Geotech Geol Eng (2019) 37:3637–3648
https://doi.org/10.1007/s10706-019-00858-5

ORIGINAL PAPER

Perception of Risk and Sustainability: Concept Analysis of Environmental Justice and Sustainable Development in Geological–Geotechnical Risk Assessment Approaches

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Received: 1 October 2018 / Accepted: 14 March 2019 / Published online: 20 March 2019

Abstract Geological–geotechnical risks studies are a traditional approach in Earth Sciences and Engineering areas. Its main focus is understood the environmental dynamics related to risk situations and the consequences of these environmental dynamics for the well-being. This article focuses on discussing the probability of the occurrence of an environmental phenomenon that endangers population and considering how socioeconomic and political factors are associated with such occurrences. The proposed analysis shows how geological–geotechnical risk studies consider basic principles of sustainability in their applications and the potential of these studies in demonstrate how effective risk monitoring and management can contribute to socially responsible policies. The bibliometric research presented allowed us to identify tendencies and emerging knowledge; specific related journals; people and institutions acting and the mean life of scientific literature in this area. We could establish a proper relationship between this contribution and the recent context of research conducted in these areas. However, limitations of data access resulting from journals and congress proceedings not being fully open access remain as barriers to deeper analysis.

Keywords Geological risk · Risk monitoring · Sustainability · Environmental justice

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1 Introduction

Studies of geological–geotechnical risks still have a long way to go in different areas of science. However, researchers from the fields of Geography, Health Sciences, Social Sciences, Demography, Earth Sciences, Engineering and Economics have emphasized relationships between factors and the probability of certain phenomena of different levels of subjectivism occurring based on empirical and spatiotemporally circumscribed studies.

Specifically, in the 1970s, interest in these studies increased, expanding their insertion into science, political debate and civil society. In general, risk, along with vulnerability, has entered scientific, mediatic and sociopolitical jargon (Marandola and Hogan 2004). A detailed analysis of the evolution of this theme applied through different approaches, scales

and areas of knowledge is addressed by Almeida (2010), (Marandola and Hogan 2006) and Cutter (2003). They emphasize the relationship between the arrival of the 1980s and the emergence of the multidisciplinary integration of the social and natural sciences and engineering. Their research focused on the understanding of circumstances that place populations at risk due to hazards. They also paid attention to factors that enhance or reduce the response and recovery capacities of populations, physical systems and infrastructures in relation to environmental threats.

In the literature, studies related to geological–geotechnical risk analysis are incorporated into theoretical and methodological approaches used in areas of Earth Sciences and Engineering based on information on natural and environmental conditions that can facilitate understanding of exposure to risk. Hence, such studies are very important to understanding the circumstances and constraints that reduce the capacities for people and places to respond to threats. These are critical for the development of strategies for limiting and mitigating the consequences of disasters and environmental degradation at various scales of analysis.

In general, the concentration of studies related to geological–geotechnical risk analysis can be observed in two main areas: (i) the development of quantitative measurement models of the probability of the occurrence of events and on their causes and (ii) the prediction of future scenarios with the appropriate identification of present conditions. However, for the well-being, there is an urgent need to understand consequences of environmental dynamics that can lead to risky situations and scientific needs in the development of systematic documentation. These approaches should be capable of measuring the probability of the occurrence of an environmental disaster and should consider socioeconomic and political factors associated with such occurrences.

According to Almeida (2010), the growth of social inequality, poverty and sociospatial segregation with trinomial capitalism-industrialization-urbanization gave rise to a theoretical approach in conjunction with the consequent degradation of the environment in its various aspects. A particular theoretical approach is sought to focus on environmental risks and studies, which not only consider physical risk triggering factors but which also take into account sociological discussions based on affected and threatened populations and places. The approach emphasizes considerations of complex social organization and collective behavior. In this sense, approaches focusing on geological–geotechnical risks should not be reduced to overlapping of environmental situations. Rather, there are specifics that require a contextual, social or historical analysis of these situations as pointed out in several recent works on geodynamic phenomena (Adger 2006; Adger et al. 2009; Cutter 2003; O´Brien et al. 2004; Marandola and Hogan 2004, 2006, 2009; Valêncio 2010, 2014). Valêncio (2014) concludes that "the social dimension becomes the precondition for the natural dimension to become destructive."

Alcántara-Ayala (2002) and Marcelino et al. (2006) point out that most events involving risk and disaster with victims have occurred in developing countries. According to records for Asia and Africa, such cases are up to 50% more significant than those of other regions. The authors show that these figures reflect the socioeconomic conditions of these countries, including a lack of planning, of adequate infrastructure and of low investment in education and health. These factors increase vulnerability and exposure to extreme events. In reference to Brazil, some authors point to a chronic-degenerative process of social exclusion intensifying the expansion of *favelas* (slums) and of other forms of marginal occupation, typically in areas at risk.

The present article presents an analysis of ways in which geological–geotechnical risk analysis, prevention and monitoring modeling surveys deal with the relationship between the objectives of proposed applications and concerns worth considering in reference to content on social and environmental justice. Furthermore, we intend to investigate how geological–geotechnical risk analysis studies consider basic principles of sustainability in their application. Moreover, we explore how main authors of the area consider such studies to be important subsidies of projects that demonstrate how effectively risk monitoring and management can contribute to socially responsible policies on, for instance, land management and sustainable planning.

2 Geological–Geotechnical Risk Approaches

In approaches involving the analysis and application of risk management, hazards, disasters and socio environmental vulnerability, contradictions and confusion regarding the meaning and definition of such terms are recurrent and are also considered in one body of research on the subject.

According to Nogueira (2002), this turbulent movement of conceptual construction is characteristic and essential for the configuration of a multidisciplinary field of technical-scientific knowledge. (Varnes 1984 apud Corteletti, 2014), in his work for the International Association of Engineering Geology published by the United Nations Educational, Scientific and Cultural Organization (UNESCO), proposed a formal definition for different meanings of risk such as specific risk, hazard and vulnerability to standardize terminology applied in geological and geotechnical studies.

On the basis of this, the present research understands all physical phenomena of a geodynamic nature in relation to geological–geotechnical risks such as slides, mass movements and landslides, floods, soil repression, erosive processes and associated events. Therefore, applications and approaches of geological–geotechnical risk analysis studies mostly deal with probability measurement tools, the intensity of these events and how they can reach populations or places.

3 Sustainable Development, Sustainability and Environmental Justice

The emergence of sustainable development as a social and political project has promoted efforts to find paths to sustainable societies (Salas-Zapata et al. 2011). Since then, there has been a great deal of literature devoted to the subject, though undoubtedly with a lack of focus.

In recent times there has been an increasing interest in sustainability in strategies of cleaner production, pollution control, eco-efficiency, environmental management, social responsibility, industrial ecology, ethical investments, the green economy, eco-design, reusability, sustainable consumption and zero residue planning (Glavic and Lukman 2007), among many others.

Such approaches depend on the field of application (engineering, economics, administration, ecology, etc.) whereby each science tends to see only one side of the equation (Chichilnisky 1996) but with a common interest in sustainability. It is not by chance that concepts of sustainability are still misunderstood and in many cases treated as synonyms. However, not all researchers of these concepts define them in this way.

Dovers and Handmer (1992) state that sustainability refers to the ability of a natural or mixed human system to resist or adapt to endogenous or exogenous change indefinitely. Furthermore, development involves a path of intentional change and improvement that maintains or enhance this attribute of a system by responding to the needs of the present population. At first glance, sustainable development is defined as they ways in which sustainability is achieved. Rather, sustainability is the ultimate, long-term goal.

For Elkington (1994), sustainability involves the balance of three pillars: environmental, economic and social. The expectation that companies must contribute progressively to sustainability comes from the recognition that businesses need stable markets. Additionally, they must have the technological, financial and managerial skills necessary to enable a transition towards sustainable development (Elkington 2001). A second view differing from the previous also defines sustainable development as an objective to be achieved and sustainability as the process through which this is achieved.

The concept of environmental justice, however, is understood based on a set of principles and practices. It ensures that no social group (ethnic, racial, class or gender) supports a disproportionate share of the negative environmental consequences of economic operations; policy decisions and federal, state or local programs or the absence or omission of such policies. The environmental justice movement itself seeks to integrate the environmental dimension with those of law and democracy through transformative actions. It has been developing over the last two to three decades through the struggle against discriminatory dynamics that affect certain population groups as malfunctions of economic and industrial development (Porto 2011).

In Brazil, the environmental justice approach has been developed with the critical contributions of authors of political ecology (Martinez-Alier 1992), the

social sciences (Acselrad 1992) and collective health (Porto 2007), among others. The discussion on the invisibility of certain social groups not only due to their condition of socioeconomic vulnerability but also as an expression of social, economic and political processes involves disputes and conflicts over resources and over ways of living in territories. For Martinez-Alier (2007), environmental justice, which he also calls popular or poor environmentalism, derives from distributive conflicts over costs and benefits of the use or preservation of natural resources or, more broadly, all economic processes.

4 Methodological Procedure

The methodological procedure was based on bibliographical research of scientific documents in the area of geo-geotechnical risk and on an analysis of these documents based on objectives of the present study.

Figure 1 illustrates the methodological procedure used, which can be divided into three main steps: (a) search of available database documents, (b) bibliometric analysis of the documents found and (c) selection and analysis of documents based on objectives of the present study.

In this study, the Scopus database was used to obtain data to be analyzed, which according to Elsevier (2017) is the largest database of abstracts and citations of peer-reviewed scientific literature. This database provides tools for tracking, analyzing and visualizing research conducted in the areas of science, technology, medicine, the social sciences, and the arts and humanities.

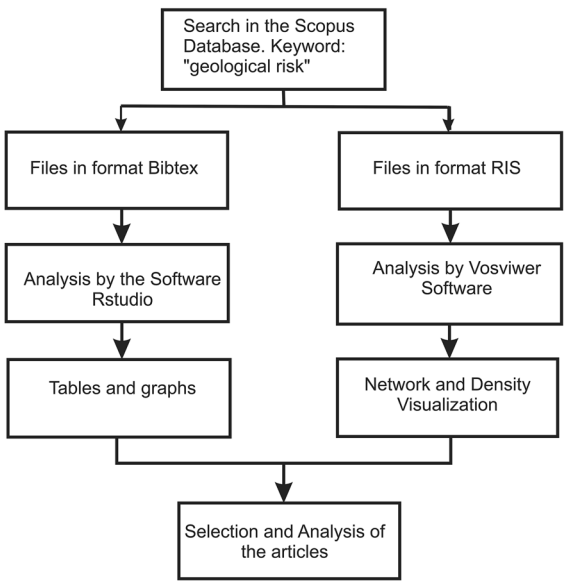


Fig. 1 Methodological flowchart of the involved steps

The research was conducted in November 2017 using the key word "geological risk." Articles published in journals, conference proceedings, bibliographic reviews, chapters of books and articles that have already been accepted by journals and are in the process of being published were considered. The present study was based only on papers published between the years 2014 and 2017 to obtain a recent overview of studies carried across the globe over the last 3 years.

The search returned a total of 135 research results. Data with information on the articles were exported in.bib and.ris formats that can be read with free bibliometric software R Studios and VosViewer, respectively.

The bibliometric analysis was performed with *R Studios* and *Vosviewer* software. In *R Studios*, we used the (Bibliometrix 2016) package, which offers several means of importing bibliographic data from the *Web of Science*, *Scopus* and *Clarivate Analytics* databases, which performs bibliometric analyses and which constructs data matrices. (Vosviewer 2017) is a software tool that was used for the construction and visualization of bibliometric networks via co-citation, bibliographic coupling or coauthorship relationships.

Finally, from the 135 existing publications, 30 papers were selected for a final analysis of the results. Such selection was based mainly on the following criteria: publications with the most cited authors, with authors from different countries, offering variation in dates of publication across the proposed time series (2014–2017) and considering areas with diverse applications in the field of geological—geotechnical risk.

From the selected data, the use of concepts of *Sustainability* and *Environmental Justice* found (1) in the discussion of results of the research, (2) in the development of methodological procedures and (3) in literature reviews contextualizing central themes was considered critical in the analysis of the documents. Theoretical considerations made on the concepts analyzed were based on those proposed by Sharachchandra (1991), Mebratua (1998), Hodge

(1999), Gallopín (2003), Ioris (2009), Acselrad (2002, 2009), Pintér et al. (2012), Sartori et al. (2014), Giovannoni and Fabietti (2013) and Sette (2015).

5 Results and Discussion

5.1 Bibliometric Analysis

As noted above, the survey on "geological hazards" for 2014 to 2017 returned a total of 135 documents published in periodicals, conference proceedings, bibliographic reviews, book chapters and articles newly accepted by journals and in the process of publication.

Tables 1 and 2 present general information on the publications found, main journals of the study area and the number of publications. Figure 2 illustrates variation in the body of research conducted in the analyzed time period.

The majority of main journals published in the area focus on the geosciences. The main journal, Neftyanoe Khozyaystvo—Oil Industry, is a Russian journal publishing research in the areas of technology, energy engineering and fuel. In this case, risk factors are discussed in works on contaminated areas and on the emission of effluents. For the other journals, it is possible to observe the multidisciplinary nature of themes discussed and indicated by the proposals of major international conferences such as: "International Multidisciplinary Scientific Geoconference Surveying Geology and Mining Ecology Management Sgem" and "6*th* Saint Petersburg International Conference and Exhibition on Geosciences 2014: Investing in the Future." Both conferences are attended by groups of geoscientists (mostly European engineers) and related publications include diverse research on risks and disasters related to geological science and technology; exploration and mining; computer science; geoinformatics and remote sensing; water, ecosystem, forestry, marine and ocean resources; ecology; economics; education and legislation; energy technologies and climates; and nanobiotechnology and technologies in facilitating a sustainable future.

Although the most frequently cited journal in the area is of Russian origin (Table 2), Italy is the country with the most publications and authors focused on geological risks (Fig. 3). As can be observed from the graph shown in Fig. 2, China comes in second followed by Brazil, the United Kingdom, Canada, Germany and Iran. According to the Institute of Environment and Human Security of the University of the United Nations (UNU-EHS), risks of a catastrophic earthquake or flood occurring are greater in Italy than in all other developed Western countries as documented by the World Risk Report published in mid-2016. It should be noted that differences in environmental conditions between Italy and Brazil give rise to quite different research fronts and applications. However, if in Italy earthquakes are common and the main impetus for conducting research on geotechnical and geotechnical risks and disasters, Brazil's tropical geodiversity makes it possible to further the study of risks related to slopes, floods, earthquakes and desertification (sandstone), among others.

5.2 Critical Analysis

Table 3 presents data used for the analysis: authors, countries of origin, years of publication, numbers of citations and journals or conference documents of research publication. Regarding countries of origin,

Table 1 General information on the studied publications

Number of publications	135
Publication period	2014–2017
Sources (journals, books, annals of congress and others)	95
Average number of citations per article	1.104
Number of authors	495
Articles published by individual authors	16
Articles published by more than one author	479
Articles by author	0.273
Author by articles	3.67

Table 2 Principal journals of the study area and the number of publications

Journal	Number of publications
Neftyanoe Khozyaystvo—oil industry	7
International multidisciplinary scientific geoconference surveying geology and mining ecology management SGEM	4
Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)	4
6th Saint Petersburg international conference and exhibition on geosciences 2014: investing in the future	3
Geomatics natural hazards and risk	3
Oil and gas geology	3
Petroleum exploration and development	3
Rendiconti Online Societa Geologica Italiana	3
Shiyou Kantan Yu Kaifa/petroleum exploration and development	3
Transactions of the institutions of mining and metallurgy section a: mining technology	3

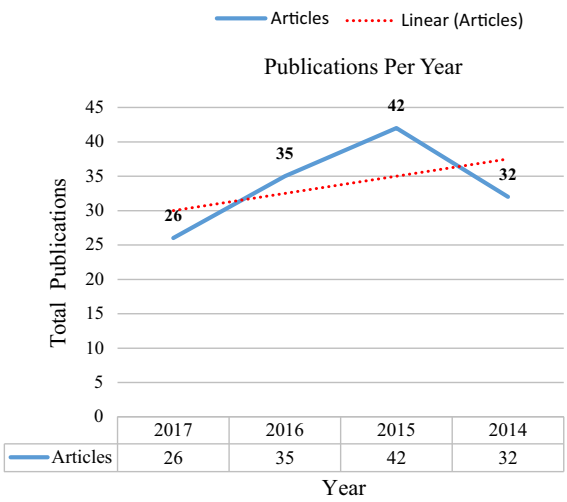


Fig. 2 Number of publications per year (2014–2017)

we used authors' nationalities as our criterion. Journal and conference origins refer to cities or locales of publication.

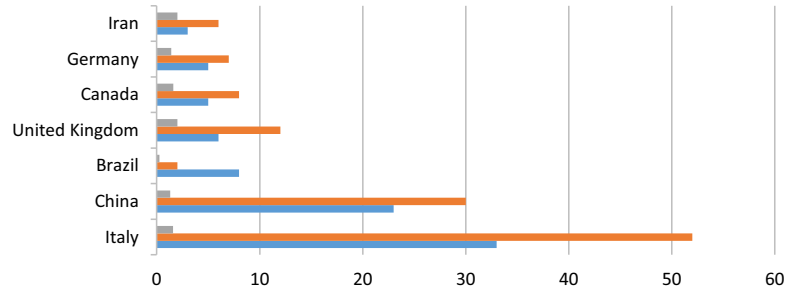
As noted above, the use of sustainability and environmental justice concepts presented in discussions of research results, in the development of methodological procedures and in the review of the literature to contextualize central themes was considered critical in the analysis of the documents. Figures 4 and 5 show keywords appearing in the articles most frequently.

All of these elements were used in an attempt to draw a profile that could define the types of queries consulted. The summary table offers a broad view of the documents, from which it is possible to observe standards of methodologies and approaches of the applications.

Table 4 catalogues the analyzed data, from which it is possible to observe an overview of characteristics of the research consulted such as central research themes, areas of interest (main objects of investigation/application), concepts of sustainability and environmental justice, type of results obtained and characteristics of approaches used.

It is important to point out that in the risk literature there is a debate marked by the distinction between hazards theory and the "theory of disasters." Hazards theory emphasizes a geographic approach through which physical mechanisms, temporal and spatial distribution, and burst dynamics of physical events play a greater role. On the other hand, "disaster theory" is constructed from a sociological approach and emphasizes considerations regarding complex social organization and collective behavior (Valêncio 2014). In this context, the analysis of documents followed the notion that different approaches can deal with concepts of sustainability and social justice in a differentiated way. So, it is important to say that the research presented here does not necessarily discuss that the theory of disasters can be seen only from the sociological point of view, since disasters also include physical and spatial components.

All surveys consulted in this study are the most relevant publications of geology and geotechnical engineering listed according to the methodology presented in previous items. According to Table 4,



	Italy	China	Brazil	United Kingdom	Canada	Germany	Iran
Average Citation per article	1.576	1.304	0.250	2.000	1.600	1.400	2.000
Total Citations Per Contry	52	30	2	12	8	7	6
Total Publications Per Country	33	23	8	6	5	5	3

Average Citation per article Total Citations Per Contry Total Publications Per Country

Fig. 3 Main countries: number of citations, number of publications and average number of citations per author

all of the studies show that end result products can address questions related to the probability, characterization and localization of risks; on quantitative and qualitative numerical modeling, and on databases (queries) and mapping. Furthermore, only one of the studied papers provides state of the art critical and bibliographical analysis on the role of geomatics in the analysis of hydrogeological risks. As a consequence, 100% of the analyzed data reflect approaches that are essentially methodological.

Regarding the analysis of concepts of sustainability and environmental justice, in the development of methodological procedures and from the literature review on the contextualization of central themes, it was found that only roughly 20% of the total papers considered align with objectives of the methods and expected results. Even for those studies dealing with the subject of sustainability in their applications, it should be said that in all analyzed cases, approaches used are brief and superficial to highlight and reinforce the methodological nature of the research. Regarding the analysis of the use of concepts of environmental justice, none of the papers offer any considerations on the theme.

In light of these results, it is clear that the proposed idea reinforces the recent line of thinking that addressed by authors from several scientific fields in the area of risk analysis and classification and especially in the field of geological–geotechnical risk analysis. Discussions offered by the proposed applications do not involve the confrontation of complex socio environmental problems, which are at the core of concepts of sustainability and environmental justice. As concluded by Valêncio (2014), this deterministic character has been established around approaches to risk, rendering it a dominant paradigm contributing to several areas of the "hard sciences." Within it, models on the quantitative measurement of the probability of dangerous event occurrence and of their causes are valued by meeting the interests of the security sector and of other sectors of the economy. Considering this approach, methods and processes that are very effective in preventing and monitoring risks related to geodynamic factors have been developed, though they impede implicit social processes.

6 Final Considerations

The surveys consulted were published in geology and geotechnical engineering sources, and showed final products including risks probability, characterization and location; its quantitative and qualitative numerical distribution.

Roughly 20% of the papers considered sustainability and environmental justice approaches, relating them with objectives, methods and expected results. In those studies themes are used to highlight and reinforce the methodological nature of the research. Discussions do not involve the complexity of socio environmental problems.

Table 3 Data evaluated for analysis

Docment	Theme	Discussion	Sustainable development	Environmental Justice	Result	Approach
1.	Rupture of soil/landslides	Mass movements induced by earthquakes in Italy	NO	NO	Database	Methodological
2.	CO^2 in the UK	Measurement of geological risks for CO^2 storage	NO	NO	Quantitative model	Methodological
3.	Hydrogeological modeling with high resolution satellites	Mapping and management of emergencies	NO	NO	Quantitative model/Mapping	Methodological
4.	Surface modeling	Potential asbestos risk	NO	NO	Quantitative model/Mapping	Methodological
5.	Underground mining production	Geological risk integrated into mine management	NO	NO	Quantitative model	Methodological
6.	Risk analysis and multicriteria analysis	Geological risk classification	NO	NO	Quantitative model	Methodological
7.	Geological risk analysis	Geological risk in the oil and gas sectors	YES	NO	Quantitative model	Methodological
8.	Modeling of soils and contaminants	Contamination of soils and groundwater by methane	NO	NO	Quantitative model	Methodological
9.	Risk assessment modeling	Geological, economic and political risks of gas projects	YES	NO	Quantitative and qualitative model	Economic, social and methodological
10.	Safety analysis of geological hazards	Assessment of exposure of students and schools in relation to risks	YES	NO	Quantitative and qualitative model	Methodological and social-political
11.	Hydrogeological risk assessment	2D and 3D photogrammetry for hydrogeological risk assessment	YES	NO	Quantitative model	Methodological
12.	Geological–geotechnical modeling	Prediction of landslides and collapses of structures	NO	NO	Quantitative model	Methodological
13.	Geomatics and hydrogeological risks	State of the art of the role of geomatics in hydrogeological risk analysis	YES	NO	Critical and bibliographical analysis	Theoretical
14.	Geological risk	Geological risk assessment in an area of significant urban growth	NO	NO	Quantitative model/mapping	Methodological
15.	Geological risk in watersheds	3D Geological Numerical Model	NO	NO	Quantitative model/mapping	Methodological
16.	Mass movements	Mass movements and turbidity currents in the great canyons	NO	NO	Quantitative model/mapping	Methodological

Table 3 continued

Docment	Theme	Discussion	Sustainable development	Environmental Justice	Result	Approach
17.	Structural analysis	Geotechnical risks for the maintenance of historical structures	YES	NO	Quantitative model	Methodological
18.	Structural analysis	Geotechnical risks in the construction of subway lines	NO	NO	Quantitative model/Mapping	Methodological
19.	Geological hazards in urban areas	Landslides in urban area of Rome	NO	NO	Quantitative model/mapping	Methodological
20.	Geotechnical cartography on GIS platform	Geological–geotechnical model by spatial bases	NO	NO	Quantitative model/mapping	Methodological

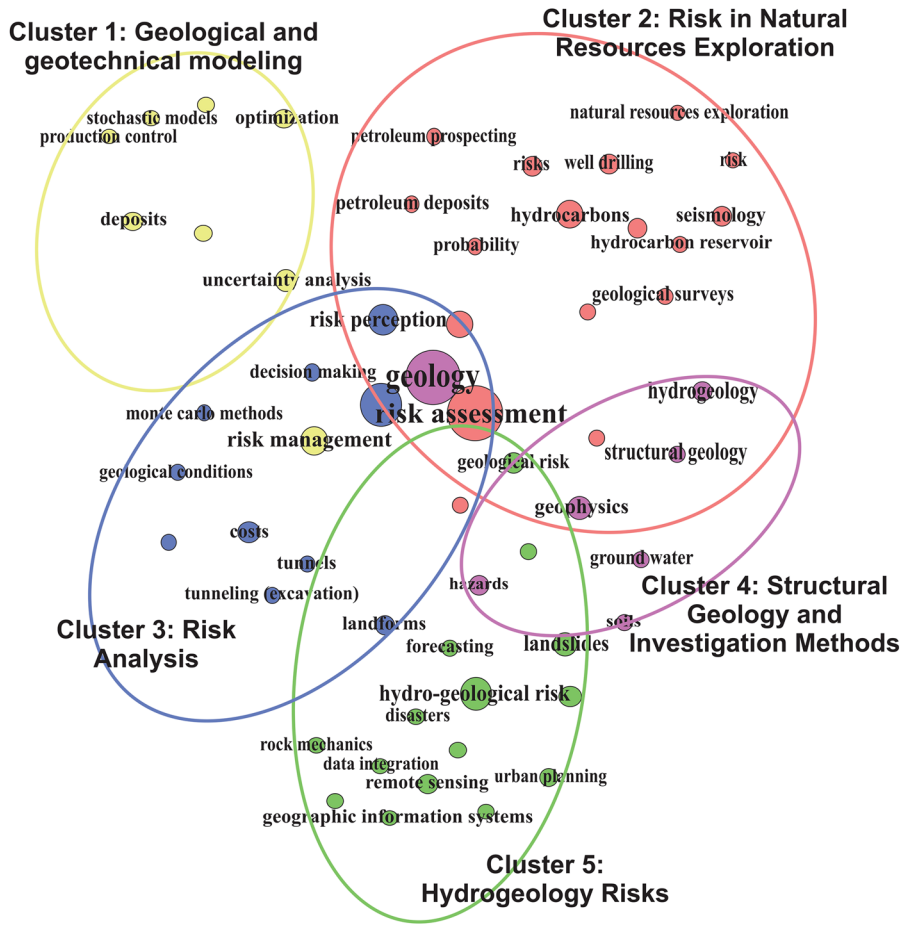


Fig. 4 Clusters of words appearing in the articles most frequently. The largest circles denote words appearing most frequently. Modified from (Vosviewer 2017)

It is known that the fields of geotechnical engineering and geology are basically areas of a "technical" nature and of technical-scientific approaches originating from the exact sciences and from the earth sciences. Thus, it is consistent that research and applications developed from such approaches mainly present mathematical and methodological results. Hence, processes and phenomena can be investigated

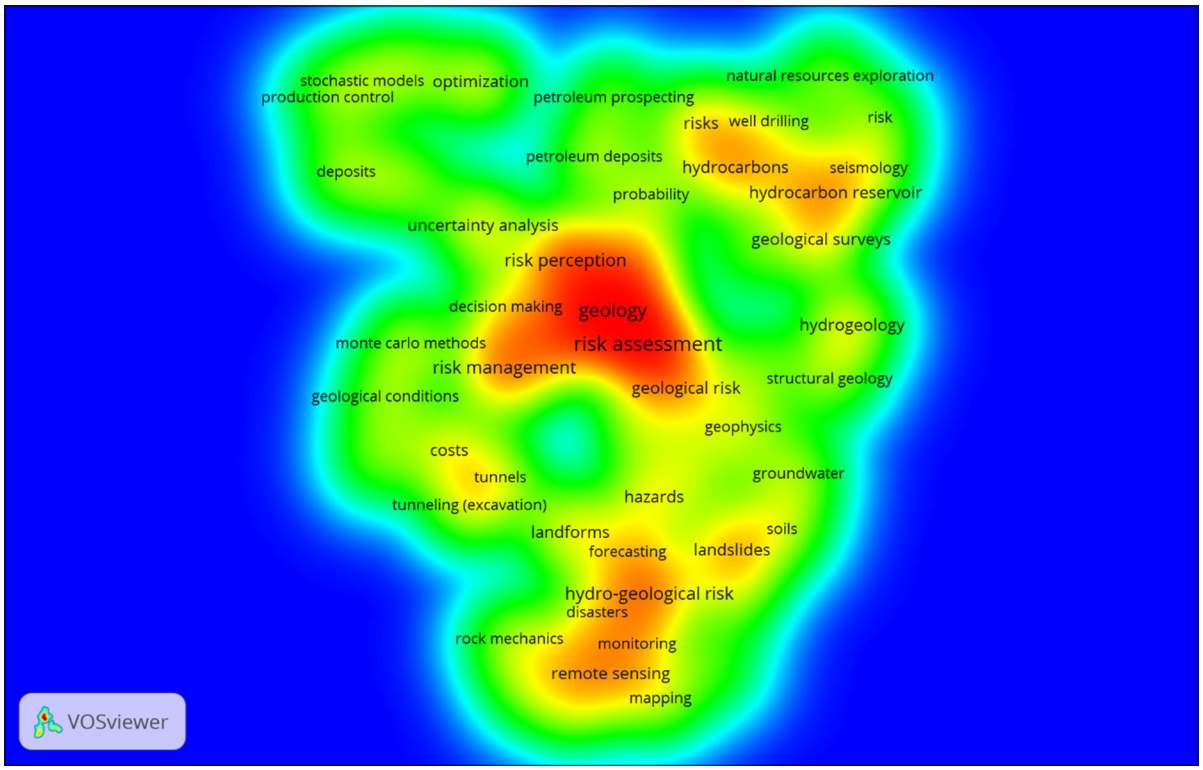


Fig. 5 Density map of words appearing most frequently in articles of this field of study. Red colors denote words appearing most frequently. Modified from (Vosviewer 2017)

Table 4 Data evaluated for analyses

Ranking	References	Country	Citation	Journal or conference
1	Martino et al. (2014)	Italy	16	Natural hazards and earth system sciences
2	Bentham et al. (2014)	United Kingdom	12	Energy procedia
3	Nascetti et al. (2015)	Italy	8	Geomatics, natural hazards and risk
4	Pacella et al. (2015)	Italy	6	Chemical geology
5	Carpentier et al. (2016)	Canada	6	Transactions of the institutions of mining and metallurgy
6	Nezarat et al. (2015)	Iran	6	Tunnelling and underground space technology
7	Milkov (2015)	EUA	5	Earth-science reviews
8	Schwartz (2015)	Germany	5	Environmental earth sciences
9	Li et al. (2016)	China	4	Sustainability (Switzerland)
10	Pazzi et al. (2016)	Italy	4	International journal of disaster risk reduction
11	Scaioni et al. (2015)	China/Italy	4	Geomatics, natural hazards and risk
12	Carlà et al. (2016)	Italy	3	Landslides
13	Pirotti et al. (2015)	Italy	3	Geomatics, natural hazards and risk
14	Yang et al. (2015)	China	3	Physics and chemistry of the earth
15	Šram et al. (2015)	Slovenia	3	Geologija
16	Li et al. (2015)	China	2	Acta oceanologica sinica
17	Robles-Marín et al. (2015)	Spain	2	Natural hazards
18	Zheng and Ma (2014)	China	2	Applied mechanics and materials
19	Alessi et al. (2014)	Italy	2	Italian journal of engineering geology and environment
20	Zharkova et al. (2016)	Russia	1	IOP conference series: earth and environmental science

using a systematic approach based on the reading of physical and natural properties of the environment.

Without intending to judge applications of the area for the analysis and classification of geological–geotechnical risks, it is understood that a discussion of such methods is necessary. There is a global tendency to invoke questions related to possibilities of the development of a science that aligns its development with proposals that address the achievement of sustainable social, economic and environmental conditions.

The present work was designed to contribute to such a discussion by presenting an overview of how the most important publications in the area deal with issues of sustainability and environmental justice in their applications. As a proposal for future research, it is recommended that the search for materials development be kept alive by expanding the key field of research and by encouraging the interaction of key concepts of interest.

The bibliometric research presented here, despite its power in gauging scientific writing, exposes some limitations related to peculiarities and limitations of the algorithms and databases used (e.g., Scopus). Rather, scientometric and bibliometric tools specifically identify (i) tendencies and knowledge emerging from a specific area; (2) journals of certain areas of knowledge; (3) people, groups, and institutions operating in certain area; and (4) the mean life of scientific literature (Vanti, 2002).

With these techniques we could establish a proper relationship between this contribution and the recent context of research conducted in these areas. However, limitations of data access resulting from journals and congress proceedings not being fully open access remain as barriers to deeper analysis.

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