DOI: https://doi.org/10.68732/7df25472282f7e21

ISBN: 978-9989-2053-6-1

Status of Rock Slope Characterization Using Remote Sensing Techniques: A Bibliometric Analysis

Raymundo Ruiz Flores[1*],Nelly Lucero Ramírez Serrato[2], Adrián J. Riquelme Guill[3], Fabiola Doracely Yépez Rincón[4], Rodrigo Gutiérrez Navarro[5] & Javier Mancera Alejandrez[5]

[1]*Posgrado en Ciencias de la Tierra, Universidad Nacional Autónoma de México, Mexico City, Mexico.*
[2]*Departamento de Recursos Naturales, Instituto de Geofísica, Universidad Nacional Autónoma de Mexico, Mexico City, México.*
[3]*Departamento de Ingeniera Civil, Universidad de Alicante, Alicante, Spain.*
[4]*Departamento de Geomática, Instituto de Ingeniería Civil, Universidad Autónoma de Nuevo León, Nuevo León, Mexico.*
[5]*División de Ingeniería en Ciencias de la Tierra, Facultad de Ingeniería, Universidad Nacional Autónoma de México, Mexico City, Mexico*
**rayruizflores2@gmail.com*

0009-0000-1843-6177

Abstract

Rock slope characterization is essential for understanding its mechanical stability and its implications for geotechnical engineering projects. Geological conditions play a key role in controlling slope behaviour and are often the primary cause of geotechnical issues. However, traditional field-based characterization methods are frequently limited by site accessibility, safety concerns, and time constraints.

In recent years, remote sensing techniques such as LiDAR and photogrammetry have emerged as powerful tools for acquiring high-resolution three-dimensional data, enabling more efficient and detailed analyses, and avoiding the limitations of traditional fieldwork. This study presents a bibliometric analysis of 1,205 publications from Web of Science database between 2010 and 2025, focusing on the application of remote sensing techniques in rock slope characterization.

Using Bibliometrix and VOSviewer, connections in authors and country co-authorship, keywords, and most cited sources were identified. Results show a significant annual growth rate of 18.31%, with a marked increase in publications after 2021. In terms of scientific production, China leads global research output, followed by European countries, however international and research group collaboration remains limited. Keyword and citation network analyses reveal a strong focus on structural characterization of rock discontinuities, as well as the integration of advanced algorithms and machine learning techniques. The findings highlight the convergence between classical rock mechanics and modern remote sensing technologies, establishing these methods as fundamental tools in contemporary geotechnical research, but also the need to strengthen collaboration between countries and research groups. This study provides a comprehensive overview of the field and future research development.

Keywords

Bibliometric analysis, Rock slopes, Remote sensing, VOSviewer, Web of Science.

1 Introduction

The study of rock slopes is of great importance to understand its mechanical stability to avoid problems during the development of geotechnical engineering works such as rockslides. It is also necessary to know that geology factors are the main causes of geotechnical issues (González de Vallejo et al. 2002).

Therefore, rock slopes undoubtedly require a thorough description of their characteristics during fieldwork; fieldwork groups activities such as identifying the geological structures, lithologies, groundwater conditions and their spatial distribution in the area. (González de Vallejo et al. 2002). Undoubtedly, fieldwork often faces certain limitations, such as long periods of time required, safety concerns for field personnel, and difficulty accessing the study areas (Riquelme et al. 2016; Mancera et al. 2021).

Likewise, in recent years, technological advances have generated numerous improvements in data acquisition and interpretation across a wide range of fields of study. One such advance is undoubtedly the use of remote data acquisition techniques, such as photogrammetry and LIDAR, that allow the acquisition of high-resolution three-dimensional representations of the terrain with high accuracy and high spatial resolution (Riquelme et al.2015).

Many researchers who employ the characterization of rock slopes for geotechnical engineering in their research fields have turned their attention to these techniques since having three-dimensional models of their study areas at their disposal would allow access to a wealth of data and to avoid the limitations that traditional fieldwork.

To understand the current state of publications related to the use of remote data acquisition techniques in studies that aim to characterize rock slopes, it is necessary to conduct a bibliometric study that allows us to track the evolution in the number of related publications over a set period, as well as to identify the main authors, countries, and cited references.

2 Methodology

2.1 Data Collection

The Web of Science (WoS) database was selected as the platform to acquire the data necessary for bibliometric analysis. On February 27, 2026, a search was conducted to obtain information on all papers relating to the application of any remote data acquisition tool in the characterization of rock slopes between 2010 and 2025. This was done using the following query: TS = ((UAV OR UAS OR RPAS OR drone* OR "unmanned aerial vehicle*" OR "unmanned aerial system*" OR "small unmanned aircraft system*" OR LiDAR OR "airborne laser scanning" OR ALS OR "laser scanning" OR "laser scanner*" OR "terrestrial laser scanner*" OR TLS OR "terrestrial laser scanning" OR "ground-based LiDAR" OR "terrestrial LiDAR" OR "digital camera*" OR "digital photograph*") AND ("rock slope*" OR "rock surface*" OR "rock face*" OR "rock wall*" OR "rock cliff*" OR "rock mass*" OR "rock outcrop*" OR "cut slope*" OR highwall OR "open pit slope*" OR "bench slope*" OR "rock joint*" OR "rock discontinuities" OR "fracture characterization" OR "joint mapping" OR "structural mapping")) AND PY = (2010-2025).

2.2 Statistical Analysis and Visualization

A proper metric and statistical analysis allow for the identification of common connections between authors (formed research groups), as well as research trends within the analysed papers. Some software specializing in bibliometric analysis allow for a concise overview of the vast amount of information obtained from scientific databases, displaying intuitive diagrams that reveal the relationships and evolution of a specific topic over the years (Xue et al., 2024). Obtaining this type of data enables detailed observations of the current state of the art in a research field.

For this purpose, the software tools Bibliometrix and VOSviewer were used to obtain data such as the number of works published during the study period, the top ten authors and journals, and to construct bibliometric networks to observe the relationships between authors, countries, keywords, and the most cited works within the publications retrieved from WoS database.

It is important to mention that a previous review of database was conducted to merge synonymous terms for keywords, and to homogenize authors' names since sometimes an author can appear under different abbreviations of its name.

3 Results and Discussion

3.1 Main information analysis

A total of 1205 papers were obtained from the search within Web of Science; their information was initially analysed with the help of Bibliometrix to extract general information from the data, as shown in Table 1. All these articles were published in 338 different journals, and only 23 of them were published by a single author, which means that almost all of them are the result of co-authorship with an average of five authors per document. However, according to the International Co-Authorship Index, only 26.14 % of the articles present international co-authorship; this reflects that although almost every article has co-authorship, most of them reflect collaboration between researchers exclusively from the same country

Table 1. Summary of the main bibliometric indicators of the analysed publications from 2010 to 2025.

Description	Results
Period	2010-2025
Journals	338
Documents	1205
Annual Growth Rate %	18.31
Average Citations per Doc	20.66
References	34850
Authors Key Words (ID)	3301
Keywords Plus (DE)	1775
Authors	3898
Single-Authored Docs	23
Co-authors per Doc	4.99
InternationalCo-Authorships %	26.14%

In the last 15 years, the number of publications has increased considerably, with an annual growth rate of 18.31%. Since 2021 the number of articles published exceeded 100, and according to the data, it is possible to infer that in 2026 it surpassed 200 per year. The highest publication volumes were registered in 2022, 2024 and 2025 accounting nearly 39% of all publications. The distribution of the annual publication output of 1205 articles along with cumulative yearly publication output can be seen in Fig. 1.

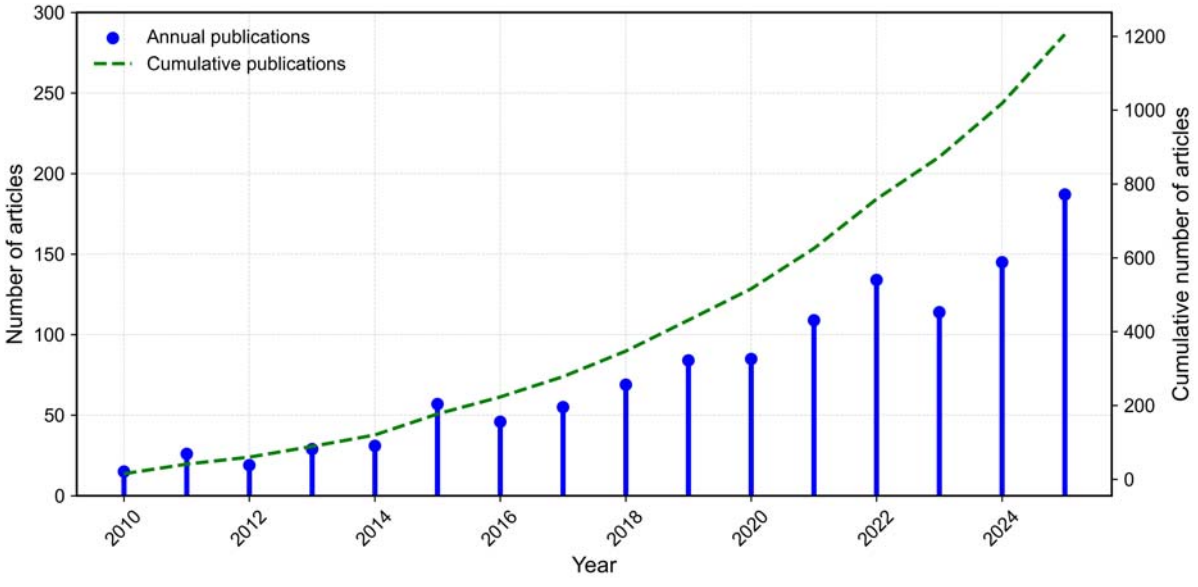


Fig. 1 Evolution of scientific production based on annual publications and cumulative output (2010–2025).

3.2 Bibliometric networks analysis

Four bibliometric networks were obtained from the analysis of the data, focusing on observing the relationship between keywords, principal authors and countries in the field and the most cited references in the papers. These networks can be seen in Fig. 2.

Focusing on the keywords, four principal clusters were obtained from the network (Fig. 2a), keywords that appear in it have at least 15 occurrences. Cluster 1 (red) shows mainly a relationship between geomorphologies and physical processes that can be related to the occurrence of material remotion processes such as landslides. Cluster 2 (green) and 4 (yellow) have some similarities, as they are mainly represented by two famous remote sensing techniques: LiDAR and photogrammetry; cluster 2centres more in the relationship between digital techniques and combination of algorithms and machine learning in identification and structural characterization of rock slopes, cluster 4 centres in the use of low-cost techniques: UAV´s and SfM, to obtain products to evaluate rock slopes and observe its accuracy; Although these clusters shows its differences, they seem to tend to combinate as there is no clear separation between them. Finally, Cluster 3 (blue) clearly shows the characteristics of joints, their behaviour and models, showing that the characterization of these elements in the papers is one of the most important things that are evaluated with remote sensing techniques in rock slopes.

The authors network (Fig. 2b), where all the authors have at least 5 published papers. This network shows principal authors such as Michel Jaboyedoff, Antonio Abellan, Zhang Wen, Doug Sted, etc.It also shows a notable pattern previously identified during the main information analysis. Although there are prominent authors who continually participate in the publication of articles related to the field, it seems that there is no great collaboration between research groups, even the main cluster (red) shows few connections with other clusters. Clusters that surround the principal cluster do not only show that research groups work exclusively between their members but also show that most of its members belong to the same country. This is an important indicator that although there has been good increase in publications, collaboration is still one of the weakest points in this research field.

Additionally, it is important to establish that not all authors appearing in this network are considered primary authors, as the software considers authorship regardless of whether they are primary or secondary authors. Therefore, it is necessary to use the information presented carefully to develop own criteria for which authors to consult when searching for information on these topics.

Fig. 2c shows the country network, where every country has at least 5 published articles. One of the first things that can be seen is that China is the most prominent country in this field of research, with 441 published articles, almost 37% of all the publications analysed in this paper. Even though there are other countries that also have a considerable number of publications, such as Italy, USA, Canada, Switzerland, none of them reach 100 publications and the rest of countries that appear in the network have an average of less than 20 publications.

Following China, it shows some connections mainly with the countries that follow it in publicised articles and most of the seen connections have low link strengths. Moving to other countries, European countries show connections with almost every country in the network; and although the connections seem to have link strengths as in China’s case, it is important to note that European countries seem to tend to collaborate extensively with each other. If we group all the scientific production of the European countries in this field, 595 publications are found. It shows that Europe has reached an important level of research in the field of remote sensing techniques in the characterization of rock slopes.

To know the most important cited references used in the 1205 articles analysed, in Fig. 2d it can be seen the network for this purpose, every cited reference has at least 50 citations. Tree main clusters appear in it. Cluster 3, though it is the smallest, collects important works that are the knowledge basis for the characterization of rock joints, having for example the SM from the ISRM (1978) and Barton and Choubey (1977). Cluster 1 shows important articles that study the use techniques such as photogrammetry, LiDAR, to generate three-dimensional models that could be used to identify and characterise discontinuities (e.g. orientation and spacing) from rock slopes using semi-automated and automated methods. Cluster 2 groups studies related to the analysis and monitoring of instabilities in rock slopes. It includes foundational works on rock slopes classification and landslide types, as well as studies that employ three-dimensional data acquisition technologies such as LIDAR and photogrammetry to detect deformations and monitor failure processes in rock slopes.

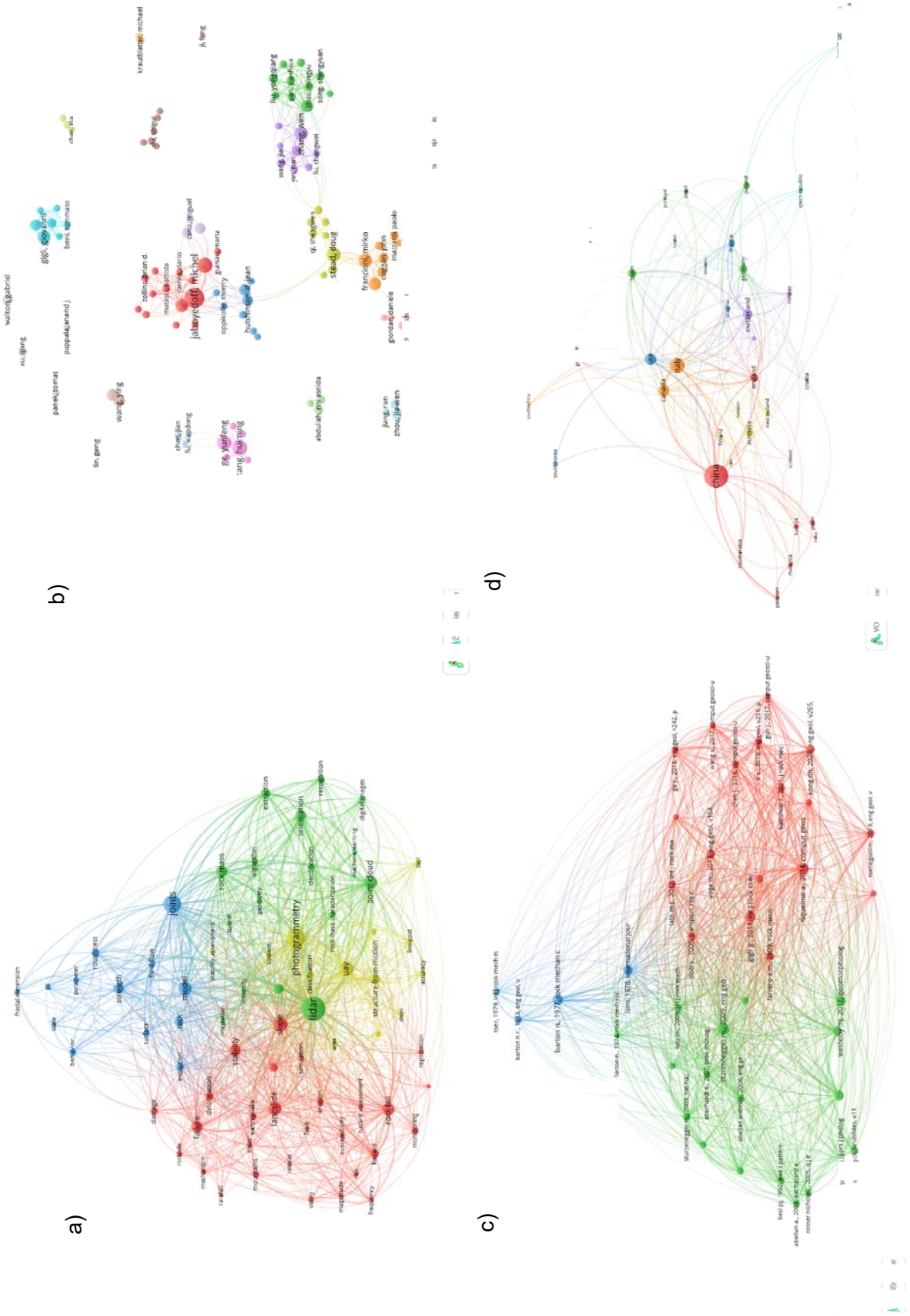


Fig. 2 Bibliometric networks. From left to right and top to botttom: a) keyword co-ocurrence network, b) author co-authorship network, c) country co-authorship network and d) cited references co-citation network.

4 Conclusions

The R-Bibliometrix and VOSviewer softwares were employed to analyze, review and create network maps of the 1205 articles of the application of remote sensing techniques in the characterization of rock slopes from 2010 to 2025 based on the data acquired from WoS database

This analysis shows a sustained and significant growth in paper production during the analyzed period, The use of technologies such as UAV's and techniques as LIDAR and Photogrammetry are some of the essential tools that much of the papers use for its methodologies, not only because of the three-dimensional products that can be obtained but also because it help to overcome the limitations of traditional fieldwork. Bibliometric networks also show the convergence between advanced algorithms in the structural characterization of rock slopes and especially of the joints, because this topic is one of the primary focuses of many papers.

With respect to international production, China emerges as the country that produced most of the papers in the analyzed database, producing almost 37% of them, competing only with European-continent production that reaches almost 39% of the paper production. However, despite this production, both research groups and international collaboration are limited, indicating little collaboration in research works but also showing an important opportunity to strengthen cooperation and foster more integrated research efforts.

Finally, the analysis of the most cited references demonstrates the coexistence of two fundamental pillars in this field: on one hand, the classical knowledge basis of rock mechanics and structural characterization, and on the other, the integration of modern data acquisition and processing technologies. This combination has enabled significant advances in accuracy, efficiency, and scope, establishing remote sensing techniques as indispensable tools in contemporary research. These bibliometric analyses can also offer ideas for future researchers about the state of the art of this field, however more discussion of this analysis is needed, due to the interpretation of the results can be subjective because different researchers may have different perspectives of the same content.

Due to the short extension of this paper, other bibliometric networks and information have been added to an additional document, Appendix 1, to give a broader and more detailed explanation of the database obtained from Web of Science; it is recommended to read this document to have a better idea of the current status of the topics that have been discussed in this paper. This document can be consulted in the next link: https://drive.google.com/drive/folders/1459RonM_gDTvnkZU2OP-4fhKE5oCIzRP?usp=sharing.

References

Barton, N., Choubey, V. The shear strength of rock joints in theory and practice. Rock Mechanics 10, 1–54 (1977). https://doi.org/10.1007/BF01261801

González de Vallejo, L. I., Ferrer, M., Ortuño, L., & Oteo, C. (2002). Ingeniería Geológica. PEARSON EDUCACIÓN.

International Society for Rock Mechanics. (1978). Suggested methods for the quantitative description of discontinuities in rock masses. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 15(6), 319–368. https://doi.org/10.1016/0148-9062(78)91472-9

Mancera-Alejandrez, J., Macias-Medrano, S., Villarreal-Rubio, E., & Solano-Rojas, D. (2021). Spherical data validation of rock discontinuities orientation from Drone-derived 3D Point Clouds. Revista Mexicana de Ciencias Geologicas, 38 (3), p. 152-163.http://dx.doi.org/10.22201/cgeo.20072902e.2021.3.1641

Riquelme, A. J., Abellán, A., & Tomás, R. (2015). Discontinuity spacing analysis in rock masses using 3D point clouds. Engineering Geology, 195, 185–195. https://doi.org/10.1016/j.enggeo.2015.06.009

Riquelme, A. J., Tomás, R., &Abellán, A. (2016). Characterization of rock slopes through slope mass rating using 3D point clouds. International Journal of Rock Mechanics and Mining Sciences, 84, 165–176. https://doi.org/10.1016/j.ijrmms.2015.12.008

Xue, Y., Niu, Z., Zhang, R., Jia, L., & Guo, S. (2024). Current status and future research of groundwater under climate change: A bibliometric analysis. Water, 16(23), 3438. https://doi.org/10.3390/w16233438