






## Article

# A Systematic Review of the Relationship between Geotechnics and Disasters

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**Abstract:** Landslides, earthquakes, and other natural events can change the landscape and generate human and economic losses, affecting transportation and public service infrastructure. In every geotechnical project, the investigation phase plays a fundamental role in reducing the risk of occurrence and mitigating catastrophes. As a result, governments have created entities to study disasters and identify triggering factors that generate huge losses worldwide. This research aims to conduct a systematic review of the relationship between geotechnics and disasters through bibliometric techniques, scientific production evaluation, and case studies analysis to recognize key topics, methods, and thematic development of the research worldwide. The research methodology consisted of three steps: (1) Database analysis, selection, and combination, (2) bibliometric analysis, and (3) systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. The systematic review with bibliometric analysis collected data from 1973 to 2021, with 1299 academic publications indexed in the Scopus and WoS database. These results indicated a growing trend of annual publications on disasters and their relationship with geotechnical studies, highlighting current issues and technological innovation. The main research trends in disaster risk assessment were topics mainly linked to landslides, earthquakes, liquefaction, and inappropriate analysis models with applications of geophysical methods, laboratory tests, remote sensing, and numerical models.

**Keywords:** geotechnical engineering; landslides; natural events; systematic review; bibliometric analysis



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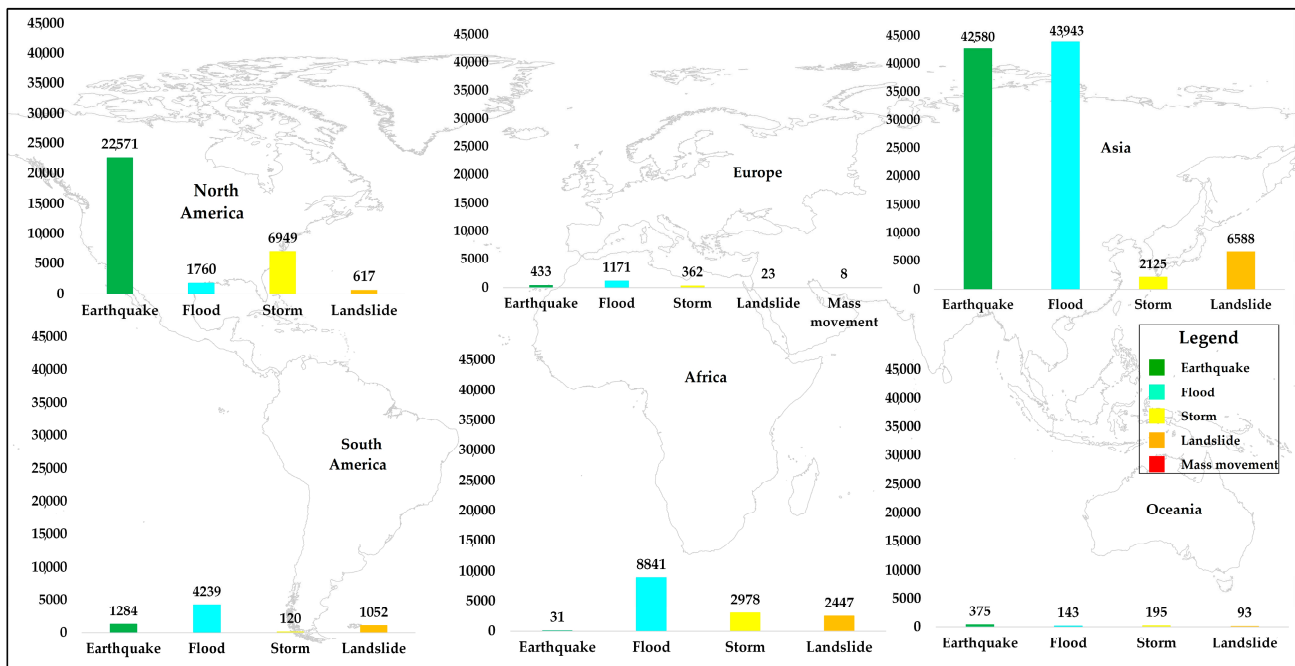
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## 1. Introduction

Disasters are generally defined as events that generate trillions of economic losses and thousands of fatalities [1,2]. The World Health Organization (WHO) defines a disaster as a natural or human-made event that alters the natural conditions of a system, causing damage to the population and infrastructure [3]. These disasters can occur worldwide, putting areas with high population density at risk (Figure 1) shows data obtained from the Emergency Events Database (EM-DAT) [4].



**Figure 1.** Human losses in disasters from the year 2000 to October 2021. Source: Modified from EM-DAT database [5].

From a geotechnical approach, most disasters happen in embankments or excavations due to different geodynamic events [3,6], such as erosion, earthquakes, and floods, which can generate landslides, slope failures, subsidence, and debris flow, among other phenomena [7–10]. However, heavy rains and earthquakes are the main factors that generate disasters, which are difficult to predict [6].

There have been past accidents in geotechnical structures even when imminent hazards were identified, such as the building collapse in Shanghai (2009), where the reinforced piles were insufficient, or the wall collapse in Germany (2009) due to the water inflow and loss of materials during the last phase of the excavation [11,12]. Technological advances solve problems in less time, avoiding economic and human losses [13]. The historical cases of collapse of geotechnical structures published in the scientific world have established the leading causes of geotechnical failure (Table 1).

**Table 1.** Examples of the relationship between geotechnics and disasters.

Causes	Description	Examples
Inadequate geotechnical investigation	Insufficient research to adequately model conditions on-site.	Nigerian construction industry [14]
Wrong parameters	Poor sampling and testing procedures, selection of inappropriate parameters, and underestimation of the variability of soil properties.	Excavation in Singapore [15]
Inappropriate analysis model	Critical failure mechanism not recognized.	Grain elevator Transcona, Canada [16]
Underestimation of actions	Inaccurate assessment of the magnitude, distribution, or combination of actions (forces or displacements) and change in use of the structure over time.	Kansai International Airport, Japan [17]
Unexpected groundwater regimes or changes in humidity content	Changes in groundwater levels can increase structure loads and decrease soil shear strength.	Liquefaction-induced caisson failure: Barcelona Harbor, Spain [18]

The case study of the earthquake in Kocaeli, Turkey, allowed observing the effect of liquefaction and soil softening by analyzing damage patterns of buildings and ground failure in the city of Adapazari [19]. The data obtained in the post-earthquake reconnaissance phase in similar seismic events in New Zealand in 2010 and 2011 have been essential for investigating and constructing the state of the art in liquefaction evaluation [20]. In the last decade, remote sensing has become a crucial tool for studying post-earthquake geotechnical reconnaissance and identifying pavement cracking and settlement using satellite images [21,22], laser imaging detection and ranging (LiDAR) [23,24], and unmanned aerial vehicles (UAVs) [25]. These remote sensing applications mainly involve documenting and identifying damage patterns, building digital elevation models on fault geometry, and measuring ground movements [26,27]. In addition, aerial photographs and LiDAR information allow obtaining data and comparing previous conditions in cases such as landslides, earthquakes, and mass movements on high slopes or in inaccessible areas to monitor ground stability, failure mechanisms, and urban planning [20,28].

The Haiti earthquake was a historical disaster that caused significant damage and more than 300,000 deaths. Post-earthquake information was collected through the LiDAR system and aerial photographs, obtaining a high-resolution digital terrain model. In addition, this allowed the development of a local geological map and slope angle map compared with damage patterns [29,30].

In March 1993, the Josefina rock slide was the biggest disaster in Ecuador. The Ecuadorian civil defense ministry reported 35 people dead, and 76 houses affected [31]. The studies identified five factors as the potential causes of instability: steep slopes, paleo-slides, a narrow canyon with river erosion, extraction of construction material at the foot of the slope, and low resistance of rock materials [32]. In addition, the event occurred in a period of high rainfall [33]. This emergency demonstrated the lack of studies to predict disaster outcomes and the need to obtain hydrological, geological, topographical, and cartographic information [34].

The increase in deaths, economic instability, damage to the environment, and the destruction of infrastructure are typical of a catastrophe [35]. These consequences make it necessary to monitor and detect disasters in real time [36]. Risk assessment involves identifying the nature and magnitude of current and future hazards by analyzing buildings or structures that endanger human lives [37,38]. Various methodological, analytical, numerical, and technological innovations exist in geotechnical structure analysis, design, and construction [11]. Furthermore, advances in disaster prevention are possible through post-disaster research, where the emergence of high-resolution data brings new insights [20]. Therefore, it is necessary to complete a compilation and analysis of case studies identifying trends and methodologies to build a broad vision of the disasters that harm society worldwide.

Literature reviews play a critical role in academic research in collecting information and analyzing a topic within a field of study [39]. A large number of articles, reports, and other documents are published in scientific journals, evidencing the exponential growth of the academic field linked to research [40]. Due to this increase in scientific publications by many journals, it becomes a challenge for researchers to identify relevant studies on a topic of interest, analyze their contribution and quality, and synthesize the research results. A systematic review helps to tackle this challenge by allowing information to be examined through a reproducible and transparent process of a small number of studies that meet the inclusion criteria [41–43].

Currently, there are bibliometric studies related to disasters [44–46], analysis of environmental justice concepts, and sustainable development focused on georisks [47]. However, a systematic review with a centralized bibliometric study on the relationship between geotechnics and disasters can be a complementary component.

The bibliometric study is a rigorous method for analyzing large volumes of scientific data [48] to determine the essential characteristics of various research topics that show key issues and updated knowledge in the area of interest [49]. Bibliometric methods provide a quantitative analysis of the academic literature [50] by examining keywords, authors, institutions and the most influential countries. These analyses use VOSviewer, Citespace, and HistCite [51,52]. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement consists of a four-phase flow diagram: identification, screening, eligibility, and inclusion [43]. It is a guideline to help authors to critically evaluate their systematic review [53].

Based on the previous information, it is essential to establish the following research questions: What are the research trends in studies relating disasters to geotechnics? How has the relationship between geotechnics and disasters evolved in recent years? Finally, what were the predominant disasters related to geotechnics and the new methodologies applied to study these events?

This research aims to evaluate the relationship between geotechnics and disasters through a systematic review using the PRISMA method, applying eligibility criteria and bibliometric techniques to analyze case studies of the last two decades, which recognize the global evolution and research trends of this topic.

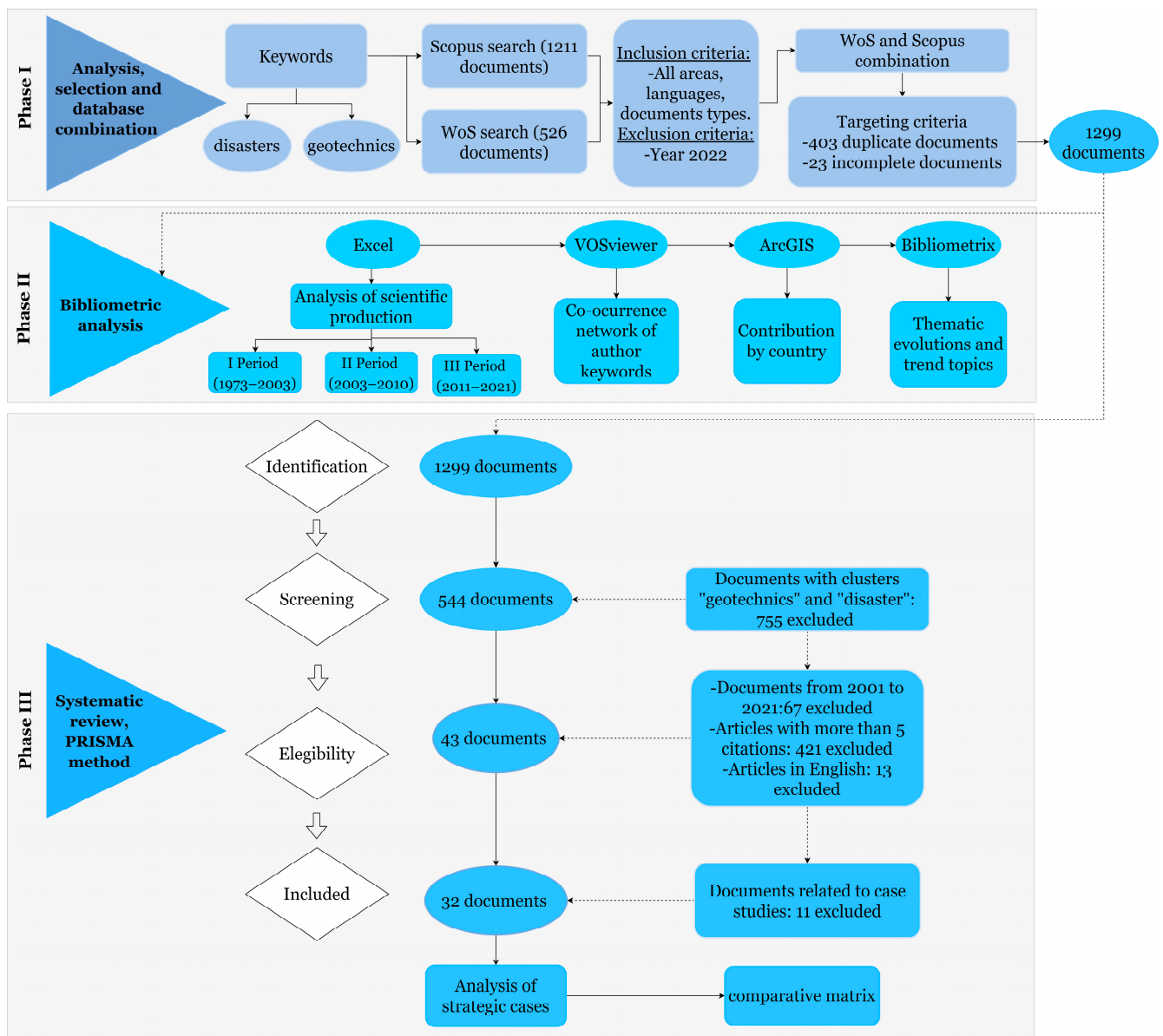
## 2. Methodological Context

The literature review helps to elaborate a comprehensive synthesis of a topic of interest, giving way to the construction of scientific knowledge, where new theories and opportunities for future research arise [54,55]. The traditional literature review assesses the mastery of a topic [56]; in contrast, a systematic review of the literature involves a comprehensive analysis of all available information in response to a research question [57,58]. Combining a systematic review with bibliometric methods brings about a significant research interest since it allows the analysis of main research trends and influential actors (journals, authors, institutions, or articles) in the field of study. Furthermore, a systematic review examines published topics, providing a complete, impartial, and relevant synthesis in a single document. The PRISMA method includes verification criteria for researchers on how to synthesize information in a systematic review [59,60].

A systematic review creates a solid state of the art, contributing to research advances with new and significant research trends. Furthermore, the systematic review and the bibliometric study examine citation patterns, providing the basis for identifying future research directions [61]. In addition, this analysis represents a research tool to explain the scientific production and trends in any branch of the different sciences [62], such as publications related to earth sciences linked to earthquakes [63], geoparks [64], soil monitoring [65], landslides [66,67], tsunamis [68], and structural geology [69].

Scientific databases such as Scopus and Web of Science (WoS) have made it easier to acquire significant scientific publications, allowing pragmatic data analysis using software such as VOSviewer and Bibliometrix [70,71].

The method proposed in this systematic review study using bibliometric analysis (Figure 2) consisted of three phases: (1) analysis, selection, and data combination, (2) bibliometric analysis, and (3) systematic review using the PRISMA method.



**Figure 2.** Methodological scheme of the bibliometric analysis of the disaster–geotechnical relationship.

### 2.1. Phase I: Analysis, Selection, and Database Combination

This paper analyzes the research trends and approaches to the geotechnics–disaster relationship from a systematic review and bibliometric analysis. Disasters are a complex social phenomenon representing a danger to the human population, causing damage and significant impact [72]. Based on this term, its evolution over time, and the different areas of knowledge in the literature, the keywords “disasters” [73–76] and “catastrophe” [77–79] are defined.

Geotechnics is a subdiscipline of civil engineering involving soil and rock mechanics, geological engineering, and other related disciplines [80] for studying terrestrial materials that improve soil conditions and prevent human losses [81]. Therefore, for this second term, the search word chosen was “geotechnics”.

Scopus and WoS were the databases selected for the document search. In 2004, Elsevier Co. created Scopus, an abstracting and indexing database with full-text links [82] containing peer-reviewed scientific information [83]. Scopus has become one of the most extensive indexing and abstracting databases ever built [82–84]. It was developed by combining PubMed and Web of Science features, allowing for better literature research results [85,86]. Scopus, at

its launch, had approximately 27 million publications. After that, its publications grew to more than 76 million annually, with a 3 million document increase [83,87,88], making it the database with the most significant number of indexed journals [89,90]. The WoS database, owned by the company Clarivate Analytics, is the oldest citation database, collecting scientific information from 1900 to the present. It includes 8700 research journals with the highest impact in the world and provides access to the “Science Citation Index” [91].

Bibliometric analysis uses quantitative analysis to widely describe, appraise, and verify scientific publications across many science and engineering disciplines [92]. In addition, together with the systematic review, they are considered a research tool that easily and understandably summarizes outstanding publications in a field of research [60]. These analyses examine many disciplines, such as earthquakes, floods, geosites, soil monitoring, landslides, tsunamis, and structural geology.

The preliminary search for this investigation was carried out on 27 December 2021. It involved the terms “disasters”, “catastrophe”, and “geotechnics”, in the titles, abstracts, and keywords using Boolean operators (and, or) to relate both terms in the following Scopus search: ((TITLE-ABS-KEY (“disaster\*”) OR TITLE-ABS-KEY (“catastrophe\*”))) AND (TITLE-ABS-KEY (“geotechnic\*”)); meanwhile, in WoS, the search used was: “disaster\*” OR “catastrophe” (Topic) and “geotechnic\*” (Topic).

In all, 1211 documents were gathered in the initial search in the Scopus database. Subsequently, after excluding the year 2022 and considering all areas/themes, types of documents, and languages, the result was 1207 publications. In the WoS database, 526 documents were initially collected, and after using the exclusion criteria of 2022, all languages, and types of documents, 518 publications were obtained. The search in the databases resulted in 1725 documents. In unification processing, RStudio and the Bibliometrix library access the Biblioshiny web page, converting the data into an .xlsx format to establish the same data fields for Scopus and WoS, obtaining one master file. In the cleaning process, 23 documents were identified that did not contain complete bibliographic information (author, title, publication year, DOI, affiliation, abstract, and keywords), as well as 403 duplicate documents, resulting in a final total of 1299 documents.

## 2.2. Phase II: Bibliometric ANALYSIS

The data obtained through the unification of databases allowed an exhaustive analysis of documents through 4 different software tools:

(i) Bibliometrix permitted the unification of databases. Through the “Conceptual Structure” option, the thematic evolution was generated using the author’s keywords with an occurrence of five and two cutting points. Further, with the “documents” option, it was possible to obtain a trending topics map with three words per year and an occurrence of five.

(ii) Microsoft Excel of Office 365 allowed database cleaning by analyzing the scientific production between the number of documents and citations by year, the languages, and the document types through the dynamic table option.

(iii) VOSviewer (version 1.6.17) is a tool that helps to process, construct, and visualize bibliometric maps [93,94] using the author’s keywords. From the 1299 documents, 2795 keywords were identified, and the occurrence criteria were applied seven times in VOSviewer. The result was 504 keywords, which permitted elaborating the relationship map of the studies’ topics. Furthermore, VOSviewer allows detailed visualization of maps containing substantial data, building maps based on a co-occurrence matrix.

(iv) ArcGIS 10.5 presents a set of tools to visualize geographic information [95]. This software displays the geographical distribution of authors, institutes, and collaborative network structures [51,96]. In addition, the VOSviewer software permitted generating a database of document numbers by country, which was used in ArcGIS to elaborate a map identifying the most productive country.

The importance of building a scientific map lies in representing the cognitive structure of a research field through the analysis of citations and keywords between documents [97].

### 2.3. Phase III: Systematic Review Using the PRISMA Method

The PRISMA method consists of four stages for the systematic review. In the first stage, “Identification”, 1299 documents obtained in the first phase of the unification of Scopus and WoS databases were used. In the second stage, “Screening”, documents were filtered using the keywords “geotechnics” and “disasters” from the clusters identified in the bibliometric analysis. By excluding 755 documents that did not meet the criteria, 544 publications were obtained. The third stage, “Eligibility”, consisted in the eligibility criteria of documents, considering, first, their publication within the last two decades (2001–2021), which produced a total of 477 documents; second, articles with more than five citations due to the impact on their field of study, which reduced the total to 56 documents; and finally, documents published in English, as it is the universal language, with 43 publications obtained. Moreover, in the “Inclusion” stage, publications related to case studies were selected, and 32 investigations were found by analyzing the strategic cases through a table containing a summary of the themes, keywords, methodologies, and authors’ references used in the disaster–geotechnics relationship. The case studies were divided into six groups (geological hazard, earthquakes, liquefaction, inappropriate analysis model, landslides, and mining disasters) for the occurrence of the main topics inside the studies cases analyzed. The problems identified permitted the creation of a summary graphic relating to methodology and the cause that generated the disaster.

## 3. Results

### 3.1. General Revision of Statistical Data

#### 3.1.1. Scientific Production

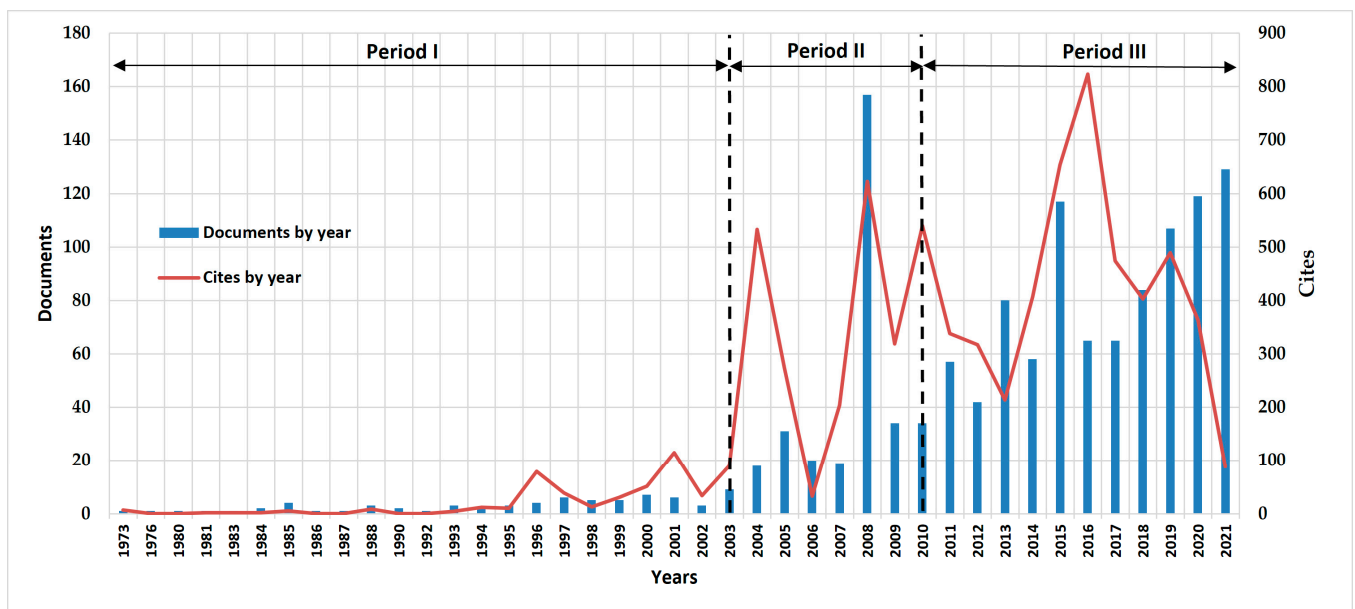
Scientific production was evaluated from 1973 to 2021 (1299 documents) in the Scopus and WoS databases, dividing the graph into three periods (Table 2). Each period was divided into peaks in the number of scientific publications. Peaks in publications and document citations could be observed, representing progressive growth trends (Figure 3).

**Table 2.** Summary of the publications corresponding to the three analysis periods.

Periods	Generalities	Study Topics and References
<b>Period I</b> (1973–2003)	In the first 30 years, there was no significant growth in scientific publications [98], with 53 documents and 264 citations.	Geotechnical investigations in mining waste lagoons [99], dumps [100], groundwater [101], sinkholes [102], waste management [103,104], debris flows [105], and shear wave velocity as a parameter in the field of geotechnical earthquake engineering [106], damage linked to geotechnical phenomena in earthquakes [107–109], landslides [110,111], soil liquefaction [112], geotechnical problems in slope stability [108], seismic microzonation [113], geotechnical characteristics of volcanic ash soils [112], and automatic monitoring of slope deformations using geotechnical instruments [114,115].
<b>Period II</b> (2003–2010)	There were 329 documents with 2765 citations, with specific growth peaks in 2005 and 2008, which coincides with the catastrophes that caused thousands of fatalities, such as the tsunami in Indonesia caused by the earthquake in the Indian Ocean (2004) and cyclone Nargis in Burma (Myanmar) (2008).	Seismological/geotechnical aspects of earthquakes [116–118], seismic wave velocity measurements [119,120], slope failure disasters [121,122], seismic behavior of geotechnical structures [123,124], realistic numerical simulations [125,126], seismic triggering of landslides [127], geotechnical failure of mining structures [128,129], landslide faults [130–132], prevention and monitoring of deformations [133,134], land subsidence [135], surrounding rock instability [136,137], rock bursts [138], slope instability [133,139,140], soft soils [139,141,142], geotechnical engineering problems in water resources projects [143,144], liquefaction susceptibility [145,146], dynamic shear modulus [147], geotechnical analysis of dams [148,149], settlements [150], and embankments [151].

Table 2. Cont.

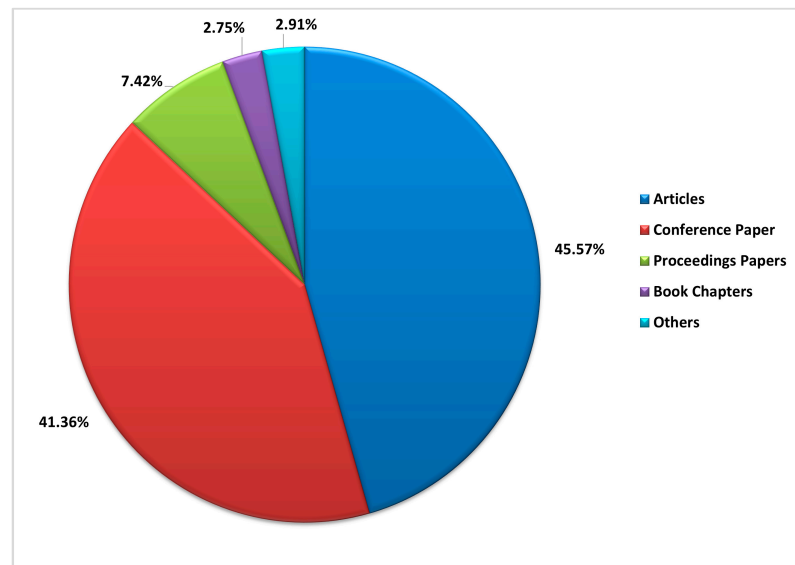
Periods	Generalities	Study Topics and References
Period III (2011–2021)	It had the most significant number of published documents (917) and included the most cited year (2016).	Studies of geological and geotechnical parameters related to natural hazard susceptibility [152], earthquake damage assessment using remote sensing [153,154], methodologies applied to disaster mitigation and monitoring [10,155–157], geotechnical investigations of earthquakes [158–160], post-disaster road reconstruction [27,161,162], slope stability [163–165], numerical simulations [166,167], mining activities [168–170], soft soils [171,172], landslides [173–175], dikes [176], dams [177–179], study of the geomechanical parameters of materials [180–182], soil liquefaction [183–185], seismic microzoning [186–188], permafrost hazard [189], damage to geotechnical structures due to tsunamis [12], sediment consolidation [190], soil improvement [191], and investigations in coastal areas [192], floods [193,194], and subsidence [195,196].



**Figure 3.** Growth of scientific production of documents and citations per year on the geotechnics–disasters relationship.

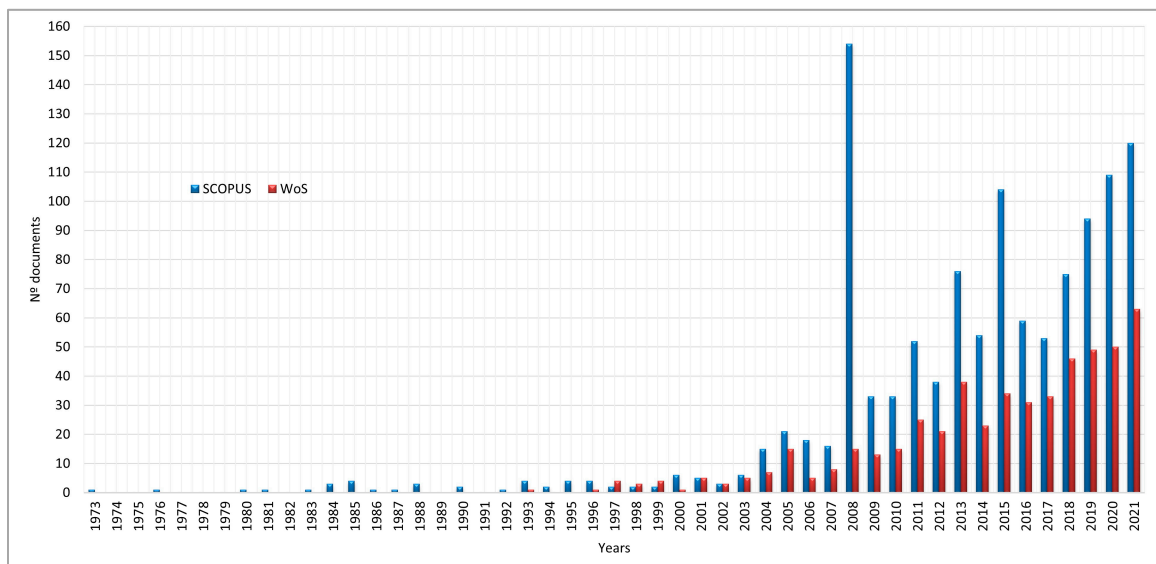
Within the earth sciences related to disasters and geotechnics, there were publications in 12 different languages. English dominated approximately 88% of scientific production [197,198] in both the Scopus and WoS databases [199]. The second relevant language in scientific publications was Chinese at 10%, with the *Journal of Geotechnical Engineering* and *Rock Soil Mech* as prominent journals. More than 45% of published documents (595) (Figure 4) corresponded to scientific articles about landslide dynamics [130], earthquakes [118,159,200], and remote sensing [27,153,201]. A total of 41% of publications were conference papers in which the “*Geotechnical Engineering for Disaster Mitigation and Rehabilitation-Proceedings of the 2ND International*” conference stood out with 129 documents, the “*15TH Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*” with 36 documents, and “*Geotechnical Special Publication*” with 35. The most outstanding conferences tackled topics of liquefaction [202–204], disaster waste [205,206], and landslides [207–209]. An amount of 7.42% corresponded to proceedings papers, with 97 documents highlighting landslides [110,210,211] and earthquakes [212–215], while 2.97% were books e.g., [216]; chapters of books, e.g., [156,217]; data papers [218]; notes [219]; reviews [220]; editorials [221], and short reviews, e.g., [222,223].





**Figure 4.** Types of documents on the geotechnics–disasters relationship.

Figure 5 shows the scientific production of Scopus and WoS, with articles as the most published types of documents. The Scopus indexed database recorded the highest number of publications on the subject from 1973 to 2021, showing a significant peak in 2008 due to a cycle of conference papers, among which the “*Geotechnical Engineering for Disaster Mitigation and Rehabilitation-Proceedings of the 2ND International*” conference stood out with 129 documents. In the last seven years, Scopus has grown due to a significant number of indexed journals [224], while WoS registered its first publication in 1993.

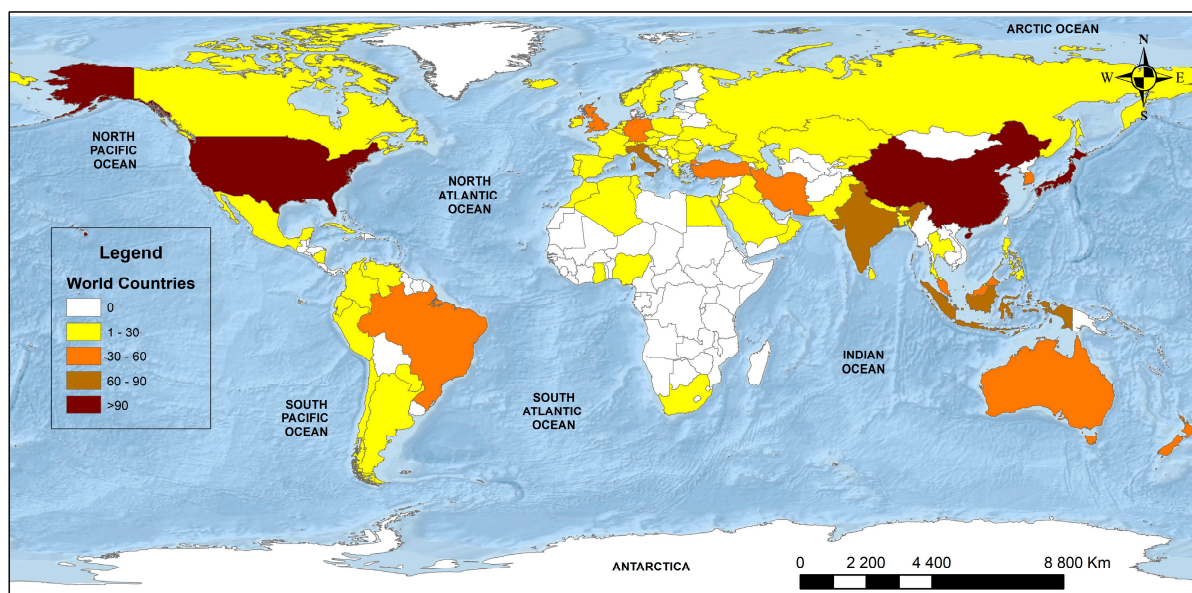


**Figure 5.** Documents published from 1973 to 2021 in Scopus and WoS.

### 3.1.2. Contributions by Country

The scientific contributions by country help to identify the affiliation and where the research topics have been investigated [225]. For this purpose, a map was generated using the ArcGIS software (Figure 6) to visualize the contributions of 70 countries. China was the most influential, with 850 publications, collaborating with 42 countries, more significantly with Japan and the United States. Through collaborative efforts between China and Japan, research was published on fault mechanisms [226], landslides [227–229], slope instability [230–232], dynamic response analysis of tailings [233], and early warning

monitoring [234,235]. Through collaborative efforts between China and the United States, researchers addressed issues related to seismic responses of foundations [236], mesomechanisms of rock failure under uniaxial compressive loading [237], progressive failures for deep tunnel roofs considering the variable dilatancy angle and detaching velocity [238], hydro-project-related geohazards [239], loess liquefaction [240], and geosynthetic reinforcement for dike stability on slopes [241]. Japan was the second country with the highest number of contributions (437 publications), with studies on geosynthetics derived from tires in geotechnical applications [242], landslides induced by rain and earthquakes [120], a hydrogeological–geotechnical model for landslide prediction [243], seismic hazard assessment using geographic information system (GIS) applications [244], and landslide risk evaluation and hazard zoning [245]. In the third place were the United States, with 263 publications, focused on issues around remote sensing methodology for pavement assessment [27], applications of drones in civil infrastructure [25], earthquake damage assessment using remote sensing [153], and residual shear strength of soil with mineralogical composition [246].



**Figure 6.** Contributions by countries—world map.

### 3.2. Bibliometric Analysis

#### 3.2.1. Keyword Co-Occurrence Analysis

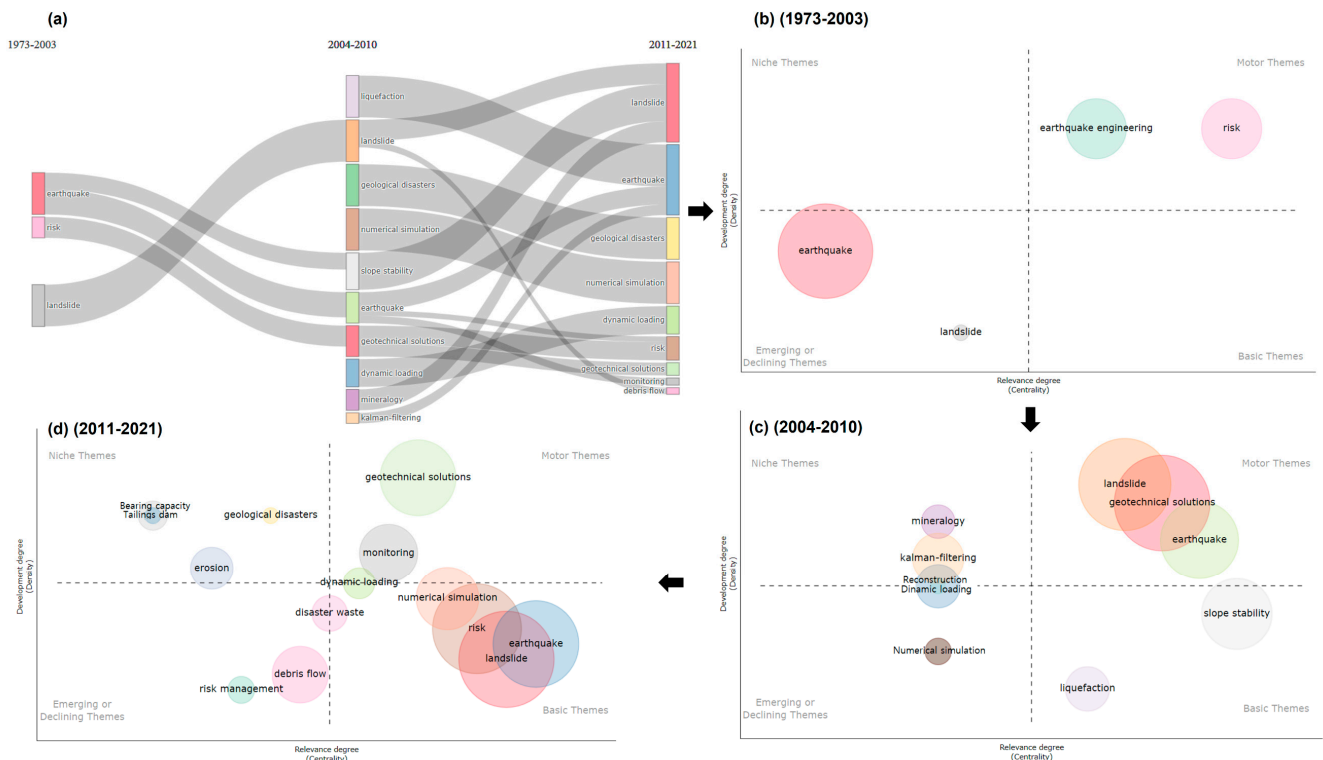
Keyword co-occurrence shows the relationship between the words most frequently used in scientific publications, the relevant topics, and the cognitive structure of the field of study [247]. Of the 1299 publications obtained from the unification of the databases (Scopus and WoS), the VOSviewer software analyzed 44 keywords, generating a multidimensional data map. Figure 7 shows the co-occurrence of keywords, which determined five clusters (group of words with the same color and occurrence of seven): geotechnical engineering, disaster, earthquake, risk, and landslide. Cluster 1, called “*Geotechnical engineering*” (with 33 occurrences), is the largest study area with 14 words related to this topic and nine nodes. The geotechnical engineering cluster is linked to research on risk assessment on slope stability [248,249], geographic information systems in geotechnical engineering [250], liquefaction during earthquakes [251], the interaction between anti-slip piles and landslides [252], site investigation for disaster reconstruction [253] and the performance of soft soil under the action of thunderstorms [254]. Cluster 2, called “*disaster*”, presents 12 nodes with themes related to debris flow disasters [255–257], geotechnical damage caused by earthquakes [258,259], damage to geostructures and slopes caused by heavy rains [258,260], erosion control and disaster prevention [261], debris flow drainage



### 3.2.2. Thematic Evolution (1973–2003, 2003–2010, and 2011–2021)

The thematic evolution reflects the predominant themes, the emergence of new ones, and the existing relationships in this field since 1973.

Figure 8a considers the occurrence of keywords a minimum of five times within the scientific production of each analysis period. The thematic evolution map is divided into three periods where the thick lines indicate the linked groups and inclusion index, while the thickness of the rectangles is proportional to the number of published documents with each theme [295,296].



**Figure 8.** (a) Thematic evolution from 1973 to 2021, (b) Period I, (c) Period II, and (d) Period III.

Figure 8b (1973–2003) shows that the topic development was limited; earthquake and landslide topics were considered emerging themes (low density and centrality), while the main themes (high density and centrality) were earthquake engineering and risk, which have a foundational role during the first period. Figure 8c (2004–2010) shows that the themes of landslide, earthquake, and geotechnical solutions become the main themes, the theme of numerical simulation emerged, while liquefaction and slope stability are considered basic and transversal themes (low density and high centrality). Figure 8d (2011–2021) shows that geotechnical solutions and monitoring were the main themes and debris flow and risk management were emerging themes, while landslide and earthquake were basic themes during the last period.

### 3.2.3. Research Trends

Figure 9 shows the trend map from 2005 to 2021, with three words per year and five corresponding to the frequency of occurrence in the research topic. The keywords were divided into analysis techniques, type of disasters, causes, and hazards. These words reflect the correlation between the various issues related to geotechnics and disasters. The words at the top, such as analysis, model test, and numerical simulation, represent the recent analysis techniques mentioned in the publications. The risk assessment keyword showed the highest frequency of occurrence (482 times) from 2013 to 2020. According to the type of disasters, publications about erosion and debris flow have been registered recently, and the terms landslide (125 times) and earthquake show the most frequency (81 times) in

the analyzed topics. The causes graph reflects an analysis from 2008 to 2021, where slope failure (19 times) and rainfall (29 times) were the last terms used in publications on the relationship between geotechnics and disasters. Recently, the hazards mentioned in the publications were seismic, vulnerability, and natural hazards.

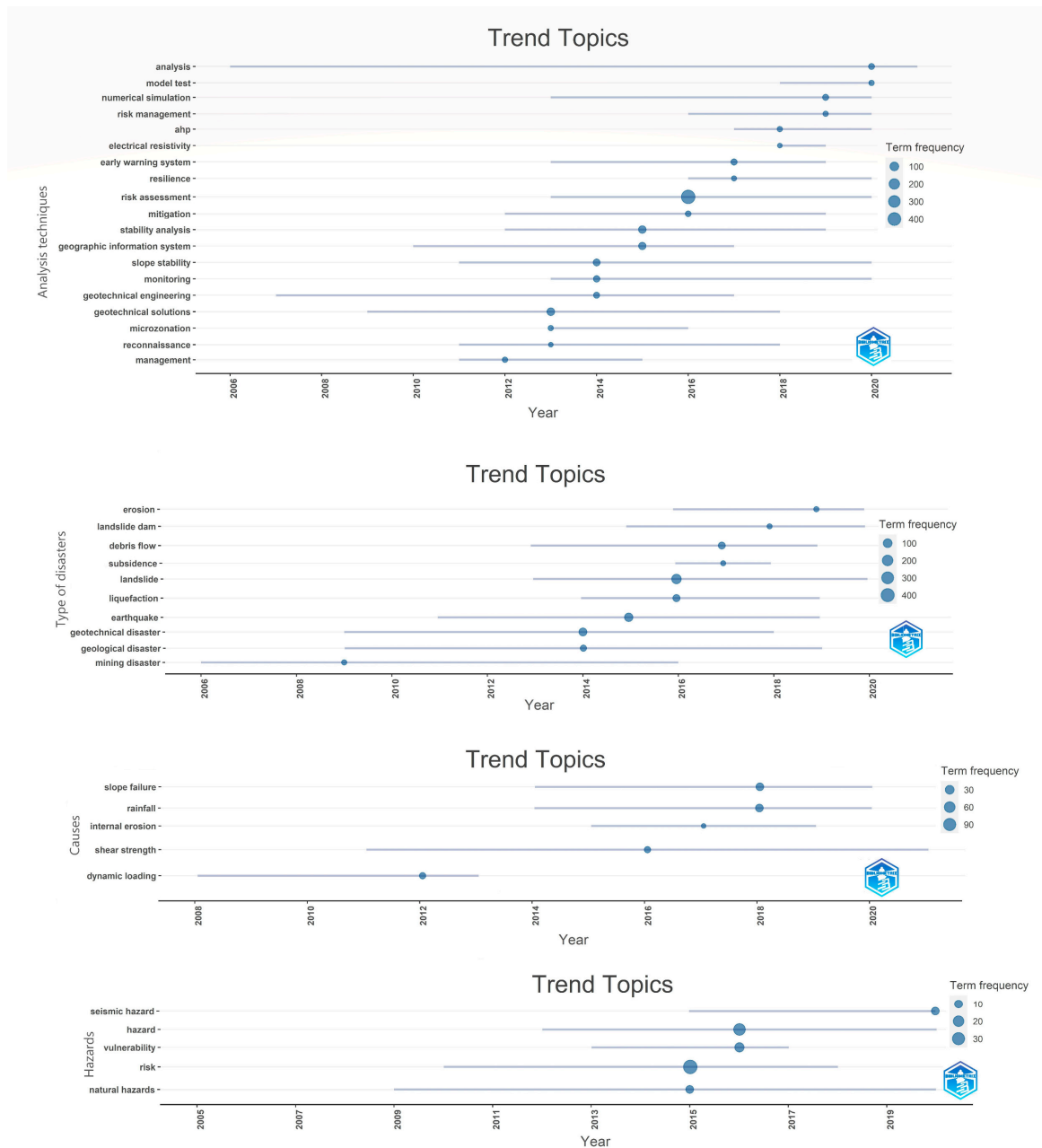
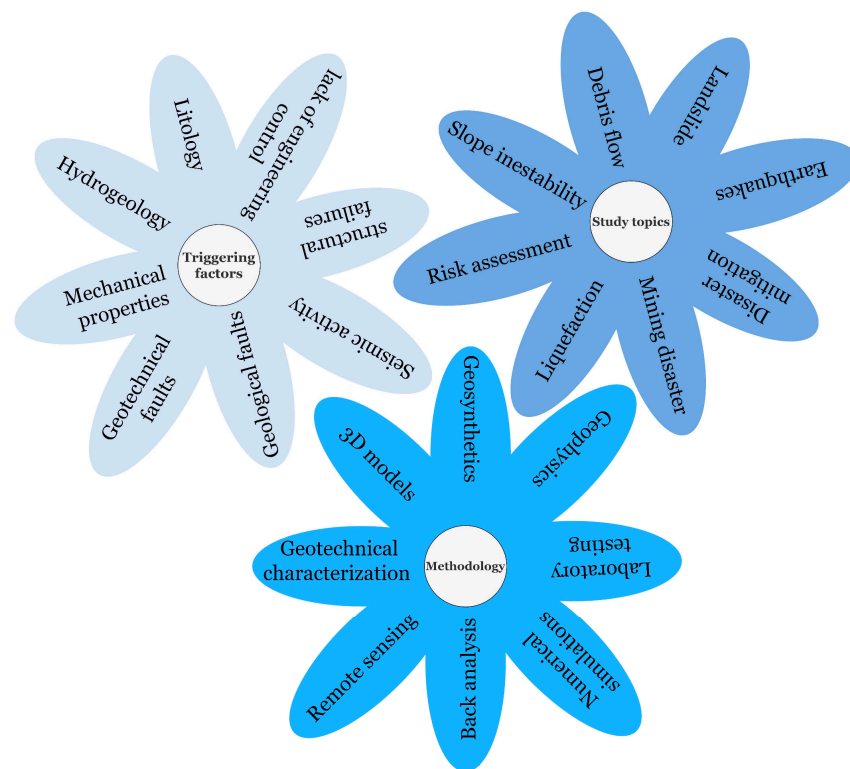


Figure 9. Research trend of keywords with a minimum frequency of occurrence of 5 from 2006 to 2021.

### 3.3. Systematic Review

In the systematic review, 32 case studies were analyzed, identifying the causes or triggering factors that generated these disasters and the different methodologies applied throughout the studies (Figure 10).



**Figure 10.** Summary graph of the themes, triggering factors, and methodologies applied in the 32 case studies analyzed in the systematic review.

For this systematic analysis, we considered the keywords used in the search “Disaster” and “Geotechnics”, documents published in the last two decades (2011–2021), documents with more than five citations, documents written in English, and the analysis of case studies, obtaining 32 publications. From these results, a summary graph of the topics, triggering factors, and applied methodologies was constructed, where the investigations could be classified into six groups (Table 3): (i) “geological hazard, soil erosion, soil freeze, and coastal area”, where research focused on stability on steep slopes, soil erosion due to construction in expansive soils, design criteria in the process of rehabilitation and reconstruction after seismic and tsunami hazards, and analysis of characteristics and mechanisms in road freezing; (ii) “earthquakes”, where investigations examined the analysis of structural damage in foundations, damage after the Wenchuan earthquake, earthquake disaster waste, and the use of wireless sensors for structural monitoring due to seismic risk; (iii) “liquefaction”, where topics dealt with liquefaction related to earthquakes, injection of bubbles into sandy ground to reduce the degree of saturation, liquefaction-induced permanent deformations, numerical simulations of liquefaction, and damage to dikes after earthquakes and aftershocks; (iv) “inappropriate analysis model”, where topics focused on the application of finite elements for the study of soil improvement using the bamboo pile–mattress system, and geosynthetics in embankments and roads to replace fill material and reduce the load applied to foundations; (v) “landslides”, which included topics around landslide vulnerability, numerical simulations, and laboratory tests applied to landslide and subsidence studies; and (vi) “mining disasters”, which considered publications on rupture mechanisms in mining areas, faults, and seepage affecting geological structures, and faults in mining tailings.

**Table 3.** Summary of the types of disasters, keywords, applied methodology, and the mentioned articles of the 32 publications analyzed in the systematic review.

Disasters	Keywords	Applied Methodology and References
Geological hazards: soil erosion, soil freeze, coastal area, disaster waste	Avalanche, landslide, rockfall, tsunami, soil erosion, expansive subgrade soils, coastal zones, geotechnical engineering, hazard, shear flow, soil freeze, pavement structure, freeze damage, freezing front, shear waves, spectrum analysis, surface waves, wave propagation, frost effects, disaster waste and developing countries.	Geological survey [118], treating measures in expansive soil subgrade [139], spectral analysis of surface waves (SASW), probabilistic seismic hazard analysis (PSHA) and EZ-FRISK software [134], expanded polystyrene (EPS) geofoam [297], primary data collection and analysis [298].
Earthquakes	Earthquake, geotechnical engineering, soft soil, damage investigation, mountain tunnels, ground faults, landslides and slope instability, disaster mitigation, ductility, stability, three-dimensional geosynthetics, UAV and wireless sensor networks (WSN).	Field visit and information gathering [116], systematic investigation [118], structural damage observation and analysis [299], earthquake early warning system (EEWS), triaxial MEMS accelerometers, down-hole (DH), multichannel analysis of surface waves (MASW) [300], tire-derived three-dimensional geosynthetics [242], UAV, drones, WSN, and LiDAR [25].
Liquefaction	Liquefaction, seismic hazards, engineering geology, geotechnics, surface geology, pond ash, sand, evaluation, soil, earthquake, numerical modelling, centrifugal testing, geotechnical engineering, earthquakes (natural disasters), and dike stability.	Liquefaction susceptibility mapping [145], triaxial test setup with a little modification to the triaxial cell [202], injecting air bubbles into sandy ground [301], rammed granular piles (RGP) [302], systematic research, MASW, piezometers [303], high-resolution satellite images, electromagnetic and electrical resistivity methods [251].
Inappropriate analysis model	Numerical analysis, bamboo piles, soil reinforcement, expanded polystyrene (EPS), disaster prevention engineering, silty soil, properties' improvement, carbon fiber, direct shear test, mechanical properties, displacement, microstructure, slopes, construction, and geotechnics.	Bamboo pile–mattress system [304], EPS geofoam [305], analysis of soil improvement methodologies [191], carbon fiber, and nanosilica [306].
Landslides	Landslides, impact factor, void ratio, deviator stress, triaxial test, residual test, residual strength, triaxial compression, debris flow, dissipation structures, drainage channel, developing countries, disaster engineering, geotechnical engineering, land subsidence, long-term monitoring, differential interferometric synthetic aperture radar (DInSAR), hyperbolic method, material point method (MPM), runout, discontinuous deformation analysis (DDA), and open multiprocessing (OpenMP).	Triaxial test [307], systematic review [308], Chasm software (combined hydrology and stability model) [309], drainage channel with an energy dissipation structure [310], DInSAR, GPS, Envisat—synthetic aperture radar (ASAR), advanced land-observing satellite (ALOS)—PALSAR and Sentinel-1 SAR data [311], MPM [312], DDA and OpenMP [313].
Mining disasters	Mine, geomechanics, failure, hydrogeology, underground workspace safety, floor water inrush, strata failure depth, combined techniques, strip mining, caving zone backfilling, dehydration, earth pressure, soil/structure interaction, stress analysis, theoretical analysis, tailings, disasters, and geotechnics.	High-pressure direct shear apparatus and triaxial servo test system [314], geological and geotechnical investigations [315], piezometers, upstream construction method, early warning systems, in situ testing, standard penetration test (SPT), cone penetration testing and vane shear tests [316], strip mining and caving zone backfilling technique [317].

#### 4. Discussion

For the systematic review with bibliometric analysis of the geotechnics–disasters relationship, 1299 documents were collected from the Scopus and WoS indexed databases, unified using the Bibliometrix software. Publications in this field of study began more than 45 years ago (1973), and the first publication was registered in the Scopus-indexed database. Production has grown over time, with the participation of 28,767 authors from more than 70 countries, predominantly in English and Chinese. Disasters in geotechnical engineering have increased exponentially in the last decade (Figure 5), especially in topics related to earthquakes, e.g., [318,319], landslides, e.g., [312,320,321], disaster mitigation, e.g., [322–324], risk assessment, e.g., [325,326] and GIS applications in geotechnical vulnerability, e.g., [327,328]. Scientific production peaked in 2008 (Figure 3) since most of the publications (129 documents) corresponded to the “Geotechnical Engineering for Disaster Mitigation and Rehabilitation-Proceedings of the 2ND International” conference. Other topics of interest studied that year were liquefaction [202,203,302], earthquake-resistant structures [329], constructions in expansive soils [139], landslides [307,330], and disasters during earthquakes [331,332]. The trending topics related to the types of disaster reflected the presence of erosion and landslide dams as the phenomena most frequently mentioned in scientific articles in the last five years (2016–2020) (Figure 9). However, historically, the dominant themes are landslides and earthquakes, associated with slope failure, rainfall, and internal erosion. The analysis of the author’s keywords showed that the predominant themes are landslides, earthquakes, and geographic information systems. Landslides often occur during heavy rainfall events or adverse tectonic conditions, especially in steeply sloping mountainous terrain [333–335]. Due to these events, technology such as remote sensing is necessary for developing early warning systems for landslides and hazard zoning as one of the most effective ways to mitigate damage [336,337]. Consequently, the connection among author’s keywords (Figure 8) denotes relationships between the clusters “earthquakes” and “risks” through studies of GIS applications in the management and evaluation of risks, landslide hazards, and liquefaction induced by earthquakes [134,200,245,338]. For example, the 2008 Wenchuan, China (magnitude M 7.9) and the 1999 Taiwan, China (magnitude M 7.6) earthquakes provided important information for the study of landslides induced by these seismic events in mountainous areas [339]. Additionally, a connection between “debris flows” and “landslides” was observed through studies on landslides and debris flows induced by rains [259], such as the case registered in Malaysia, whose major impacts (debris flows and landslides) were related to geotechnical faults. The systematic review using the PRISMA method allowed focusing on 32 documents, classified into six disasters in the last two decades, where earthquakes, liquefaction, inappropriate analysis models, and landslides predominated. Natural disasters such as earthquakes, tsunamis, and floods can cause significant human losses and rubble dumps [340,341]. Therefore, risk management has been a growing issue in recent years (Figure 9). Most urban areas are generally affected during a seismic event due to the lack of implementation of construction regulations in buildings, such as in the case of India in 2001 [116] and the Pedernales earthquake in Ecuador (2016) [342]. In the last case, more than 85 buildings had captive columns, experiencing greater shear demand than assumed in the design. In addition, these populated areas are susceptible to landslides caused mainly by settlements, construction on low-quality or hazard-prone land [157], and liquefaction in residential areas [304,343]. Most of the case studies (22 publications) were of events in Asian and Oceanian countries, as evidenced in Figure 1, since these two continents presented the most deaths caused by natural disasters, generating publications related to this topic.

The economic and human losses caused by the natural disasters identified in the systematic review were related to the economic development of a country [309], such as the case of the Bhuj earthquake in India [116], considered the most serious in the history of the Asian country. Although developed countries’ regulations guarantee earthquake-resistant construction and urban planning, they are not exempt from suffering severe damage after a natural disaster, as in the case of Newfoundland and Labrador, a Canadian province



where there have been human losses related to landslides, avalanches, and tsunamis since some populated areas are settled on steep slopes. Therefore, it is essential to develop maps delimiting areas vulnerable to geological hazards [344].

Madhav and Krishna [302] mention that liquefaction is the most dangerous disaster during a seismic event. Most are generated by human settlements on land susceptible to liquefying, as in the case of the 2011 Tohoku, Japan earthquake [251]. The injection of air bubbles in sandy soil [345] and installing granular piles/drains [346] have proven valuable methods for mitigating these events. In addition, landslides are one of the disasters with the most significant impact on geotechnical engineering [308,309]. For example, the Oso landslide in the United States was a catastrophic event considered one of the worst in the history of the country [312]. Over 230,000 people worldwide have died in the last 20 years from disasters such as landslides, earthquakes, floods, and storms [4,5] (Figure 1). For this reason, numerous investigations address them, such as the case study of Kobe, Japan (1996), where infrastructure damage due to liquefaction and settlements caused by an earthquake left over 5500 victims [345].

The research trends in the last three years reflect the applications of new methodologies for the study of monitoring, prediction, and mitigation of disasters, using different techniques such as geosynthetics, e.g., [242,346,347], landslides and disaster prediction models, e.g., [243,348,349], remote sensing, e.g., [350,351], and numerical simulations and applied biotechnology to geotechnical problems, e.g., [319,352].

## 5. Conclusions

This study includes information from 48 years of research. The topics that have prevailed in history and are still valid are stability, shear strength, and slope stability. In contrast, the current research topics are related to seismic hazards, early warning systems, numerical simulation, and model testing (Figure 9). In the systematic review using the PRISMA method, 32 case studies were evaluated related to geological hazards, failure in geotechnical parameters, earthquakes, mining disasters, landslides, and liquefaction, applying a range of integrated methods, such as small baseline subset (SBAS)–DInSAR interferometry in land monitoring subsidence; high-pressure direct shear apparatus; triaxial servo test system and simplified Seed–Idriss method for liquefaction; MPM to model large deformations in landslides; Chasm software to model dynamic slope stability processes; prospecting and survey techniques such as down-hole (DH); MASW, horizontal to vertical spectral ratio (HVSR); and refraction microtremor (REMI) and electrical tomography tests for the subsurface model of seismic microzonation. In the last 15 years, solutions such as tire-derived three-dimensional geosynthetics have prevailed for maintaining high permeability under high compressive load; the use of carbon fiber and nanosilica in silty soil for improving shear strength, friction angle, and cohesion; the use of EPS as a replacement for fill material to reduce the load applied to the foundations; a method of reducing the degree of saturation by injecting air bubbles into sandy soil; RGP for the dissipation of pore pressures in the soil; treatment technology of flexible support reinforced with geogrids to prevent the collapse of excavation slope; and treatment techniques of expansive soil subgrade for soil erosion prevention and bamboo pile–mattress for reinforced embankments on soft clay.

This study showed that disasters such as landslides and liquefaction are of significant interest in disaster prevention and mitigation studies due to their relationship with innumerable human and economic losses. Human settlements in vulnerable areas, such as high slopes and unstable soils, in addition to the lack of implementation of building regulations and codes, are among the leading causes of losses, which increase during a natural disaster. This study explored disaster prevention and monitoring, focusing on landslides, earthquake, debris flow, and liquefaction. By integrating new methodologies and trends, this research sheds light on the topic and contributes to preventing and solving crucial geotechnical engineering problems related to human lives.

Among the methodological trends in this field of study, geophysical detection methods such as electromagnetic radiation (EMR) and electrical resistivity tomography (ERT) applied in the characterization of dikes, landslides, mining, and early warning of disasters stand out. Furthermore, the combination of 3D models such as Scoops3D and TRIGRS (3D) for predicting the spatiotemporal distribution of surface landslides and UAV or “drones” and 5G IoT technology for the monitoring and early warning of landslides are also highlighted.

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