assessment.	Mixed

Figure 5 summarizes the distribution of the selected studies according to the type of analysis. Mixed (qualitative–quantitative) approaches predominated, followed by quantitative studies, whereas exclusively qualitative analyses represented the smallest proportion.

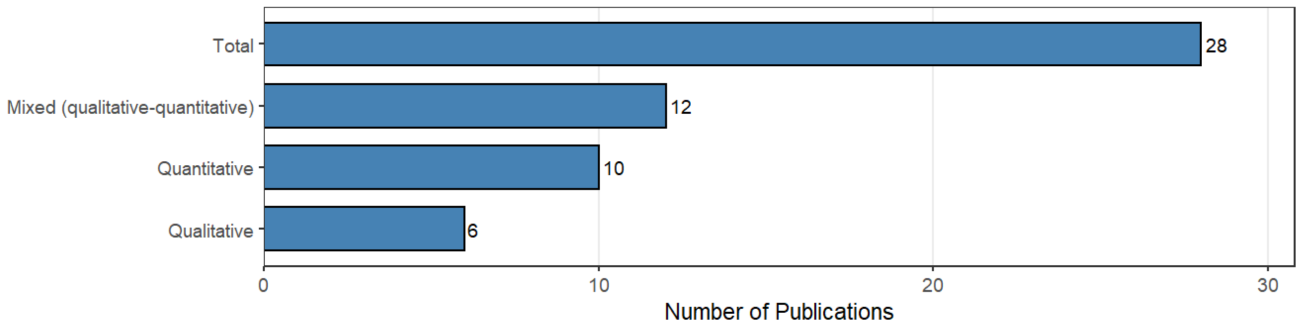

Figure 5. Number of publications by type of analyses.

Regarding the geographical distribution of the selected studies, this review considered the study area reported in each publication. For studies covering more than one state or the entire country, each Southern Brazilian state included in the study was counted individually.

Paraná accounted for the largest number of studies, most of which were conducted in the Serra do Mar region. Rio Grande do Sul and Santa Catarina showed similar numbers of publications. In Rio Grande do Sul, research is predominantly conducted in the Serra Gaúcha and adjacent border areas with Santa Catarina, whereas studies in Santa Catarina are mainly concentrated in the Vale do Itajaí and Serra Geral (Canyons) regions. Figure 6 illustrates the distribution of the selected studies by state, whereas Figure 7 shows the distribution of studies according to their spatial scale.

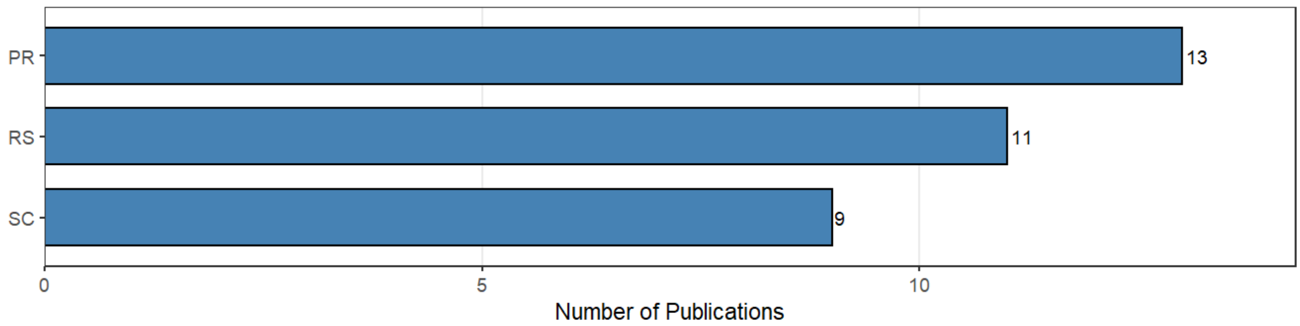

Figure 6. Number of publications by state.

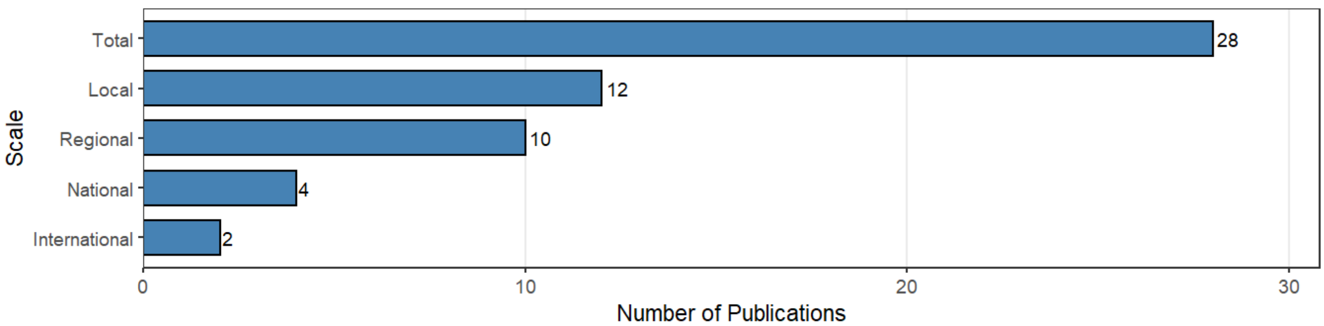

Figure 7. Number of publications by scale.

Figure 8 presents the geographical distribution of the study areas analyzed in the selected publications. Although this review focused on Southern Brazil, some selected studies included analyses conducted at national or international scales, as illustrated in the zoomed-out map on the left. To improve visualization and minimize overlap among study locations, enlarged maps of the main concentration areas are presented on the right side of the figure.

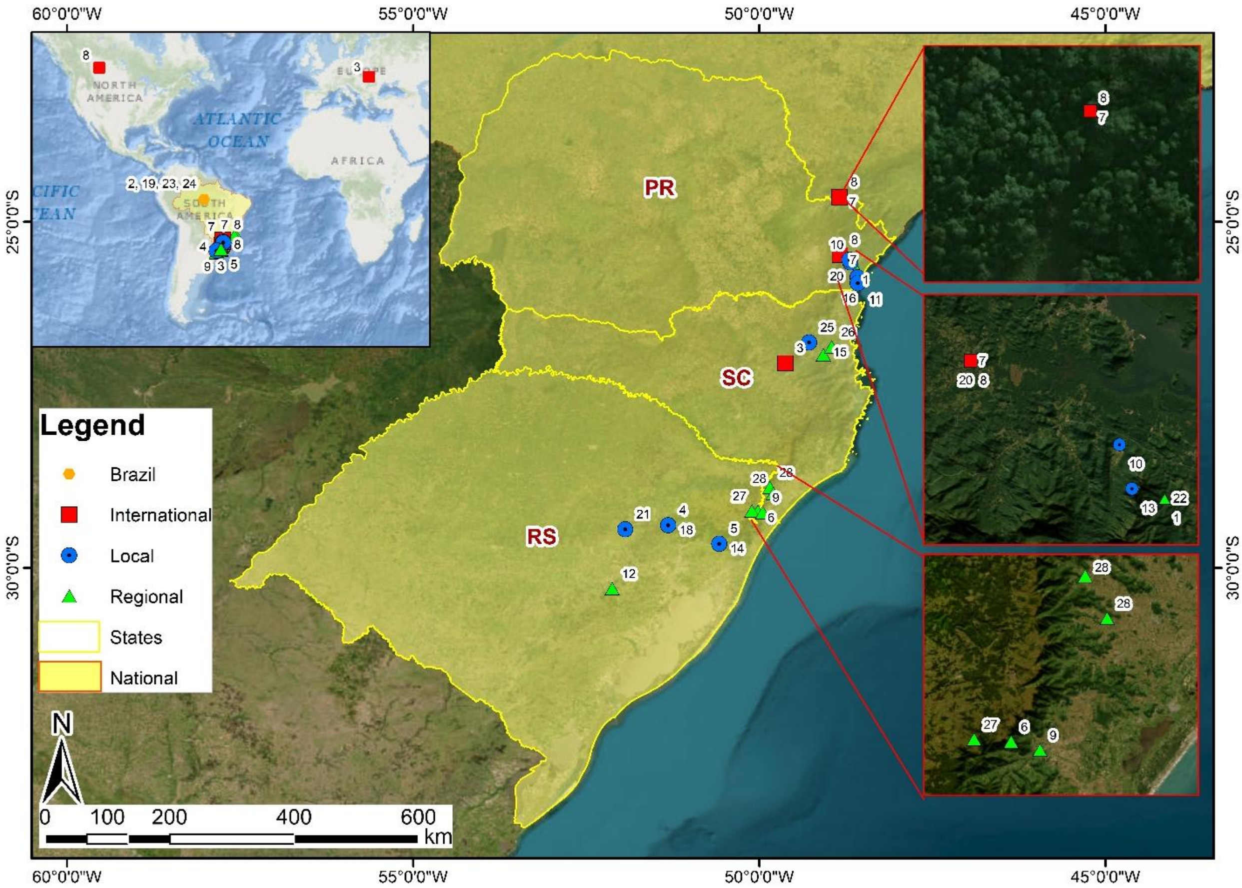

Figure 8. Geographical distribution of the study areas (the point IDs were the same as those presented in Table 1).

5. Discussions

Overall, debris-flow research in Southern Brazil has shown gradual development over the 24-year period analyzed. However, the number of studies remains modest considering the frequency and socioeconomic impacts of debris-flow disasters in Brazil. The increase in publications after 2018 may reflect the growing availability of high-resolution topographic data and advances in computational modelling. It may also be associated with the greater emphasis on disaster risk reduction following major debris-flow disasters in Brazil, including the 2011 event in Paraná and the 2013 disasters in Rio de Janeiro and São Paulo, which caused substantial human and economic losses (Cabral et al., 2023). Although a direct causal relationship cannot be established, these events likely contributed to growing scientific interest in debris-flow research over the following years. Nevertheless, progress remains constrained by the limited availability of real-time monitoring data, highlighting that debris-flow science is still an evolving field with considerable opportunities for future research.

The predominance of mixed (qualitative–quantitative) approaches highlights the importance of correlating simulated results with descriptive information. This prevalence reflects the intrinsic complexity of debris-flow processes, which require both quantitative and qualitative perspectives to be properly understood. This combined approach is particularly relevant in the context of disaster risk management. While quantitative results provide a basis for hazard assessment and technical decision-making, qualitative information plays a key role in translating scientific knowledge into accessible insights for stakeholders, including policymakers, local communities, and emergency managers. Therefore, the integration of qualitative and quantitative analyses not only enhances the robustness of scientific investigations but also facilitates the communication and practical application of results, which is essential for effective risk reduction strategies.

Although the number of studies was relatively similar among the three states, the concentration of studies in Paraná is likely associated with the recurrence of debris-flow events in the Serra do Mar region, where steep terrain, intense rainfall, weathered regolith, and favorable geological conditions create an environment highly susceptible to debris-flow initiation, as also reported by Picanço, Mesquita and Melo (2019); Paz and Paula (2022).

The dominance of local-scale studies reflects the highly site-specific nature of debris-flow processes. Although debris flows have considerable destructive potential, their impacts are generally concentrated along well-defined flow paths, while adjacent areas may remain almost unaffected. This spatial variability reinforces the need for detailed local investigations to identify the conditions controlling debris-flow initiation and to improve hazard assessment, because debris-flow triggering results from complex interactions among topography, geology, sediment availability, and rainfall.

One of the most consistent findings of the reviewed studies was the limited availability of monitoring data for debris-flow events. Several studies identified this limitation as one of the main obstacles to improving model calibration and understanding debris-flow dynamics (Salvador; Michel, 2023; Kobiyama; Michel, 2019). Consequently, post-event surveys and detailed mapping are essential before sediment remobilization modifies the affected area (Dias; McDougall; Vieira, 2022; Kobiyama; Michel; Goerl, 2019). These findings reinforce the need to expand hydrometeorological and topographic monitoring networks, although field investigations remain challenging in densely vegetated terrain (Picanço et al., 2016).

Another recurrent finding of the reviewed literature concerns the role of sediment connectivity in debris-flow dynamics. Despite recent advances, difficulties in quantifying the coupling between debris flows and channel networks remain a major challenge, limiting the understanding of sediment transfer during high-magnitude events (Paul et al., 2023a). Integrating connectivity metrics with debris-flow modelling has been identified as a promising approach to improve process representation and hazard assessment (Abatti et al., 2021). Furthermore, investigations of sedimentary structure and sediment availability highlight the strong interaction between geomorphological controls and hydrosedimentological responses, reinforcing the importance of detailed geomorphological and geomorphometric analyses as a basis for numerical modelling (Paz; Paula, 2022). These findings are consistent with recent studies, which discuss the role of sediment connectivity in linking debris flows and fluvial systems (Cavalli et al., 2026; Fan et al., 2020).

Only a small proportion of the reviewed studies addressed disaster education and public awareness. Nevertheless, the available literature consistently emphasizes the importance of integrating debris-flow knowledge into education and community preparedness programs (Kobiyama; Michel; Goerl, 2019; Kobiyama et al., 2015). To broaden understanding of debris-flow science, it is essential to integrate this knowledge across all levels of education in Brazil (Kobiyama et al., 2015) to improve risk awareness and disaster preparedness.

The systematic literature review also revealed several methodological gaps in debris-flow research in Southern Brazil. In computational modelling studies, approaches based on specific attributes often lack well-defined criteria and standardized mapping methodologies (Oliveira et al., 2018). As a result, it is difficult to compare susceptibility or hazard maps produced for different regions, since they may use subjective criteria or distinct methodological approaches (Facuri; Picanço, 2021). Furthermore, the reviewed studies emphasize the need to strengthen the integration between natural hazard assessment and land-use planning (Fernandes et al., 2009; Kobiyama et al., 2010; Pellerin et al., 2002). Geotechnical and soil properties (Picanço; Mesquita; Melo, 2019), sedimentological evidence (Picanço et al., 2016), steep-slope hydrology (Kobiyama et al., 2010), and debris-flow frequency analyses (Cabral et al., 2021; Cabral et al., 2020) should be more consistently incorporated into hazard assessment and susceptibility studies. Other relevant triggering factors, such as ground cover, bedrock geology, and antecedent rainfall conditions, also require further investigation (Dias; McDougall; Vieira, 2022).

More broadly, previous research has shown that the occurrence and spatial extent of landslide events are often recognized only after scar mapping, which can be performed using satellite imagery, particularly in hard-to-reach areas (Lopes, 2006; Marcelino, 2003; Okida, 1996; Riffel; Ruiz; Guasselli, 2016; Sestini, 1999). Consistent with this broader literature, remote sensing was one of the most widely used tools among the studies included in this review. In computational modelling, the reviewed studies showed that the Digital Elevation Model (DEM) is one of the most common input datasets for debris-flow simulations. However, model performance is strongly influenced by the quality and spatial resolution of the input data (Silveira; Silveira, 2025; Salvador; Michel, 2023; Kobiyama; Michel, 2019).

Finally, the reviewed studies in Southern Brazil suggest that future research should prioritize improving risk assessment, particularly through better identification of vulnerable areas and the definition of priority zones for preventive disaster risk reduction measures (Sugiyama; Gomes, 2022; Pellerin et al., 2002).

6. Conclusions

The present study assessed the current state of knowledge on debris flows in Southern Brazil and identified the main gaps limiting hazard assessment and risk management. The systematic review revealed that, although debris-flow research has advanced over the past two decades, the number of studies remains limited considering the frequency and socioeconomic impacts of these events in the region. The main advances include the expansion of computational modelling, susceptibility assessments, and event-based analysis, with a predominance of mixed (qualitative–quantitative) approaches and local-scale investigations. These studies have contributed to a better understanding of debris-flow dynamics and to the identification of potentially hazardous areas.

Despite these advances, important research gaps remain. The reviewed studies consistently highlighted limitations related to data availability, long-term monitoring, methodological standardization, and the understanding of debris-flow initiation and sediment connectivity. In addition, the relatively small number of studies addressing disaster education and community preparedness indicate that the practical application of scientific knowledge in Disaster Risk Reduction remains limited. Addressing these gaps will require improved monitoring networks, standardized methodologies, and stronger integration between scientific research, land-use planning, and community-based risk management.

Author Contributions: Idea L.L.C. and M.A.P.; methodology, L.L.C. and M.A.P.; software, L.L.C and I.G.A; formal analysis, L.L.C. and M.A.P.; research, L.L.C. and A.B.B.; review, M.A.P., I.G.A. and F.M.F.; supervision, M.A.P. All authors read and agreed with the published version of the manuscript.

Funding: This research was funded by the Research Support Foundation of the State of Rio Grande do Sul (FAPERGS) under grant agreement 24/2551-0002124-8 (FAPERGS Call for Proposals 06/2024 – Research and Development Program focused on climate disasters).

Acknowledgments: To the Federal University of Rio Grande do Sul (UFRGS), Institute of Hydraulic Research (IPH), and Coordination for the Improvement of Higher Education Personnel (CAPES).

Conflict of Interest: The authors declare no conflict of interest.

Declaration of Artificial Intelligence Use: The authors declare the use of a generative artificial intelligence tool, ChatGPT, for grammar and fluency review, subject to human supervision and verification.

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