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# A BIBLIOMETRIC ANALYSIS OF THE EVOLUTION OF KNOWLEDGE ABOUT ANDEAN PÁRAMO

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**Abstract:** The páramo is a high-altitude ecosystem characterized by its herbaceous vegetation and distribution in tropical and subtropical regions. This ecosystem is highly sensitive to environmental disturbances, making it a priority area for conservation and research due to its biodiversity and strategic ecosystem functions. Consequently, it is essential to conduct ecological and conservation studies of páramo areas within interdisciplinary frameworks that address the various environmental, geopolitical, economic, and sociocultural challenges. The objectives of this study were: (1) to identify the richness of páramos and the evolution of knowledge in research during the period from 2014 to 2023; and (2) to determine the scientific output, keyword co-occurrence in articles, and the most influential researchers in the field during the period from 2014 to 2023. The methodology employed was descriptive bibliometric analysis, involving a comprehensive search for scientific articles in the Scopus database. For parameter visualization, VOSviewer and the Bibliometrix package in R Studio were used to apply Lotka's Law. The results show that Colombia is the leading country in scientific production in this field, playing a central role in advancing knowledge about the páramo. Furthermore, the findings indicate that the impact of climate change and intensive human activities (such as agriculture, grazing, pine plantations, and tourism) have increased the risk of páramo degradation, altering hydrological cycles and reducing its regulatory capacity. This bibliometric study provides a robust foundation for the planning of public policies aimed at conservation, sustainable water resource management, and biodiversity protection in páramo ecosystems. Therefore, it is crucial to promote research that considers the páramo as a socio-ecological system, analyzing the interactions between human actors and the natural environment, which will enable the design of more equitable and effective management policies.

**Keywords:** Páramo, Scopus, bibliometric review, ecosystem, tourism

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## INTRODUCTION

Peru is a country with remarkable biological diversity, characterized by its wide variety of flora and fauna species. It hosts a range of ecosystems that function as the "lungs of the planet," one of which is the páramo, located in the northern of the country (Dunin, 2023). This system collects, retains, regulates and distributes water (Ventura et al., 2012). The páramo plays a key role in providing essential ecosystem services to the Andean region and is globally recognized for its biological diversity and high degree of endemism (Alvarez-Hincapié et al., 2017). This ecosystem harbors approximately 25% of the planet's biodiversity (Gutiérrez et al., 2020), reinforcing its classification as a strategic ecosystem due to its role in species conservation and regulation of fundamental ecological processes (Vanegas et al., 2018). In this context, Parra (2023) argues that the páramo plays a crucial role in climate change mitigation, as a result of its unique characteristics that enable it to function as hydrological regulator (Anzoategui et al., 2023; García et al., 2016; Torres et al., 2023).

In South America, the páramo covers an area of approximately 30,000 km2 (Carrillo et al., 2015). Notably, Colombia contains the largest portion of this ecosystem, where local communities remain closely tied to the geographical space of 266,750 hectares (Borrelli et al., 2015). Venezuela holds about 266,000 hectares (Hofstede et al., 2014), while Ecuador encompasses around 1,250,000 hectares (Benítez et al., 2019). Peru represents the southernmost part of this vast ecosystem, with an estimated 60,000 hectares (Rubio, 2012). In Central America, the paramo is found in Costa Rica (15,000 ha) and Panama (2,000 ha), totaling 17,000 hectares (Hofstede et al., 2014). The páramo occurs at elevations ranging from 3,400 to over 4,500 meters above sea level, which shapes its extreme climatic conditions (Hofstede et al., 2014). These features

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make it an ecosystem with biodiversity highly adapted to low temperatures and reduce atmospheric pressure (Şahin & Barinova, 2025). The biodiversity of the páramo is both endemic and fragile, with emblematic species such as frailejon, the spectacled bear and various high-Andean bird species (Olaya et al., 2019). Biodiversity refers to all forms of life on Earth and encompasses different levels of biological organization (Martínez et al., 2014). It also includes the variety of ecosystems and the genetic diversity within species inhabiting these environments (Caurín & Martínez, 2013; Astudillo et al., 2023). Studying ecosystems is essential for understanding ecological processes, the resilience of natural systems, and the interdependence between organisms and their environment. Despite numerous ecological and conservation studies on páramo regions, it is necessary to adopt interdisciplinary frameworks to address the diverse environmental, geopolitical, economic, and sociocultural challenges – such as those face by rural communities – in today's context (Matlovič & Matlovičová, 2025). This approach is essential to gain comprehensive understanding of the páramo as socio-ecological system.

The diversity and assembly structure of plant communities in the páramo are influenced by a complex interaction of abiotic and biotic factors (Acuña et al., 2022). Peña et al. (2016) emphasize that the páramo provides essential services to local communities, particularly in terms of water resources critical for human consumption, livestock and agriculture. In addition, the páramo holds significant cultural value, as it is inhabited and controlled by local communities that have developed ancestral knowledge and practices for its conservation (Tena et al., 2012). The páramo is a space where various social and economic activities take place, such as extensive livestock farming, agriculture, collection of natural resource gathering, ecotourism development (Serrano & Galárraga, 2015). These practices have shaped the socio-economic dynamics of páramo communities; however, they have also posed significant challenges for sustainability and conservation of this strategic ecosystem. In Colombia, the páramo ecosystem is undergoing substantial change due to the establishment of agroecosystems (Eraso & Amarillo, 2016), which, together with rural communities, are facing sustainability challenges (Blake et al., 2023). Furthermore, land-use conflicts have become increasingly evident, particularly in areas inhabited by communities engaged in potato cultivation and livestock farming (Alzate et al., 2018). Similarly, in Peru, páramo vegetation is under growing pressure from overgrazing, which indirectly affects bird communities by reducing the likelihood of habitat occupancy by various species (Dunin, 2023). This anthropogenic activity constitutes a large-scale socio-environmental problem that threatens the stability of this highly vulnerable ecosystem (Avellaneda et al., 2014). Moreover, the alteration of vegetation structure resulting from these practices changes the reproductive conditions for bird species by creating a heterogeneous mosaic in vegetation cover, thereby affecting the availability of shelter and critical resources for their survival (Douglas et al., 2017).

Globalization, climate change, and agricultural industrialization—as part of a broader polycrisis—are increasingly impacting the future of peasant communities. Processes such as depeasantization and rural aging are realities reflected in most countries (Karlin, 2025). In this context, humanity currently faces challenges and pitfalls that arise from the complex interactions between communities and their environment (Matlovič & Matlovičová, 2024). The environmental impact on the páramo is evident in the disruption of ecological balance within the ecosystem, as well as in social and economic terms, due to the establishment of settlements in páramo zones. These communities have adapted to harsh climatic conditions—such as low temperatures, high humidity, limited oxygen availability, constant fog, and even low solar radiation. However, rural depopulation and migration to urban areas have increasingly left these natural areas unprotected. As a result, they are often exploited by outsiders seeking to profit through various extractive activities (Lis-Gutiérrez et al., 2023).

The páramo is therefore increasingly affected by global climate change and human activities such as cultivation, intensified grazing, pine plantations, and tourism. These impacts have escalated, significantly altering the hydrological system of the ecosystem. In this context, seasonal climate changes strongly influence carbon fixation, resource allocation, and plant growth. This convergence of effects signals a bleak outlook for the páramos unless robust conservation measures are implemented (Sánchez et al., 2025). The growing concern over the impacts of global change on páramo biodiversity and ecosystem services calls for intensified research efforts and the adoption of holistic perspectives and adaptive strategies for ecological conservation (Díaz et al., 2024). Given that these ecosystems play a crucial role in regulating both the water cycle and biodiversity, it is essential to manage, preserve, and restore their ecological functions. This includes targeted actions such as promoting sustainable agricultural practices to enhance the páramo's capacity for carbon storage and support global mitigation efforts (Vistin-Guamantaqui et al., 2024).

It is important to note that disturbances in the páramo date back to the period of armed conflict, particularly in Colombia, where military infrastructure development and limited environmental regulation played a significant role (Méndez-Garzón et al., 2024). Likewise, land-use changes have led to a fragmented and discontinuous landscape, negatively impacting biodiversity structure and function, nutrient cycles, and overall ecosystem dynamics (Yela-Lara & Baca-Gamboa, 2023). Camacho (2014) explains that, in an effort to improve soil fertility in the high-altitude páramos, livestock herders have implemented a burning system in grasslands to "fertilize" the soil using potassium from ash and to promote the regrowth of tender grass with higher quality and palatability. Meanwhile, Muñoz-Saba et al. (2024) argue that there is a widespread lack of recognition of the páramo as a strategic ecosystem that provides essential resources for the well-being of both urban and rural communities, largely due to ongoing conflicts between humans and natural environments. Consequently, the limited environmental awareness among local inhabitants regarding the use of natural resources can lead to overconsumption and exploitation, ultimately compromising the ecosystems' ability to meet human needs (Clavijo, 2024).

Outdated regulatory frameworks regarding the páramo have led to interpretive gaps in legislation, weakening its legal protection. Moreover, the lack of clarity in defining permitted and prohibited activities fails to reflect the ecological evolution of the ecosystem and the emerging challenges that no longer align with changing social needs (Salas & Estupiñan, 2024). In this context, the formulation of public policies and laws related to the páramo has been approached

from an integrative and holistic perspective, recognizing these territories as historically inhabited, lived-in, and represented by diverse human communities (Acevedo-Zapata, 2025). Thus, monitoring efforts in these areas go beyond addressing questions related to water resource management; they also promote a culture of research, critical inquiry, and reflection (Floréz et al., 2025). In this regard, environmental assessments facilitate the characterization of social actors, environmental management strategies, and territorial organization. These assessments are essential for informed decision-making and provide a comprehensive understanding of the region's ecological, social, and economic dynamics. They also help foster the participation of local stakeholders, making it important to evaluate both the frequency of ecosystem service use and the volume of resources extracted (Vergara & De Pellegrin, 2025).

Tourism in the páramo has gained increasing interest in recent years due to the diversity of flora, fauna, and Indigenous cultures that contribute to the planet's ecological heritage (Villarreal et al., 2023). In this context, ecotourism has emerged as an alternative to diversify tourism activities in rural areas rich in natural resources (Polanco, 2017; Real & Geovannini, 2024). The integration of the páramo into selected tourist routes represents a strategy to promote sustainable tourism development and improve the quality of life of páramo communities (Duarte et al., 2021). In Colombia, tourism development plans have been designed based on analyses of community potential and limitations (Toro et al., 2015). One notable example is Los Nevados National Natural Park, one of the country's main ecotourism destinations, which includes zones from all three páramo levels: subpáramo, páramo, and superpáramo (Pérez, 2019). Visitor profiles are often defined by the activities they engage in, such as mountaineering, hiking, and wildlife observation. It is important to note that this ecosystem cannot be visited year-round due to constantly changing climatic conditions (Ciri, 2003).

Tourism represents an opportunity to develop regions with high potential, as it promotes the sustainable use of natural resources (Silva et al., 2021; Oviedo et al., 2021; Luján-Vera et al., 2023). Moreover, it is characterized as an inclusive and decentralized activity (García et al., 2023; Martínez et al., 2022; Luján-Vera, 2023). In Ecuador, visitors can explore diverse landscapes through various tourist routes that combine páramos, lagoons, and trails, as well as a rich diversity of flora and fauna. These areas are ideal for the development of scientific tourism, adventure tourism, recreational tourism, and gastronomic tourism (Villacís et al., 2016).The Peruvian páramo is a small but ecologically significant ecosystem. Inhabitants of the villages of San Juan and Totora, located in the San Juan de Cachiaco area, along with the sectors of El Toldo and Espíndola within the rural community of Samanga (Piura), have undertaken efforts to develop a Participatory Management Plan for the páramo in their territories. Based on the ecological richness of the Ayabaca páramo, local residents have improved accessibility by installing signage to guide visitors toward the lagoons formed by rainfall. Tourism activities—such as community-based tourism and ecotourism—are managed by community members, allowing visitors to engage in knowledge exchange and explore the natural wealth of the páramo (Torres, 2012).

In Colombia's Sumapaz region, however, peasant communities are under threat of displacement, which restricts their traditional activities, including agriculture (Castillo, 2023). In Peru, there are currently no laws that regulate the protection of the páramo, yet local communities are aware of the need to safeguard the ecosystem and avoid full-scale encroachment into these areas. In contrast, páramo inhabitants in Colombia have defined and implemented a range of activities to protect and restore degraded páramo areas. These efforts combine local knowledge with recommendations from foreign experts, resulting in the development of social technology, which includes practices such as relocating livestock to lower elevations outside protected zones that are still considered part of the páramo ecosystem (Torres et al., 2023).

In Peru, the páramo is located in the northwestern regions of Ayabaca and Huancabamba. These areas are composed of chains of lagoons and grasslands, and are characterized by a climatic regime influenced by constant drizzle and persistent cloud cover (López, 2010). The páramo is a high-altitude mountain ecosystem with unique ecological features, known for its high fragility and significant environmental and sociocultural value (Torres, 2012). In the highlands of Piura, the ecological characteristics differ from those of the Ecuadorian and Colombian páramos, indicating a transition toward lower vegetation formations adapted to specific climatic conditions. Its physiognomy resembles that of the Jalca, a high-mountain ecosystem predominant in the central and southern parts of Cajamarca, characterized by grasslands, scattered shrubs, and a lower presence of frailejones compared to the more northern páramos (Hofstede et al., 2014). These properties are shaped by variations in altitude, water regimes, and the influence of local climatic factors, which determine differences in floristic composition and ecological dynamics within these Andean ecosystems. The use and management of the páramo may include complementary activities adapted to its environmental conditions, such as tourism—particularly agrotourism and ecotourism (Verano & Villamizar, 2017). Academic research on páramo ecosystems provides a valuable framework for analyzing the prevailing theories and methodologies in environmental science, offering a comprehensive foundation to understand international approaches. This analysis is essential for contextualizing current studies within a solid theoretical-methodological base, and for guiding future research focused on conservation and sustainable resource management in these ecosystems. From an ecological perspective, the páramo is defined as a tropical alpine vegetation zone without forest cover, composed of insular shrublands and grasslands located above the forest line (Farfán et al., 2020). In this sense, Díaz et al. (2019) associate high-mountain páramos with biomes located at high altitudes, subject to extreme environmental conditions. As such, the páramo is considered an ideal model for studying the effects of spatial heterogeneity at different scales, allowing researchers to analyze the dynamics and structure of natural vegetation mosaics (Duarte et al., 2021).

## MATERIALS AND METHODS

This study employed a descriptive-retrospective bibliometric analysis methodology, which enabled the identification of changes and trends in research on páramos over time (Rios et al., 2024). Bibliometric research is a discipline that quantifies

scientific output and evaluates author performance by analyzing a sample of selected articles from one or more databases (Bervanger & Sâmara, 2016). This approach is based on the systematic collection of available scientific literature, ensuring a structured and rigorous analysis of academic production related to the páramo ecosystem (Rita & Fermín, 2024). The search focused on identifying existing publications on the topic using the Scopus database, a key tool for bibliometric analysis, which enables the identification of trends, publication impact, and the mapping of scientific output across various disciplines (Velasco et al., 2023).

**Search Strategy**

For this bibliometric analysis, an electronic search was conducted using the Scopus database due to its extensive coverage of scientific journals. The search string included a set of keywords related to the topic of study, specifically: (paramos OR “paramo” OR “ecotourism” OR “sustainable tourism” OR “conservation” OR “biodiversity”). The authors carefully reviewed the titles and abstracts of all relevant publications related to the páramo. Figure 1 presents the flow diagram outlining the methodological steps followed.

**Inclusion/Exclusion criteria**

To ensure that the search results accurately reflected the core intellectual framework of the field, specific terms were selected as inclusion criteria for the bibliometric analysis (Dávid et al., 2024). The study analyzed publications from 2014 to 2023, limited to articles, and included documents written in both English and Spanish. To eliminate false positives, articles were selected based on their titles and abstracts. Therefore, duplicate, inaccessible, and irrelevant articles were excluded from the final sample to ensure the reliability of the selected publications.

**Data Analysis**

For data processing, the selected documents were exported from the Scopus database in CSV format to ensure compatibility with the analysis software. The analysis was conducted using VOSviewer v.1.6.20 (https://www.vosviewer.com), an effective tool for visualizing and analyzing bibliometric data through the construction of scientific maps (Dávid et al., 2024). It is important to note that the terms were standardized according to the following criteria: singular and plural forms were unified, selecting the most frequently used terms. In addition, Lotka’s Law was applied, and the Bibliometrix package was used to process and analyze the data and to generate high-quality graphs of the bibliometric parameters. The Bibliometrix R package provides a comprehensive set of tools that supports a recommended workflow for conducting bibliometric studies (Aria & Cuccurullo, 2017).

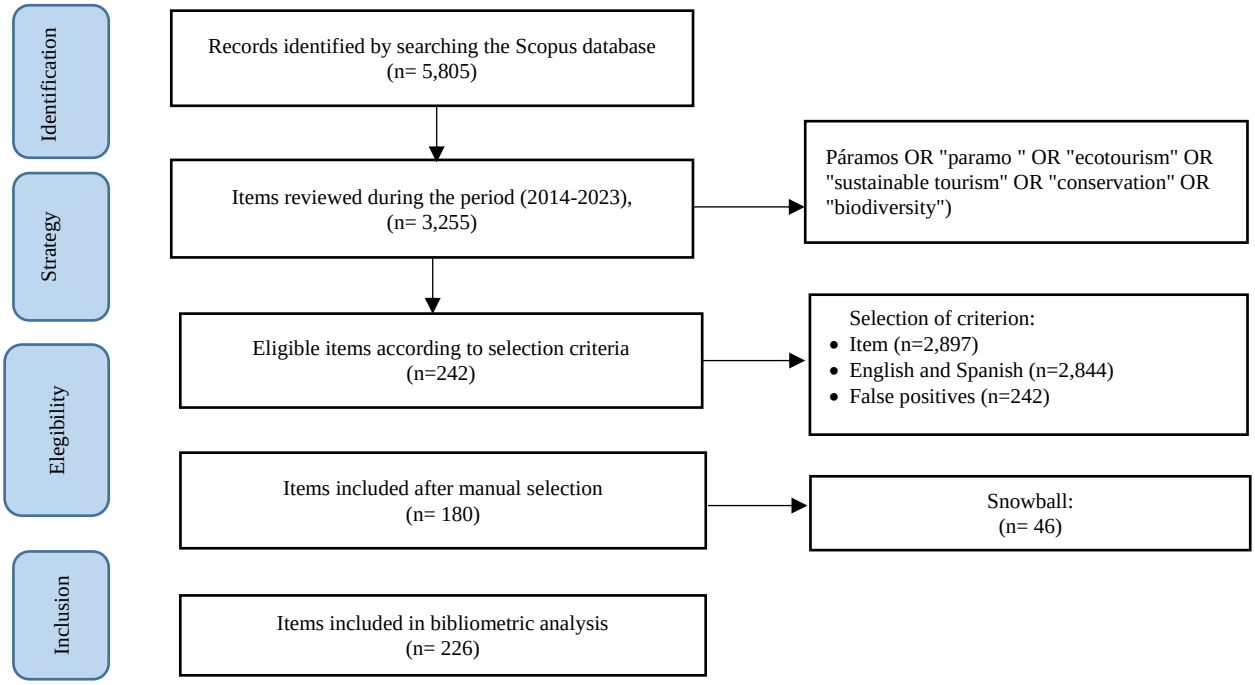


Figure 1. Flowchart of the steps in the methodology for extracting and filtering data from páramo-related publications

**RESULTS AND DISCUSSION**

Then it begins with the bibliometric analysis of the total set of publications from the last ten years obtained from Scopus. There was an exponential increase in the number of publications over time, as shown in Figure 2.In 2014, the number of publications was 16 articles; in 2015, 7 indexed articles were found; for 2016 there was a total of 20 articles; in 2017, 13 articles; for 2018, 15 articles were identified; in the year 2019, a total of 35 articles, in the year 2020, 22 scientific articles, in the year 2021, 26 articles, in the year 2022, 33 articles and in the year 2023, 39 scientific articles are viewed.

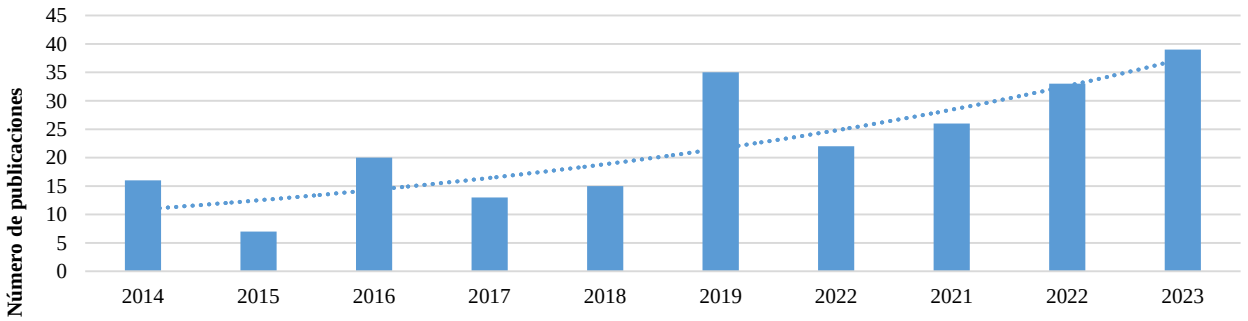


Figure 2. Average annual scientific production on páramos (Source: Scopus)

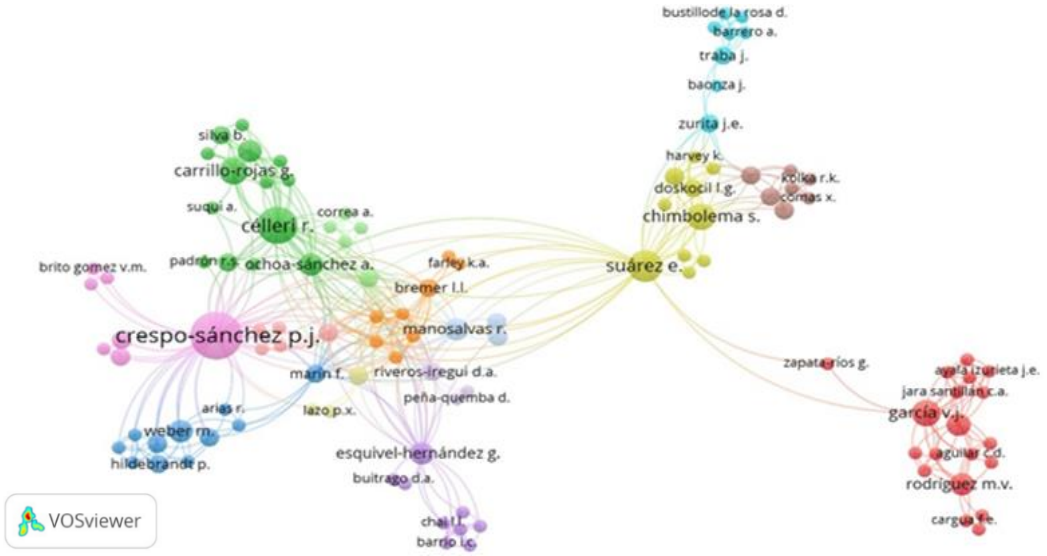


Figure 3. Map of co-authoring on páramo themes over the last ten years (Van & Waltman, 2010).

It can be seen that the scientific production in páramos research is increasing. This is reflected in its growth rate, as publications have increased significantly over the past four years. In the analysis of the co-authoring network, carried out through the VOS viewer software, a total of 14 clusters were identified, as seen in Figure 3, which have been grouped as follows: clusters 1 (19), clusters 2 (14) clusters 3 (11) clusters 4 (10) clusters 5 (9) clusters 6 (8) clusters 7 (8) clusters 8 (7) clusters 9 (7) clusters 10 (5) clusters 11 (5) clusters 12 (3) clusters 13 (3) clusters 14 (3), indicating a diverse and distributed collaboration among authors in the area of study. The visualization shows a complex structure of relationships between different researchers, suggesting the existence of several interconnected lines of research. The main author, Crespo, stands out with the largest number of publications (11 documents), indicating that he has a central role in the field, either as leader of research on páramos or as principal referent within a collaborative network. Other important authors on the network, such as Celleri (8 documents), Morales (6 documents), Suarez (6 documents), Avellaneda (5 documents) and other authors also show a significant contribution to the body of knowledge, although with a lower participation compared to the main author.

The co-authoring analysis reveals not only the main authors on the subject of páramos, but also a collaborative network involving several actors, which reflects the collective and dynamic nature of research in this area. In the Table 1 shows compliance with Lotka's law. 86% of the authors have contributed only 1 article, 9% have contributed 2 articles, 3% of the authors have contributed 3 articles, while 1% has contributed 4 publications in the field of study.

Páramo is an ecosystem of great importance for biodiversity and the water cycle (Suárez et al., 2023); and its vulnerability to climate change has been a growing concern in environmental research, because it has been threatened by factors such as climate change and human activities (Torres & Proaño, 2017).

Table 1. Lotka's law (processed with Bibliometric in R; Aria & Cuccurullo, 2017, based on Lotka, 1926)

| Published documents | N° of authors | Proportion of authors |
|---|---|---|
| 1 | 661 | 86% |
| 2 | 72 | 9% |
| 3 | 22 | 3% |
| 4 | 5 | 1% |
| 5 | 2 | 0% |
| 6 | 2 | 0% |
| 8 | 1 | 0% |
| 11 | 1 | 0% |

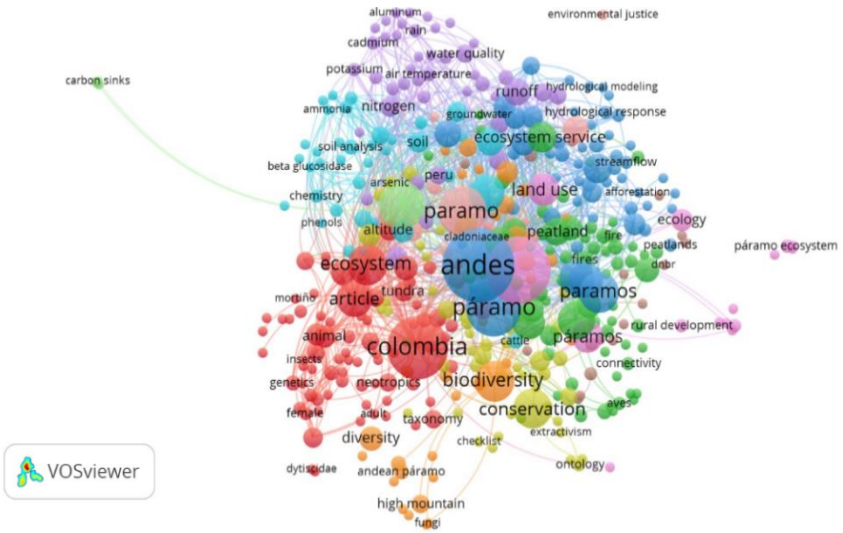


Figure 4. Map of keyword co-occurrence in páramo articles from the last ten years (Van & Waltman, 2010).

Through term co-occurrence maps, it is possible to visualize the conceptual relationships between words, this conceptual structure is a key tool to identify and understand the most relevant and current research topics. From the screening and eligibility of bibliographic data, Figure 4 was generated, showing the most frequent words in the various articles. From this analysis, it was concluded that the main keywords in this research are: "Páramos", "Andes", "Colombia", "ecosystem", "biodiversity", "conservation" and "ecosystem service". Thus, as mentioned in the study by González et al. (2017), the páramo provides ecosystem services to communities and its climate is usually cold and humid throughout the year, with significant variations in daily temperatures, largely depending on altitude (Ramsay, 2014). Figure 5 shows how the leading countries in páramo research have changed over the past few years. The countries of Colombia and Ecuador in the co-authoring network reflect their central position in the research and conservation of the páramos, ecosystems found mainly in the Andean area of these two countries. The country-by-country co-authorship visualizations in the figure highlight the importance of the páramos in the context of international research, as key actors in local and global research on these ecosystems.

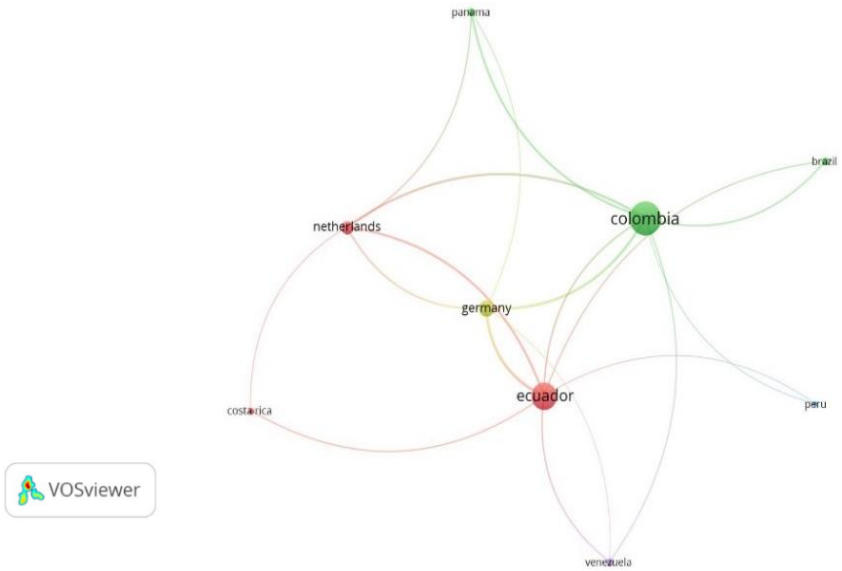


Figure 5. Map of co-authoring countries in páramo articles over the last ten years (Van & Waltman, 2010)

The relevance of the most cited journals, as shown in Figure 6 are the Journal of Tropical Biology, Caldasia, Frontiers in Ecology and Evolution and Sustainability, as they impact on research trends and scientific publications in this field of study, they are shown in 4 clusters: clusters 1 (10), clusters 2 (7), clusters 3 (4) and clusters 4 (2), which, when joined by the color of the lines, reflecting the interconnectedness between journals, those that focus on tropical and sub - páramo ecosystems, making them a key source for studies of fauna, flora, and the ecological processes they possess.

Frontiers in Ecology is a more global, open-access journal that publishes research on aspects of ecology, including biodiversity, climate change, conservation and vulnerable ecosystems such as páramos. The leading authors in the citation network of this study are Ramsay (2014) and Flantua et al. (2019), as illustrated in Figure 7. This indicates that their articles are the most frequently cited and likely address fundamental aspects of páramo ecology, biodiversity, and environmental dynamics. Their centrality confirms their dominance in shaping the academic field, positioning them as key

references in the scientific discourse. The high citation frequency suggests that their research constitutes a theoretical and methodological cornerstone for the development of new lines of inquiry concerning high mountain ecosystems.

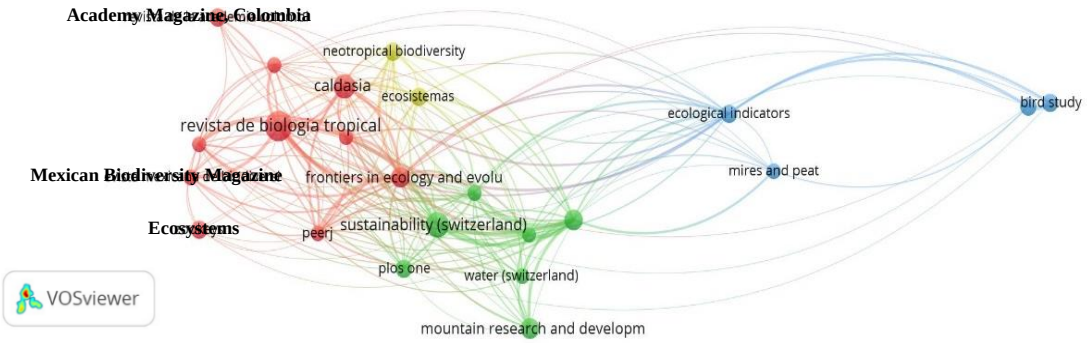


Figure 6. Map of bibliographic linkage by sources in the páramo articles of the last ten years (Van & Waltman, 2010)

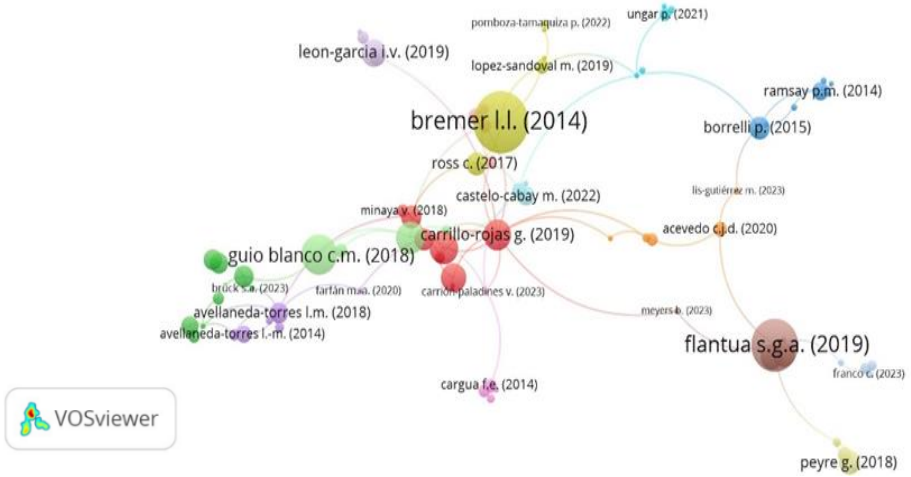


Figure 7. Author citation map by documents in páramo articles 2014-2023 (Van & Waltman, 2010)

The findings reveal that, although there are contributions within the environmental and ecological fields, there remains a relatively small proportion of comprehensive bibliometric analyses focused specifically on the páramo's biodiversity, an ecosystem uniquely characterized by the predominance of herbaceous vegetation (Sylvester et al., 2019). Based on the VOSviewer analysis (Van & Waltman, 2010), a sustained increase in scientific production over recent decades is observed, reflecting growing interest in the conservation, ecology, and management of high mountain ecosystems (Cajamarca et al., 2024; Razzaq & Shah, 2025). This trend aligns with the observations of Murad et al. (2024), who note that the greatest concentration of research is located in countries such as Colombia, Ecuador, and Venezuela, where a significant extent of the ecosystem remains preserved.

The co-occurrence analysis of keywords identified core thematic areas including climate change, biodiversity, ecosystem services, and conservation, reaffirming that the research aligns with global concerns related to environmental sustainability (Vanegas & Salazar, 2020; Acosta et al., 2024). However, this research agenda also reflects regulatory and social limitations. For instance, unclear restrictions on productive activities and outdated legal frameworks have constrained páramo protection, resulting in gaps in information (Salas & Estupiñán, 2024). Similarly, historical disturbances linked to armed conflict and military infrastructure expansion demonstrate that pressures on these ecosystems are not solely environmental but also deeply embedded within sociopolitical contexts (Méndez-Garzón et al., 2024).

The results also indicate that land-use changes have produced fragmented landscapes, negatively impacting biodiversity and ecosystem dynamics (Yela-Lara & Baca-Gamboa, 2023). This is attributable to traditional practices such as controlled burning of grasslands for soil fertilization purposes (Camacho, 2014) and a limited recognition of the páramo as a strategic ecosystem for water provision (Muñoz-Saba et al., 2024; Clavijo, 2024).

At a global scale, the impacts of climate change and intensive human activities—such as agriculture, grazing, pine plantations, and tourism—have increased the risks of páramo degradation by disrupting hydrological cycles and diminishing its regulatory capacity (Sánchez et al., 2025). Recent literature (Díaz et al., 2024; Vistin-Guamantaqui et al., 2024) underscores the urgent need to promote comprehensive conservation strategies that integrate sustainable practices with ecological restoration to maintain the provisioning of ecosystem services in páramo environments.

In terms of planning and management, public policies regarding páramos have evolved toward holistic approaches that acknowledge the social dimension of these territories (Acevedo-Zapata, 2025). Likewise, environmental assessments and continuous monitoring have been established as technical tools and spaces for social construction (Floréz et al., 2025; Vergara & De Pellegrin, 2025). This integrative perspective is crucial for understanding páramos as socio-ecological systems (Matlovič

& Matlovičová, 2025), wherein ecological, social, economic, and cultural dimensions are integrated. Within this context, the relationship with the livelihoods of rural farmers is fundamental, as local communities—although dependent on agriculture and livestock—have developed their own adaptation and restoration strategies based on traditional knowledge and innovations in "social technology" (Torres et al., 2023). However, broader processes such as globalization, agricultural industrialization, and climate change threaten to accelerate rural depopulation and aging (Karlin, 2025; Lis-Gutiérrez et al., 2023).

Another significant finding emerged from the co-authorship analysis, which revealed existing collaboration networks among academic institutions and research organizations, as shown in Figure 5, while also identifying gaps in international cooperation. Furthermore, the evaluation of productivity by authors and journals indicates that publications specializing in ecology and conservation have played a key role in disseminating research on the páramo. The productivity assessment, supported by Lotka's Law, revealed patterns of concentration in scientific output. This law demonstrated that a small number of authors account for the majority of publications, exemplified by Crespo, who contributed eleven works within the analyzed period. Ecological and conservation studies have significantly contributed to the understanding of páramo ecosystems; however, it is essential to adopt interdisciplinary approaches that integrate environmental, geopolitical, economic, and sociocultural dimensions, incorporating the perspectives of rural communities, with the aim of achieving a broader and more complex understanding of the páramo as a socio-ecological system (Matlovič & Matlovičová, 2025). Collectively, the findings of this study identify research gaps, provide definitions of key terms within the field, recognize emerging trends in páramo research, and offer promising perspectives. The use of bibliometric tools such as VOSviewer software has proven to be an effective methodology for analyzing the evolution of knowledge in this domain, providing a robust foundation for decision-making in environmental policy and academic research (Dong et al., 2025).

## CONCLUSION

The bibliometric study demonstrates that the systematic analysis of scientific production concerning páramos constitutes a key tool for the development of conservation policies and practices. The information obtained through the identification of the most productive authors, co-authorship networks, leading research countries, and main thematic trends allows for the strategic guidance of research efforts toward areas of greater environmental and social impact. Such studies not only reflect the state of the art but also facilitate informed decision-making and prioritization of actions in these fragile zones. Moreover, bibliometrics contributes to transparency and standardization in academic processes, helping to define more precise conceptual frameworks and strengthen scientific communities. The findings provide a solid foundation for planning public policies aimed at conservation, sustainable management of water resources, and biodiversity protection within páramo ecosystems.

The results indicate that páramos have attracted growing interest within the scientific community, especially in Andean countries such as Colombia, Ecuador, and Peru. However, this attention cannot be analyzed in isolation, as global factors such as climate change, the globalization of scientific research, pressures on natural resources, and international environmental policies directly influence how these studies are approached. For instance, climate change increases the vulnerability of páramos to variations in temperature and precipitation patterns, underscoring the urgent need for research focused on resilience and adaptation of these ecosystems. Similarly, globalization fosters the creation of scientific networks that facilitate the transfer of methodologies and experiences. Páramos are strategically important ecosystems due to their role in hydrological regulation and biodiversity conservation. Their close connection to the socioeconomic dynamics of local communities necessitates a holistic approach to management.

However, the limited number of studies incorporating social, cultural, and economic dimensions into ecological analyses hinders the development of sustainable conservation strategies. Therefore, it is essential to promote research that views páramos as socio-ecological systems, analyzing the interactions between human actors and the natural environment, thereby enabling the design of more equitable and effective management policies.

The integration of emerging fields such as critical political ecology, anthropology, ecological economics, and rural studies can enrich the understanding of the multiple challenges facing these ecosystems. Furthermore, it fosters the recognition of local and ancestral knowledge, as well as the active participation of communities in conservation decisions, ensuring that páramo protection aligns with the social and cultural needs of their surroundings.

### Limitations

This research presents several limitations that should be acknowledged. First, the data were exclusively sourced from the Scopus database, which, although prestigious in the scientific community, represents only a portion of the total available data. This highlights the need for future studies to utilize different databases, such as Web of Science, Science Direct, or Google Scholar, which would allow for comparison and validation of the findings presented here. Additionally, the study focused solely on scientific articles published in English and Spanish, implying that contributions from other countries or in other languages may not have been captured. Similarly, books, book chapters, reviews, or technical reports were excluded, although these could enrich the bibliometric landscape.

Articles that did not contain the specified keywords were excluded from the sample; thus, their content was not subjected to bibliometric analysis and warrants deeper examination within this subfield using this methodology. Data were collected within a specific temporal framework, so the number of citations and publications may vary slightly in the future. Despite these limitations, the results provide a comprehensive bibliometric overview of the main research trends in páramo studies.

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