



Vulnerability and Resilience of Ecosystems and Communities Facing Climate Change: A Bibliometric Analysis

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Abstract

Concepts of vulnerability and resilience are complex, multidisciplinary phenomena. The bibliometric analysis serves as a reference for the research world. It offers a quantitative and objective overview of scientific activity, allowing researchers, institutions, and decision-makers to navigate more effectively in the complex landscape of knowledge. The main objective of a bibliometric analysis is to quantify and analyze scientific production to understand the structure, dynamics, and impact of research in a given domain. This study has quantitatively analyzed three major themes, including vulnerability and resilience of climate change ecosystems, vulnerability and resilience of communities to climate change, and adaptation of ecosystems and communities to climate change, as well as the global trends in micro, meso, and meta scale research using the Open Alex database from 1994 to 2024. The analysis has particularly emphasized historical development, keywords, citations and co-citations, institutions, and countries. The results have made it possible to identify globally 2510, 2042, and 1038 research articles, respectively, on the vulnerability and resilience of ecosystems, the vulnerability and resilience of communities, and the adaptation of communities and ecosystems to climate change. The study also revealed an emerging and rapidly growing trend for studies conducted particularly in the field of vulnerability and resilience of communities and ecosystems to climate change. In addition, this analysis shows that the number of publications on the vulnerability and resilience of climate change ecosystems exceeds those on the vulnerability and resilience of communities and significantly exceeds those on the adaptation of ecosystems and communities. This study shows that the majority of publications were in English.

Keywords

Vulnerability, Resilience, Ecosystem, Climate Change, Adaptation, Community

1. Introduction

The average temperature at the surface of the earth, following the increase in the concentration of greenhouse gases in the atmosphere due to anthropogenic activities, has led to global warming. Indeed, climate change is one of the largest environmental challenges of the century. The global average temperature increased by about 1.5°C compared to the pre-industrial period. In Africa, temperatures are increasing at a faster pace than the world average, which is 1.5°C (IPCC, 2018). West Africa faces complex risks related to climate change. These climate changes affect the structure, composition, and functioning of ecosystems, leading to the loss of biodiversity and ecosystem services (Heubes et al., 2011). For the coming decades, several authors predict a strong degradation of habitats favorable to the development of several animal and plant species, with the consequences of their regression, or even their extinction (Heubes et al., 2011). In addition, several studies have emphasized the increase in the frequency of extreme weather events, especially droughts, floods, and extreme temperatures, leading to the alteration of the availability and quality of resources (land, water, fodder, etc.), and thus, severely affecting the livelihoods of communities, particularly those based on agriculture, pastoralism, and forestry (Ouoba, 2013). This situation is much more worrying for the Sahel, due to its geographical position in the south of the Saharan desert and the strong dependence of its population on rainfed agriculture and livestock (Ouoba, 2013). In the central Sahel, and in particular in Mali, Burkina Faso, and Niger, the effects of climate change are expected to intensify over the next decades. Analyses of expert data suggest that the region will experience more severe and frequent extreme weather (drought, floods), but also more pronounced progressive effects, such as more variable rainfall and higher temperatures, and humidification, among others (IPCC, 2019; IPCC, 2021).

Climate change is now recognized as a systemic disruptive factor simultaneously affecting ecosystems and human societies at all scales (IPCC, 2022). Rising average temperatures, altered precipitation patterns, and the increasing frequency of extreme events exert unprecedented pressures on socio-ecological systems (Pörtner et al., 2022). These pressures result in accelerated biodiversity loss, degradation of ecosystem services, and heightened socio-economic vulnerabilities, particularly in regions with low adaptive capacity (Hickel et al., 2022).

Vulnerability to climate change is defined as the degree to which a system is likely to be adversely affected, depending on its exposure, sensitivity, and adaptive capacity (Füssel, 2007; IPCC, 2022). Coastal ecosystems, arid zones, and tropical forests are among the most exposed, while communities dependent on natural

resources are particularly sensitive to climatic disturbances (Smit & Wandel, 2006; NatureServe, 2019).

In parallel, resilience refers to the capacity of a socio-ecological system to absorb disturbances, reorganize, and maintain its essential functions (Holling, 1973; Folke, 2016). Recent studies emphasize the importance of integrating ecological and social resilience into public policies, combining nature-based solutions, adaptive governance, and socio-technical innovations (Challinor et al., 2023; UNDP, 2023).

In this context, bibliometric analysis is a strategic tool for mapping scientific production, identifying collaboration networks, emerging themes, and research gaps (Aria & Cuccurullo, 2017; Donthu et al., 2021). Applied to vulnerability and resilience in the face of climate change, it allows researchers to identify conceptual trends, assess the evolution of methodological approaches, and highlight underrepresented disciplines and regions.

The objective of this article is therefore to conduct an in-depth bibliometric analysis of the scientific literature on the vulnerability and resilience of ecosystems and communities in the context of climate change, to provide an integrated view of research dynamics and to guide future scientific and policy priorities.

Thus, climate change impacts both natural and human systems, and many terrestrial and ocean ecosystems, and some of the services they provide have already changed (IPCC, 2018). These effects are very severe in developing countries because of the high variability of rainfall and excessively high temperatures (Pradhan & Ghosh, 2019), challenging all policies in the fight against poverty. These effects exert pressure on the resilience capacities of communities, which differ according to individuals and various factors, including gender and age (Desmidt et al., 2021). In the central Sahel, the climate crisis is acute. Strengthening the resilience of communities here, as the ability to respond and adapt to shocks, but also to improve the ability to do so, is paramount. Regional, national, and local actors implement a series of activities to support this goal, with more or less success. The combined effects of climate change and socio-economic exclusion (which particularly affects young people, women, girls, remote rural areas, and some ethnic groups) erode the resilience of populations. This hurts the effectiveness of (re)constructing or strengthening resilience. In some cases, this combination of pressures can make certain population groups (especially young people) more vulnerable to violent extremist rhetoric. According to Karimi et al. (2017), agriculture is the most vulnerable sector to climate change. This climate change thus compromises the evolution of rainfed agricultural systems and therefore the food security of the populations through the decrease in the surfaces of arable land, the duration of the growing seasons, and the decline in returns per hectare. The livestock sector is also affected by the phenomenon of climate change. According to FAO (2016), the variability of precipitation and high temperatures leads to a decrease in the yields of animal production in general. The effect of climate change on livestock is manifested directly (for example: with thermal stress and increased morbidity

and mortality) and indirectly (for example: by the quality and availability of food and fodder, and diseases in animals).

1.1. Vulnerability

Vulnerability describes how susceptible a system, ecosystem, or community is to the harmful effects of climate change, including variability and extreme events. It arises from the combination of three factors: exposure to climate hazards, sensitivity to impacts, and capacity to adapt and respond (Füssel, 2007).

The concept of vulnerability occupies a central place in the analysis of climate change impacts. The Intergovernmental Panel on Climate Change (IPCC) has gradually evolved its definition through its various evaluation reports, reflecting the evolution of scientific knowledge and adaptation approaches. In its fourth evaluation report (AR4), the IPCC defined vulnerability as follows: “The degree to which a system is likely to be affected, or unable to deal with the adverse effects of climate change, including climate variability and extreme phenomena” (IPCC, 2007). This definition emphasizes the exposure and sensitivity to climate hazards, but also the ability to deal with them. In the sixth evaluation report (AR6), the definition has been updated to further integrate the dimension of adaptive capacity: “Vulnerability refers to the propensity of a human or natural system to be negatively affected, taking into account its sensitivity or its susceptibility to damage and lack of adaptability” (IPCC, 2022). This version highlights the multidimensional complexity of vulnerability, which depends on exposure, sensitivity, as well as resources, institutions, and locally available adaptation capabilities. Thus, the analysis of vulnerability to climate change requires a systematic approach, integrating biophysical, socio-economic, and institutional factors at different scales (Figure 1).

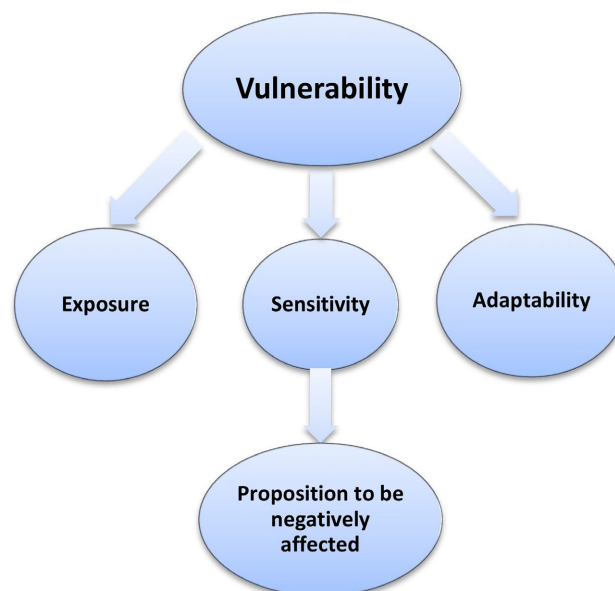


Figure 1. Explanatory diagram of vulnerability.

1.2. Resilience

Resilience is the capacity of a socioecological system to absorb disturbances, adapt, and transform while maintaining its essential functions, identity, and structure. In the context of climate change, it involves not only resisting shocks but also the ability to shift toward more sustainable trajectories in the face of uncertainty (Sharifi & Yamagata, 2023).

The concept of resilience is essential to analyze the ability of societies and ecosystems to deal with the impacts of climate change. The IPCC defines resilience as evolving through its reports. In its fifth evaluation report (AR5), the IPCC defines resilience as follows: “Resilience is the ability of social, economic and environmental systems to face a hazardous event, reacting or reorganizing themselves by keeping essentially the same functions, structures, identity and capacity of adaptation, learning and processing” (IPCC, 2014). This definition focuses on the functional stability of shock systems, as well as their ability to learn and evolve. In the sixth evaluation report (Intergovernmental Panel on Climate Change, 2022), the notion of resilience is more widely integrated with a perspective of transformation towards development resilient to climate. The IPCC stresses that: “Resilience is the ability of human and natural systems to face, adapt, transform and recover from the effects of climate change while reducing future risks” (IPCC, 2022). This definition insists not only on the absorption of impacts, but also on the proactive transformation of systems in response to future risks. Thus, resilience is not limited to passive resistance, but includes essential adaptive and transformative capacities in the context of global warming. As part of this study, resilience is understood as the capacity of a system to resist, adapt, and recover quickly as a result of seizures and/or shocks. A system is said to be resilient when it can not only withstand and absorb the shock to maintain the existing state by actively responding to the disturbances (defensive attitude) but also adapt, transform, modify, or break with the existing state in an offensive attitude (Lallau & Thibaut, 2009). Strengthening resilience requires a long-term approach, based on the mitigation of underlying causes conducive to crises and capacity improvement to better manage ecosystem services. Resilience leads to integrative reasoning. The factors that are mobilized are multiple, heterogeneous, and use different fields of knowledge. Analyzing the resilience of households around a natural resource against climate and socio-economic disturbances is essential for two reasons. First, natural resources play an important role in the economic activities and livelihoods of rural households in developing countries (Goffner et al., 2019). But with the strong vulnerability of households to climate hazards and food insecurity, this statement encourages an analysis of the sustainability of natural resource conservation. Secondly, these natural resources, more specifically vegetation, make it possible to mitigate the effects of climate change (Solly, 2020).

1.3. Adaptation

Adaptation refers to the process of adjusting human and natural systems to actual

or expected climate change effects, to moderate potential damages or take advantage of beneficial opportunities. It can be anticipatory (preventive) or reactive, and can occur at different scales (local, national, international) (UNDP, 2023).

Adaptation to climate change is one of the essential pillars of resilience strategies, particularly in vulnerable contexts such as Sahelian countries. The IPCC (Intergovernmental Expert Group on Climate Change) has refined the definition of adaptation over its reports. In the fifth evaluation report (Intergovernmental Panel on Climate Change, 2014), adaptation is generally defined as: “The processes of adjustment to current or planned climatic conditions, as well as their effects.” (IPCC, 2014) This definition highlights the idea of continuous adjustment, whether in the face of changes already observed or expected. In the sixth evaluation report (Intergovernmental Panel on Climate Change, 2022), the IPCC proposes a more detailed definition: “Adaptation refers to the process of adjusting to the current or expected climate effects and their impacts. In human systems, adaptation aims to moderate or avoid harm or to exploit beneficial opportunities. In some natural systems, human intervention can facilitate adjustment to climate change.” (IPCC, 2022) This definition highlights not only the preventive and adjustment aspects of adaptation, but also the opportunity to take advantage of new opportunities. It also recognizes that some natural systems cannot adapt without external support. Adaptation can be classified according to several criteria: temporally, anticipatory adaptation (preventive) vs. reactive; institutionally, autonomous adaptation (unplanned) vs. planned (policy, programs); structurally, incremental adaptation (progressive adjustments) vs. transformational (deep changes). Thus, adaptation is a dynamic process, integrated with efforts to reduce vulnerability and the construction of climate-resilient development.

2. Methodology

As part of this study, a review of longitudinal and exploratory literature has been conducted, utilizing bibliometric analyses and historical trends. The study quantitatively analyzed the global trends in micro, meso, and meta-scale research. The publications used for the analysis were consulted from the Open Alex database. Work has explored published research articles on the following themes:

- Vulnerability and resilience of climate change ecosystems.
- Vulnerability and resilience of communities to climate change.
- Adjustment of ecosystems and communities to changes in climate.

2.1. Data Collection

The Open Alex database has been systematically consulted to find research articles on the vulnerability and resilience of ecosystems and communities in the face of climate change. The downloaded articles have been classified into three groups, namely the vulnerability and resilience of climate change ecosystems, the vulnerability and resilience of communities to climate change, and the adaptation of ecosystems and communities to climate change.

Table 1 shows the keyword search for each category or group. The subject search field has been used for the selected keywords. Research by subject includes keyword searches from the title, summary, and keywords of the author. However, the oldest article, according to the keywords, is from 1994. As a result, the research items were extracted from the period between 1994-2024, or 30 years. The complete file and references cited included information on the publication: the title, the author, the year of publication, the summary, the title of the source (name of the journal), the affiliation of the authors, the keywords of the author, the categories of subjects (disciplines), language, and number of citations (if present for an article). As only one database (Open Alex) has been used, the risk of repetition was minimal.

Table 1. Research criteria.

Vulnerability/Resilience	Keywords used	Database	Document type
Vulnerability and resilience of ecosystems and communities to climate change	Vulnerability and resilience of climate change ecosystems Vulnerability and resilience of communities to climate change Adjustment of ecosystems and communities to changes in climate	Open Alex	Articles

2.2. Data Analysis

This study used descriptive statistics to analyze the debate on the vulnerability and resilience of ecosystems and communities in the context of climate change science. The study used four different analyses. A historical analysis was conducted to understand the temporal trend of research on the vulnerability and resilience of ecosystems and communities in the face of climate change over three periods (1994-2004, 2004-2014, and 2014-2024). An analysis of the keywords was performed for the author's keywords to understand the nature, links, and concepts used by the author(s). The term keyword will be used for concrete purposes. Visualizer VOSviewer 1.6.20 was used to build viewing cards of key co-occurrence keywords. The co-occurrence limit has been set to create easily readable and understandable keywords in the figures. An analysis of the quotes has been made to identify the number of citations in a particular article. The analyses of the institutions and countries have been carried out to identify prolific organizations and countries publishing on the vulnerability and resilience of ecosystems and communities to climate change. The software used is Microsoft Excel 2013 for descriptive statistics and VOSviewer 1.6.20 for the analysis of the keywords.

3. Results

3.1. Overview of Publications

The summary of the three categories sought is presented in **Table 2**. The overall results showed that the number of publications on the vulnerability and resilience of climate change ecosystems is 2510, exceeding those on the vulnerability and resilience of communities to climate change with 2042 articles and adaptation of

ecosystems and communities to climate change with 1038 articles. Sources (magazines) publishing on the vulnerability and resilience of communities to climate change (2973) are significantly larger, followed by those publishing on the vulnerability and resilience of climate change ecosystems (1521). However, the magazines publishing articles on the adaptation of communities and ecosystems to climate change were only 847. Articles on the vulnerability and resilience of communities to climate change used 477 keywords, followed by the adaptation of ecosystems and communities to climate change with 261, and vulnerability and resilience of climate change ecosystems with 199 (**Table 2**).

Table 2. Overview of publications in open Alex databases (1994-2024).

	VUL & RES/ECO/CC	VUL & RES/COM/CC	Adapts/ECOS & COM/CC
Articles	2510	2042	1038
Sources (newspaper)	1521	2973	847
Authors/keywords	199	477	261

- **VUL & RES/ECO/CC:** Vulnerability and resilience of ecosystems to climate change;
- **VUL & RES/COM/CC:** Vulnerability and resilience of communities to climate change;
- **Adapts/ECOS & COM/CC:** Vulnerability and resilience of ecosystems and communities to climate change.

With regard to languages, most publications are in English, followed by Spanish, French, Catalan, and Portuguese (**Table 3**).

Table 3. Number of publications per language.

N°	Language	VUL & RES/ECO/CC	VUL & RES/COM/CC	Adapts/ECOS & COM/CC
1	English	2504	2040	1033
2	Spanish	2	1	1
3	French	2	1	3
4	Catalan	1	0	1
5	Portuguese	1	0	0
6	Japanese	0	0	0
7	German	0	0	0
8	Chinese	0	0	0
9	Korean	0	0	0
10	Indonesian	0	0	0

Table 4 reflects most of the author's publications on the selected topics. The Luca researcher, S., is at the top of the list with 28 publications on the vulnerability and

resilience of climate change ecosystems, followed by the Timon researchers, Mr. P. and Steward, T. A. P., with 19 and 16 publications each. At the level of research on the vulnerability and resilience of communities to climate change, the analysis showed that the researcher Geoff, A. W. is at the top of the list with 10 publications, followed by Nina L. and Angelo J. I., with 9 and 8 publications, respectively. The theme of the adaptation of ecosystems and communities to climate change has not been the subject of many publications in terms of articles, and the analysis shows that the researcher James, D. F. is in the lead with 11 publications, followed by the Rustell researchers, Mr. W and Adger, N. W., with 8 publications each.

Table 4. Authors with more publications (vulnerability, resilience, and adaptation of ecosystems and communities in the face of climate change) (1994-2024).

N°	VUL & RES/ECO/CC		VUL & RES/COM/CC		Adapts/ECOS & COM/CC	
	Author's name	Number of publications	Author's name	Number of publications	Author's name	Number of publications
1	Luca, S.	28	Geoff, A. W.	10	James, D. F.	11
2	Timon, M. P.	19	Nina, L.	9	Rusell, M. W	8
3	Steward, T. A. P.	16	Angelo, J. I.	8	Adger, N. W.	8
4	Sandra, L.	12	Frank, V.	8	Jan, M.	8
5	Erik, A.	12	Finn, L.	7	Siri, E.	7
6	Niki, F.	11	Reinhard, M	7	Karen, E. M.	7
7	Davide, G.	11	Rajib, S.	7	Walter, L. F.	7
8	Thomas, E.	10	Susan, I. C.	6	James, B.	6
9	Peter, H. V.	10	Lei, Z.	6	Matthew, J. C.	6
10	Graeme, S. C.	10	Ann, S. M.	6	Russell, G.	6

Regarding institutions, the analysis clearly shows that institutions such as the United States Department of the Interior, the United States Department of Agriculture, and the Aru Self-Government have more publications on the vulnerability and resilience of climate change ecosystems, with 53 publications each. Griffith University, the United States Department of Commerce, and Louisiana State University have more publications on the vulnerability and resilience of communities to climate change, with 19, 18, and 17 publications, respectively (**Table 5**). Institutions such as the Australian Government, the Commonwealth Scientific and Industrial Research Organization, and the Department of Industry, Science, and Resources have more publications on the adaptation of communities and ecosystems to climate change, with 40, 38, and 38 each (**Table 5**).

In addition, country analysis results also reveal that the United States of America is at the top of the countries that have more publications on the vulnerability and resilience of climate change ecosystems, with 391 publications, followed by Australia and the United Kingdom of Great Britain and Northern Ireland, with 149 and 133 publications each, respectively (**Table 6**). The United States of America has more publications (409) on the vulnerability and resilience of communities

to climate change, followed by the United Kingdom of Great Britain and Northern Ireland and Australia, with 174 and 133 publications, respectively. The United States of America, the United Kingdom of Great Britain and Northern Ireland, and Australia are also the countries that have more publications on the adaptation of communities and climate change ecosystems, with 168, 107, and 98 publications, respectively (Table 6).

Table 5. The ten institutions that have more publications on the vulnerability and resilience of ecosystems and communities to climate change (1994-2024).

VUL & RES/ECO/CC		VUL & RES/COM/CC		Adapts/ECOS & COM/CC	
Institution	Publications	Institution	Publications	Institution	Publications
United States Department of the Interior	53	Griffith University	19	Australian Government	40
United States Department of Agriculture	53	United States Department of Commerce	18	Commonwealth Scientific and Industrial Research Organization	38
Australian Government	53	Louisiana State University	17	Department of Industry, Science and Resources	38
US Forest Service	48	University of London	17	University of Leeds	19
United States Geological Survey	46	Texas A&M University	17	CGIAR	16
Consejo Superior de Investigaciones Científicas	39	RMIT University	14	University of East Anglia	14
Centre National de la Recherche Scientifique	37	National Oceanic and Atmospheric Administration	13	University of Tasmania	14
Department of Industry, Science and Resources	33	University of Queensland	13	University of British Columbia	14
Commonwealth Scientific and Industrial Research Organisation	32	University of Melbourne	13	University of Oxford	14
Chinese Academy of Sciences	31	University of Colorado Boulder	13	Griffith University	13

Table 6. The ten countries that have the most publications on the vulnerability and resilience of ecosystems and communities to climate change.

VUL & RES/ECO/CC		VUL & RES/COM/CC		Adapts/ECOS & COM/CC	
Country	Publications	Country	Publications	Country	Publications
United States of America	391	United States of America	409	United States of America	168
Australia	149	United Kingdom of Great Britain and Northern Ireland	174	United Kingdom of Great Britain and Northern Ireland	107
United Kingdom of Great Britain and Northern Ireland	133	Australia	133	Australia	98
Germany	93	Canada	80	Canada	66
Spain	92	Indonesia	77	Germany	55

Continued

Canada	88	Netherlands	42	China	36
China	82	China	40	India	30
France	59	Japan	39	South Africa	30
Netherlands	57	South Africa	37	Kenya	28
Italy	54	New Zealand	36	France	27

Figure 2 reflects the number of publications per period. The analysis revealed that the period 2014-2024 has more publications, with 1543 publications on VUL & RES/ECO/CC, followed by VUL & RES/COM/CC with 1313 publications, and ADAPTS/ECOS & COM/CC has fewer publications with 881. The period 2004-2014 has more publications on VUL & RES/COM/CC and VUL & RES/ECO/CC, with respectively 922 and 702 publications, and ADAPTS/ECOS & COM/CC with 147. The period 1994-2004 has fewer publications, with 45 publications on VUL & RES/COM/CC, 27 publications on VUL & RES/ECO/CC, and 10 publications on CAP/ECOS & COM/CC.

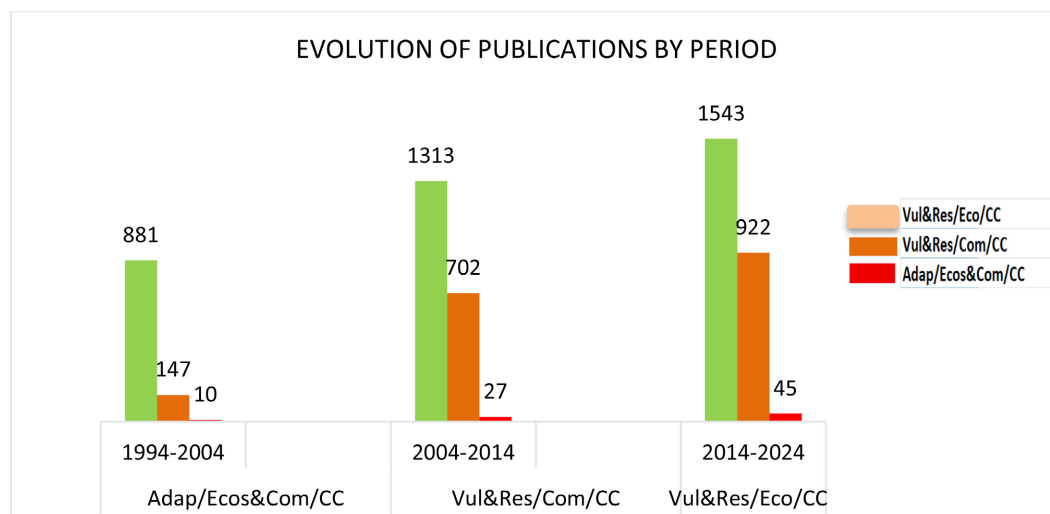


Figure 2. Number of publications by period 1994-2004, 2004-2014, and 2014-2024.

3.2. Historical Development

The bibliometric analysis, as a quantitative tool for the study of scientific publications, has experienced significant development in exploring the theme “Vulnerability and resilience of ecosystems and communities in the face of climate change.” This field of research, inherently interdisciplinary and an increasing emergency, has seen its scientific landscape evolve rapidly, reflecting societal concerns and methodological progress. This historical development is traced into three distinct phases, each characterized by specific bibliometric trends and approaches: phase 1: emergence and initial awareness (1990s-early 2000s). This period marks the beginning of a scientific and political awareness of the extent of climate change. IPCC reports begin to structure research and popularize vulnerability and impact

concepts. Initial Bibliometric Approaches: Identification of Pioneers: The first bibliometric analyses often focus on the identification of the founding articles and key authors who have introduced the concepts of vulnerability and resilience in the environmental context. Citation analyses make it possible to identify seminal items. Mapping Emerging Domains: Keyword and co-occurrence analyses make it possible to delimit the first sub-themes (for example, ecosystem-ecosystems, “Impacts on agriculture”). Analysis of Institutions and Countries: A first cartography of the most active countries and institutions in scientific production on these topics emerges, often dominated by developed countries. Limit: Bibliometric tools are less sophisticated. The analyses are often descriptive and are based on volumes of publications still relatively weak.

Phase 2: Structuring and Diversification (mid-2000s-late 2010s) Climate change research is becoming more densified. The concepts of vulnerability and resilience are refined as interdisciplinarity intensifies, integrating more social and human sciences. The notion of socio-ecological systems is gaining importance. Advanced Bibliometric Approaches: Analysis of Co-Author Networks and Co-Quote: These analyses become more common in identifying international collaborations and emerging research communities. They allow for the visualization of bridges between disciplines (e.g., Climatology and Sociology). Detection of Emerging Topics and Thematic Breaks: Clustering and detection algorithms applied to keywords or abstracts reveal more specific research subdomains (e.g., Urban Raines, Adaptation based on ecosystems, climate, and vulnerability). Analysis of Idea Flows (Quote Analyses): The study of quotation patterns makes it possible to understand how concepts and theories diffuse and influence different areas of research. Evaluation of Impact and Visibility: Indicators such as H-Index, the number of citations, and altimetric measures (Web Impact Measures and Social Networks) are used to assess the influence of publications and researchers. Regional and Sectoral Comparisons: Bibliometric studies are multiplying to compare research efforts on the vulnerability and resilience of different regions of the world or for specific sectors (agriculture, health, water). Methodological Advances: The appearance of dedicated software (VOSviewer, CiteSpace, Bibliometrics) and access to more complete databases (Web of Science, Scopus) facilitate the realization of more complex analyses.

Phase 3: Integrated and Prospective Approach (2020-Present) The complexity of climate change interactions, ecosystems, and companies is fully recognized. The focus is on solutions, transformative adaptation, and systematic resilience. Artificial intelligence and Big Data open up new perspectives. Innovative bibliometric approaches: analysis of the dynamics of concepts and their interconnection. Beyond the simple detection of themes, the analysis focuses on how the concepts of vulnerability and resilience co-evolve and clear with other notions (e.g., “Transformation”, “Quade”, “Corporate financing”). Identification of research gaps (Research Gaps): Sophisticated analyses can help identify under-explored subjects or collaborative gaps between certain disciplines, thus leading to future

The keyword data analysis was performed on the following criterion basis: 60 co-occurrences and 40 keywords, and the result of the analysis highlighted an interrelation between the different disciplines composed of five colors or clusters (blue, red, green, purple, and yellow). Different clusters demonstrate interrelations between them and networking with other clusters (disciplines); the blue cluster has a more significant interrelation, and the most studied discipline in this cluster is climate change (Figure 3). Other clusters have low interrelation between them and low networking with other disciplines.

3.4. Analysis of Citations and Co-Citations

The analysis of citations and co-citations demonstrates the interrelationships between the authors and their networking. The results of this analysis demonstrate that researchers who have more publications on the vulnerability and resilience of communities and ecosystems to climate change are Luca Salvati and Timon McPhearson, followed by Susan I. Cutter, Rajib Shaw, Angelo Jonas Imperiale, and Geoff A. Wilson. Quotes that have the same networks have virtually the same colors (Figure 4). However, networks that have the same color (cluster) mean they have more common quotes and work in networking with others.

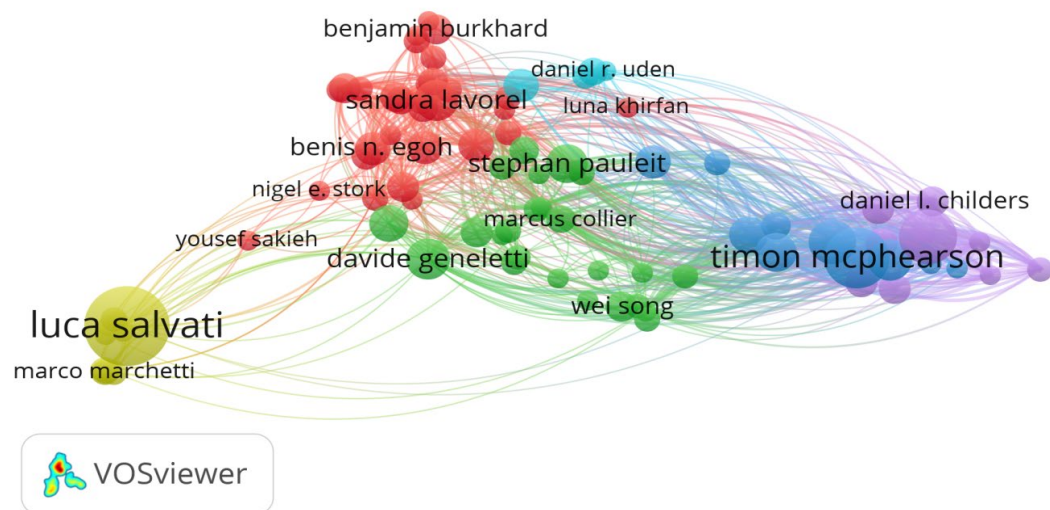


Figure 4. Highly cited references of references used in publications on the vulnerability and resilience of climate change ecosystems (maximum 88 quotations).

3.5. Analysis of Publications by Institutions and by Country

3.5.1. Institutions

The result of the analysis of the institutions has highlighted the institutions that have more publications on the vulnerability and resilience of communities and ecosystems in the face of climate change, their interrelation, and their relationship with other research institutions. The same color cluster reflects the interrelation between these institutions, and networking shows that these institutions work in a network (Figure 5).

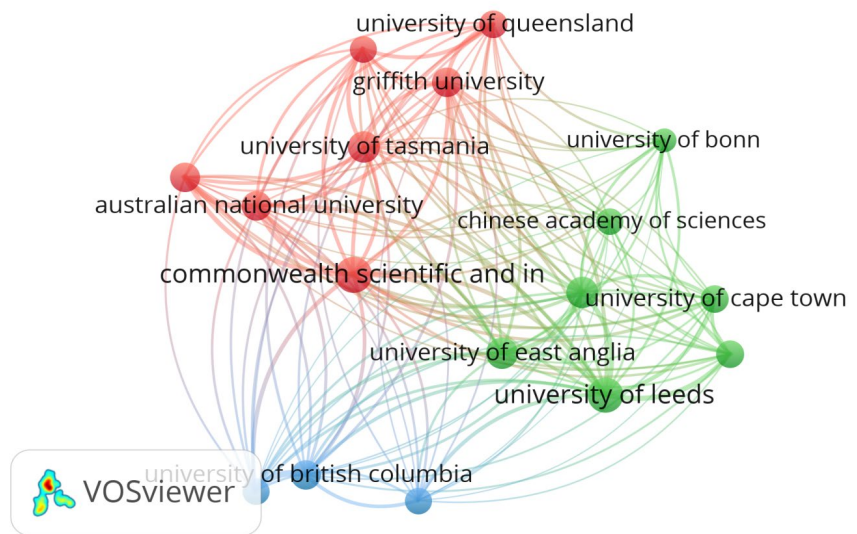


Figure 5. Analysis map of highly cited institutions in publications on the vulnerability and resilience of ecosystems and communities to climate change.

3.5.2. Country

The result of data analysis shows that countries with more publications on the vulnerability and resilience of communities and ecosystems to climate change are the United States, followed by Australia and Canada. **Figure 6** reflects the interrelation between countries and their relationships with other countries. Countries that have the same cluster color have a stronger relationship than those with a different color, and countries work in a network.

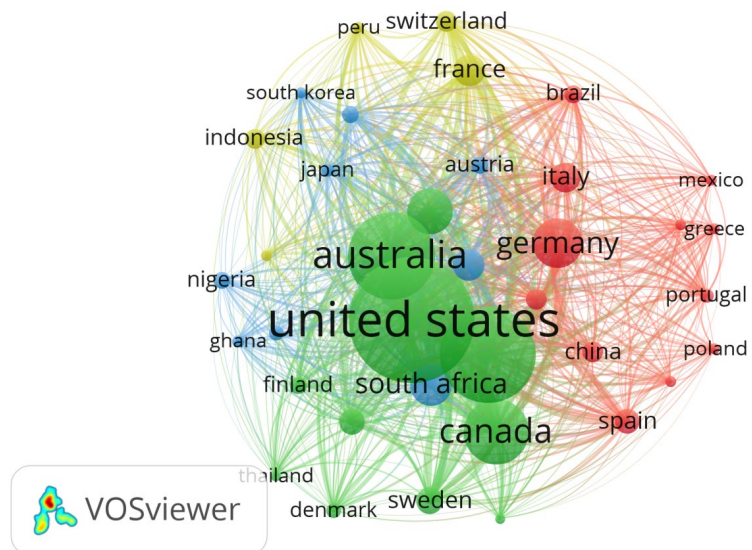


Figure 6. Country analysis map highly cited in publications on vulnerability and resilience of ecosystems and communities to climate change.

4. Discussion

The growth of publications is a strong indicator. The exponential growth of sci-

entific production on vulnerability and resilience, as observed in this study (from 1038 publications in 1994-2004 to 2510 in 2014-2024), is consistent with overall trends reported by Rana (2020) in a bibliometric analysis on disaster resilience and climate change, which also highlights a rapid increase in academic interest in climate change and its socio-ecological dimensions, particularly after the 2000s and the publication of successive IPCC reports. The preponderance of the United States as the most productive and studied country on the vulnerability and resilience of climate change, as revealed by our data, is a frequent observation in the bibliometric literature. Work like that of Haunschild et al. (2016), who reviewed climate change research until 2014, has clearly demonstrated the quantitative dominance of the United States. This trend has been maintained in more recent analyses (Qiu et al., 2024), where the United States continues to produce the largest volume of publications on climate impact resilience strategies. The cards highlight the central actors (the most connected institutions and countries), often leaders in the research and implementation of climate solutions. These dense nodes suggest increased capacity, mobilized knowledge, and resources, which are essential for adaptation (Cash et al., 2003). The identification of geographical or thematic clusters indicates regional synergies or specializations. However, weakly connected or isolated areas on maps report gaps, representing vulnerability points, where access to expertise and support is limited (Adger, 2006). Integration into these networks can influence climate policies and guide global agendas towards more effective approaches to vulnerable regions (Biermann et al., 2009). Isolated actors often lack access to information, financing, and expertise, resulting in inefficient solutions and insufficient preparation in the face of climate impacts (Wisner et al., 2004). Although revealing, these VOSviewer cards are a snapshot. They show who collaborates, but not the quality or effectiveness of these collaborations. Non-visible factors such as power imbalances can also influence these dynamics. Future research could assess the actual impact of collaborative projects and analyze the evolution of these networks over time to identify more successful adaptation strategies.

Despite significant exposure to the impacts of climate change, Africa remains underrepresented in the global scientific production concerning the vulnerability and resilience of ecosystems and communities. This weak involvement is largely due to chronic underfunding of research, with the majority of African countries investing less than one percent of their GDP in research (UNESCO, 2021). In addition, Africa contributes about two percent of global scientific publications, illustrating persistent marginalization in international scientific networks (Confraria & Godinho, 2015). Furthermore, research agendas are often determined by international donors, reducing the autonomy of African researchers and relegating them to secondary roles in consortia (Sanni et al., 2020; Gaillard & Gomez, 2015). Added to this is an undervaluation of local and traditional knowledge, which is crucial to understanding the dynamics of resilience at the community level, but is rarely integrated into the dominant scientific literature (Leach et al.,

2012). These combined challenges hinder the continent's ability to produce and disseminate locally anchored and scientifically recognized knowledge about climate resilience.

5. Conclusion

This study used the vulnerability and resilience of communities and ecosystems in the face of climate change to better understand historical trends and developments through the bibliometric method. This global bibliometric analysis of the vulnerability and resilience of ecosystems and communities in the face of climate change reveals a growing field of research, characterized by thematic diversity. The analyzed corpus testifies to a global awareness of the challenges posed by global warming, with a significant acceleration of publications in recent decades. Research highlights the interconnected and multifactorial nature of vulnerability, influenced by ecological factors (loss of biodiversity, soil degradation), physical (sea level rise, extreme weather events), and socio-economic (poverty, inequalities, governance) factors. Resilience, meanwhile, is conceptualized in various ways, ranging from the absorption capacity of shocks to adaptive transformation. The resilience strategies studied are varied, including ecosystem-based adaptation, technological innovations, public policies, community initiatives, and the mobilization of indigenous knowledge. Geographically, research is inequitably divided, with a high concentration in developed countries, while the most vulnerable regions, including sub-Saharan Africa and small island developing States, remain underrepresented despite their increased exposure to the impacts of climate change. This disparity suggests an urgent need to strengthen local research capabilities and international collaborations. In short, although the landscape of vulnerability research and climate resilience is rich and dynamic, it is imperative to guide future efforts to more inclusive, interdisciplinary, and operable approaches to effectively support global adaptation and mitigation efforts.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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