UDC 504
SCOPUS CODE 2301
https://doi.org/10.36073/1512-0996-2025-2-310-325

The Role of Sustainability and Mountain Development Topics in Current Scientific Literature

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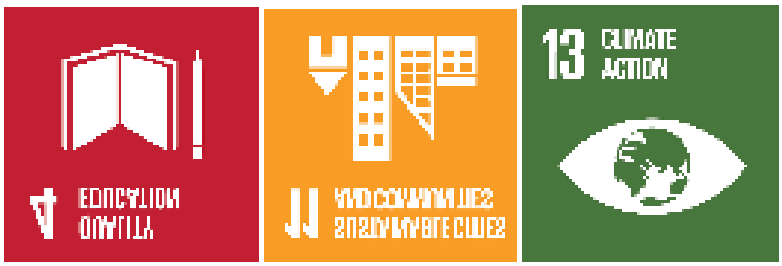


Abstract. Mountains play a critical role in global sustainability, serving as vital ecological, socio-economic, and cultural hubs. However, sustainable mountain development remains a relatively new research field, with a limited understanding of its complexities. This study provides a bibliometric analysis of the scientific literature on sustainable mountain development using data from Scopus, with keywords such as "sustainable development," "mountain region," and "mountain area." The analysis identifies three primary dimensions: social, economic, and environmental. Results highlight the dominance of research from countries like China, Italy, and Switzerland, while regions such as Africa and South America remain underrepresented. Key terms, including "climate change," "biodiversity," and "land use change," underscore the interdisciplinary nature of this field, revealing pressing challenges and opportunities. The findings emphasize the urgent need for global collaboration, targeted policy interventions, and capacity building through initiatives such as specialized educational programs, including a proposed **Master's Degree in Sustai-**

nable Mountain Development, to address sustainability challenges in mountainous regions effectively.

This article aligns with Sustainable Development Goals (SDGs) 4 (Quality Education), 11 (Sustainable Cities and Communities), and 13 (Climate Action). It emphasizes the importance of education, the sustainability of mountain communities, and the protection of vital environment..

Keywords: Mountains Development; Mountain Tourism; Sustainability; SDGs.

Introduction

Mountains have socio-economic and environmental importance for the entire world, and they are also one of the region's most crucial ecosystems (Palau & Claramunt-López, 2024). The environmental protection of the local population, ethics and environmental history, and the ecological, economic, and social cultures of the population of the mountain region are crucial. In the mountainous regions of Georgia, there is a high potential for creating cultural landscapes, based on the results of the long-term and effective interdependence of man and nature. Cultural landscapes, depending on their importance, will further increase the sustainability of the socio-ecological system of mountainous regions (Elizbarashvili et al., 2024).

Mountains play a key role in sustainable development, and their importance will increase in the future. As the water towers of the world, mountains will play a crucial role in providing fresh water for a growing number of people, for industrial development, and for agriculture and irrigation in mountains and downstream areas. Food security, poverty alleviation, and, ultimately, political stability will thus be critically linked to mountain resources, and hence to the development taking place in mountain areas. Mountains will also continue to play an important role as hotspots of biodiversity. Increasing urbanization within mountains will put additional stress on scarce resources such as water. At the same time, mountains are characterized by specific development challenges. Typically, these include difficult access, economic and political marginality, outmigration, environmental sensitivity, diversity of livelihoods, and cultural diversity. These challenges need to be addressed by specific policies, laws, and institutional arrangements at the international, national, and local levels (Walther et al., 2002).

As part of the Promoting Sustainable Mountain Development for Global Change (SMD4GC) programme, the Mountain Research Initiative and the Centre for Development and Environment are developing an approach to assessing sustainable mountain development (SMD) using the SDGs as a framework. Such assessments can help contextualize and highlight the specific needs of and challenges for mountain communities and ecosystems in addressing SMD, backed by sound evidence. They can help inform policy and decision-making at the global, national, and subnational levels in steering SMD efforts for the benefit of people living in highlands and adjacent lowlands (Bracher et al., 2018).

The dynamics of tourism evolution in a mountain destination are significantly shaped by the intricate interplay between natural factors, such as ecological and climate change considerations, and human factors, encompassing economic, social, and political aspects (Chakraborty & Ghosal, 2024).

There is a clear need to develop tourism strategies that align with sustainability principles, ensuring that the Carpathian Mountains region remains attractive and resilient for future generations (Dobre et al., 2024)

Main Part

Research Methods

In this study, we used bibliometric statistical methods to identify, better understand, and evaluate recent patterns, techniques, findings, and improvements in sustainable mountain development. Bibliometrics is a statistical method that provides a transparent framework to better understand publication trends in research papers, articles, and documents (Rashmi and Kataria, 2022), Additionally, bibliometric analysis was used to evaluate current trends, patterns, and key themes in

scientific literature related to sustainable mountain development. Bibliometric analysis is a quantitative research method that examines large volumes of academic literature to identify publication trends, collaborations, and thematic focuses.

Steps in Research

1. **Data Collection**:
- The Scopus database was used to extract relevant literature published between 2005 and 2024. Keywords such as "sustainable development," "mountain region," and "mountain area" were utilized to identify 655 articles and documents for analysis.
2. **Bibliometric Analysis**:
- Bibliometric techniques were applied to quantify the number of publications, citation frequencies, and co-occurrence of keywords. These metrics provided insights into the prominence of specific terms, their relationships, and the contribution of different countries to the field.
3. **Keyword Analysis**:
- A keyword frequency analysis was conducted to identify the most frequently occurring terms, such as "sustainable development," "mountain region," "climate change," and "biodiversity." This analysis provided insights into the thematic focus of the literature.
4. **Geographical Analysis**:
- A country-wise breakdown of publications and citations was performed to assess the geographic distribution of research activities. Countries with significant contributions, such as China, Italy, and Switzerland, were highlighted.
5. **Network and Cluster Analysis**:
- Network visualization tools were used to map the relationships between key terms and research themes. Terms were grouped into clusters representing specific thematic areas, such as sustainable development, environmental protection, and socio-economic sustainability.
6. **Trend Analysis**:
- A longitudinal analysis of keyword usage over time was conducted to identify emerging and declining topics. This analysis revealed how research priorities have evolved in response to global environmental and socio-economic challenges.

Limitations:

- The reliance on the Scopus database may have excluded relevant literature indexed in other databases.
- The analysis is limited to English-language publications, potentially overlooking significant contributions in other languages.
- Bibliometric methods are quantitative and do not capture the qualitative nuances of the research.

This methodological approach offers a comprehensive overview of the scientific landscape of sustainable mountain development, highlighting key themes, trends, and gaps in literature. It helps identify priority areas for future research and policy interventions.

The study answers the following question: How has the scientific literature on sustainable mountain development evolved over the past two decades, and what are the key themes, geographic focuses, and gaps in addressing social, economic, and environmental challenges in mountainous regions?

Results and Discussion

A total of 242 sources were analyzed for the period 2005-2024 (annual growth rate of 11%), 655 documents that were jointly submitted by 2050 authors. The level of international collaboration in scientific publications reached 24.58%, and the average citation rate of one document was 18.09.

Key Insights about Countries and Scientific Production:

1. **Top Countries:**
- **China** stands out as the most frequent country mentioned, with **1283** mentions, significantly outpacing all other countries. This suggests that China is a dominant focus in the dataset under analysis.
- Other highly mentioned countries include **Italy (231)**, **Spain (88)**, **USA (86)**, and **Switzerland (79)**,

which might indicate a high volume of research, publications, or data from these countries.

2. **European Countries:**

- Several European countries like **Germany (71)**, **Austria (57)**, **Greece (52)**, **France (40)**, and **Serbia (30)** show notable frequency, which might point to a concentration of interest in Europe for the subject at hand.
- **Romania (68)**, **Poland (19)**, **Portugal (28)**, and **Bulgaria (8)** also appear, suggesting diverse representation from different parts of Europe.

3. **Asian Countries:**

- Countries in Asia like **India (57)**, **Nepal (52)**, **Pakistan (23)**, and **Japan (13)** are well-represented.
- **Kyrgyzstan (13)** and **Kazakhstan (4)** also show up, indicating some focus on Central Asia.
- **Bangladesh (2)** and **Afghanistan (1)** appear less frequently but still contribute to the dataset.

4. **Africa:**

- **South Africa (24)** is the most frequent African country, with mentions also coming from **Kenya (5)**, **Botswana (1)**, **Ethiopia (1)**, **Uganda (1)**, and **Madagascar (1)**.
- The relatively low frequency for Africa overall may suggest a more limited focus or representation in the context you're analyzing.

5. **Other Regions:**

- **South America**: Countries like **Argentina (18)**, **Brazil (7)**, **Chile (4)**, and **Peru (4)** appear, with **Argentina**being the most frequently mentioned in South America.
- **Middle East**: Mentions of **Iran (10)**, **Saudi Arabia (10)**, and **United Arab Emirates (8)** point to some regional focus in the Middle East.
- **Oceania**: **Australia (17)** and **New Zealand (1)** are mentioned, with Australia being the dominant country in this region.
- **North America**: The **USA (86)** and **Canada (19)** have moderate frequencies, suggesting involvement or focus on these countries in the context at hand.

6. **Low-Frequency Mentions:**

- Countries like **Armenia (1)**, **Botswana (1)**, and **El Salvador (1)** appear only once, indicating that while they are included, they do not play a major role in the dataset or topic you're working with.
- The relatively large number of countries with very few mentions (e.g., **Tunisia (1)**, **Singapore (1)**, **Philippines (1)**) suggests either that the context is very specific or that some countries are not a primary focus in the research, report, or dataset.

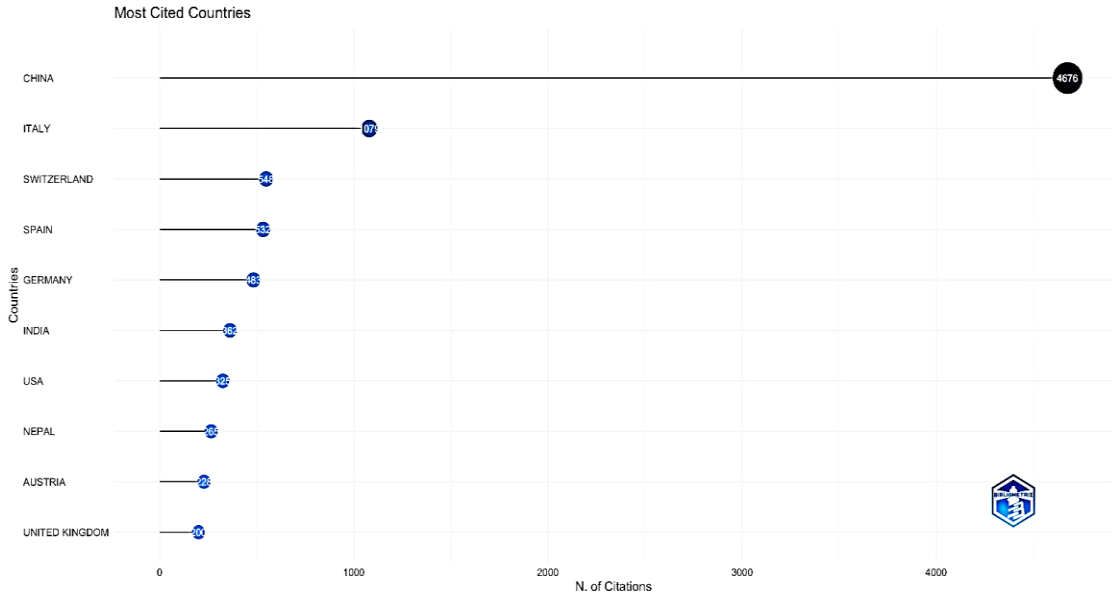
The diagram (1) shows the "Most Cited Countries" based on the number of academic or scholarly citations. The graph ranks countries by the volume of citations they have received, with the x-axis representing the "Number of Citations" and the y-axis listing the countries.

Key Observations:

- **China** is prominently the most cited country, significantly exceeding all others, with a citation count surpassing 4,000.
- Other highly cited countries include **Italy**, **Switzerland**, and **Spain**, each showing substantial but considerably fewer citations compared to China.
- The middle tier includes **Germany**, **India**, and the **USA**, indicating moderate academic influence.
- Countries like **Nepal**, **Austria**, and the **United Kingdom** are represented as having fewer citations but still notable enough to be included in the list.

The visualization highlights global contributions to academic research or a specific area of study, with **China's dominance** suggesting its leading role in the field under examination. The positioning of other countries reflects varied levels of influence and engagement in the scholarly domain.

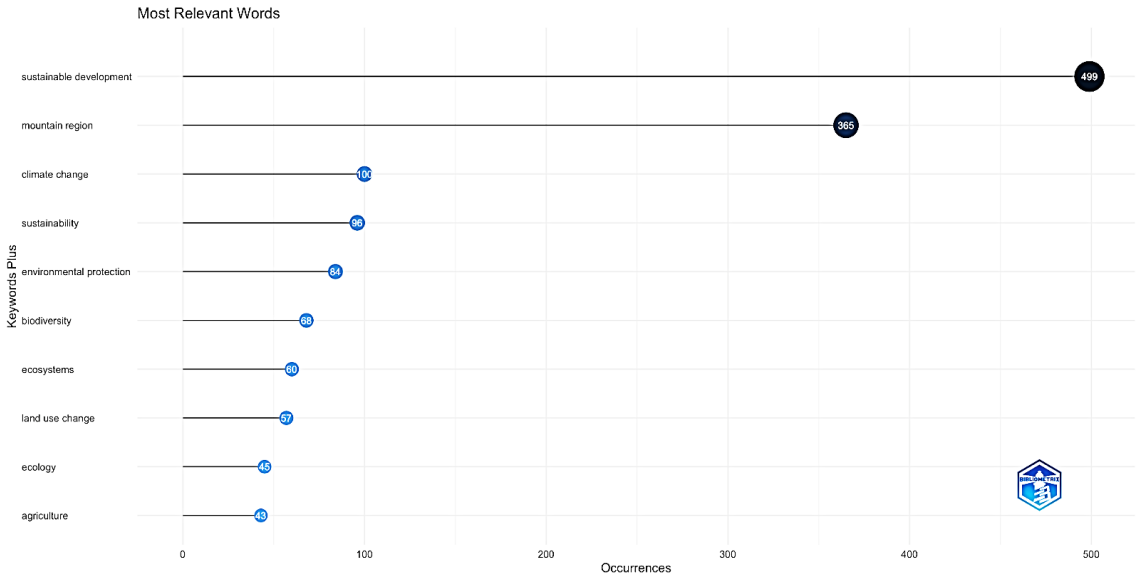
Diagram 1. Most Cited Countries



Note. Authors, according to the research

This diagram (2) shows the "Most Relevant Words" based on their frequency of occurrence in a specific context or dataset. The x-axis quantifies the "Occurrences" of each term, while the y-axis lists the keywords or phrases.

Diagram 2. Most Relevant Words



Note. Authors, according to the research

Key Observations:

- The term **"sustainable development"** is the most frequently occurring keyword, with 449 instances, underscoring its centrality to the analyzed content.
- **"Mountain region"** is the second most prominent keyword, with 346 occurrences, highlighting its thematic importance alongside sustainable development.
- Additional highly relevant terms include **"climate change"**, **"sustainability"**, and **"environmental protection"**, each reflecting core aspects of environmental and ecological discussions.
- Other terms such as **"biodiversity," "ecosystems," "land use change," "ecology,"** and **"agriculture"** show a moderate frequency, suggesting their role as supporting concepts in the broader thematic framework.

This visualization effectively illustrates the dominant focus on sustainability-related themes, particularly in the context of mountainous regions and environmental challenges. The frequency distribution indicates a strong emphasis on interconnected issues like climate change, resource management, and ecological conservation.

High Frequency Terms:

1. **Sustainable Development (499)** – This is the most frequently mentioned term, reflecting its central role in global scientific discussions. **Sustainable development** often refers to achieving economic, social, and environmental goals that can be sustained for future generations. It's a broad and interdisciplinary field, addressing issues like poverty, inequality, energy, and environmental protection.
2. **Mountain Region (365)** – This term appears with a very high frequency, likely indicating the significant attention paid to the unique challenges and opportunities of mountain ecosystems. Mountains are often biodiversity hotspots, and climate change, land use changes, and population pressures make sustainable management of these regions a critical concern.
3. **Climate Change (100)** – **Climate change** is a globally dominant issue, and its relatively high frequency reflects widespread research on its impacts, mitigation strategies, and adaptation measures. It's a crucial area of research, touching upon a wide range of topics such as emissions, renewable energy, and environmental policy.

Moderate Frequency Terms:

1. **Sustainability (96)** – This term is closely related to sustainable development but typically focuses more on balancing environmental, economic, and social systems in a way that meets current needs without compromising future generations. **Sustainability** is a key theme in many fields, from urban planning to energy systems to agriculture.
2. **Environmental Protection (84)** – Given the growing concerns over pollution, deforestation, and resource depletion, **environmental protection** is a frequently studied and discussed topic. This term often overlaps with research on regulatory frameworks, conservation, and policy development.
3. **Biodiversity (68)** – **Biodiversity,** the variety of life forms on Earth, is another crucial focus of environmental science. Researchers are concerned with conserving biodiversity, protecting endangered species, and maintaining ecosystems. The loss of biodiversity has wide-ranging implications for ecosystem health, agriculture, and human well-being.

Lower Frequency Terms:

1. **Ecosystems (60)** – This term appears less frequently but is still a key area of research, with studies focused on ecosystem services (e.g., clean water, soil fertility), restoration, and the impacts of human activity and climate change on ecosystems.
2. **Land Use Change (57)** – **Land use change** refers to the transformation of natural landscapes into urban, agricultural, or industrial land. This term is relevant in studies related to deforestation, urban sprawl, agricultural expansion, and the

impacts of these changes on the environment and climate.

3. **Ecology (45)** – **Ecology,** the study of organisms and their interactions with the environment, is a foundational science in understanding biodiversity and ecosystems. The term is used less frequently than others in the list, but it remains a core discipline in environmental science.
4. **Agriculture (43)** – **Agriculture** is deeply linked to environmental sustainability, climate change, and land use. Research in this field focuses on sustainable farming practices, the environmental impacts of agriculture (e.g., soil degradation, water use), and how agriculture can adapt to changing climate conditions.

Key Observations:

- **Focus on Sustainability and Environmental Protection**: There is a clear emphasis on **sustainable development** and **environmental protection,** showing that the scientific community is actively engaged in finding solutions for long-term ecological balance.
- **Importance of Mountain Regions**: The high frequency of **"mountain region"** suggests that mountain ecosystems are a critical area of study, particularly regarding climate change, biodiversity conservation, and sustainable development.
- **Climate Change Dominance**: While **"climate change"** is a well-known term, its slightly lower frequency (compared to **sustainable development** or **mountain regions**) might indicate that climate change research is often embedded within broader topics like ecosystems, biodiversity, and land use.
- **Land Use Change and Agriculture**: Both "**land use change"** and **"agriculture"** are often discussed in the context of sustainability and environmental impact. **Land use change**, especially in relation to deforestation and urbanization, has significant implications for climate change and biodiversity loss.

Analysis of Words' Frequency Over Time

The trends provide valuable insights into the evolution of research priorities and thematic focus over the years.

Key Observations

1. Overall Growth in Frequency

- All terms show a significant increase in frequency from 2005 to 2024, reflecting a growing research interest in sustainability and mountain development topics.
- **"Sustainable development"** leads with the highest frequency, increasing from 3 mentions in 2005 to 499 in 2024, underscoring its central role in global discourse.
- **"Mountain region"** follows closely, increasing from 4 mentions in 2005 to 365 in 2024, indicating the growing focus on mountain ecosystems within sustainability research.

2. Emerging and Dominant Topics

- **"Climate change"** shows a sharp rise, particularly after 2010, growing from 0 mentions in 2005 to 100 mentions in 2024. This trend aligns with the increasing global attention to climate change mitigation and adaptation strategies.
- **"Sustainability"** demonstrates steady growth, from 1 mention in 2005 to 96 in 2024, reflecting its importance as a conceptual framework alongside sustainable development.
- **"Environmental protection"** and **"biodiversity"** also exhibit notable increases, with frequencies reaching 84 and 68, respectively, in 2024, emphasizing their critical role in ecological and conservation-related research.

3. Moderate Growth in Supporting Topics

- **"Ecosystems," "land use change,"** and **"agriculture"** show moderate but consistent growth, indicating their relevance as interconnected areas of study:
  - **"Ecosystems"** grew from 0 mentions in 2005 to 60 in 2024.
  - **"Land use change"** increased from 1 mention in 2005 to 57 in 2024.

ISSN 1512-0996
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- **"Agriculture"** rose from 0 mentions in 2005 to 43 in 2024, suggesting a focus on sustainable agricultural practices in mountain regions.

4. Significant Milestones

- Around **2015–2017**, many terms saw a marked increase, likely influenced by global initiatives such as the adoption of the **UN Sustainable Development Goals (SDGs)** in 2015. Terms like **"sustainable development," "climate change,"** and **"biodiversity"** experienced sharp growth during this period.
- Post-2020, there is a notable acceleration in terms like **"climate change," "sustainability,"** and **"environmental protection,"** reflecting the heightened urgency of global environmental challenges.

Key Insights

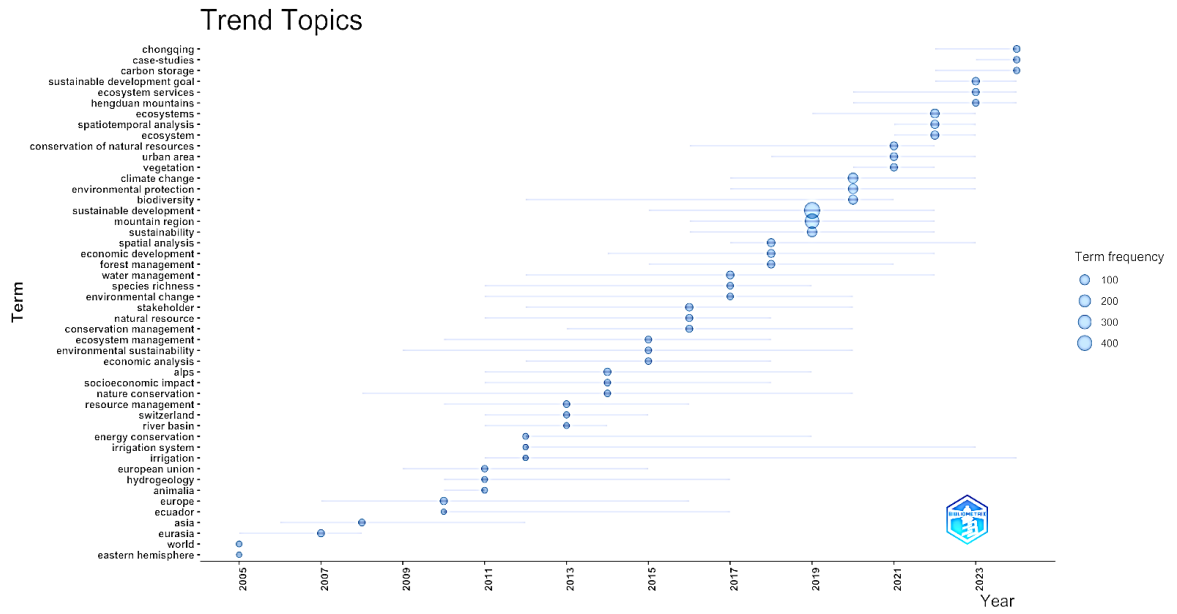
1. **Dominance of Sustainable Development**: The consistent rise in the frequency of **"sustainable development"** highlights its overarching importance as a unifying theme in the analyzed literature.
2. **Rising Focus on Climate Change**: The sharp growth in **"climate change"** frequency post-2010 aligns with global policy initiatives like the **Paris Agreement (2015)** and growing scientific consensus on the urgency of climate action.
3. **Increasing Attention to Mountain Regions**: The prominence of **"mountain region"** reflects an increasing awareness of the unique challenges and opportunities presented by mountain ecosystems, particularly in the context of biodiversity conservation, resource management, and climate adaptation.
4. **Interdisciplinary Nature**: The steady growth in terms like **"ecosystems," "land use change,"** and **"agriculture"** indicates the integration of ecological and socio-economic dimensions into sustainability research.

Implications

The increasing attention to sustainable mountain development suggests a growing recognition of mountains as critical regions for addressing global challenges.

- The data underscores the need for interdisciplinary approaches to address interconnected issues such as climate change, biodiversity loss, and land use changes in mountain areas.Future research could explore the underrepresented topics and regions to ensure more comprehensive and Diagram 3 represents "Trend Topics" over time, illustrating the evolution and frequency of specific terms across different years. The x-axis denotes the **year**, while the y-axis lists the **terms**. The size and density of the markers correspond to the **frequency** of each term, with larger markers representing higher occurrences.
- **Prominent terms** include "sustainable development," "climate change," "ecosystem services," "biodiversity," "environmental protection," and "mountain region." These keywords consistently appear across the timeline, with a marked increase in usage in the last decade.
- Topics like **"sustainable development goals" (SDGs)**, **"conservation of natural resources"**, and **"urbanization"** emerge strongly in later years, likely aligning with global environmental policy trends such as the UN's SDGs.
- Terms associated with specific geographical or thematic contexts, such as "Himalayan ecosystems," "resource management," and "climate adaptation," appear sporadically but gain momentum in recent years.
- The distribution of terms reflects an **interdisciplinary focus**, integrating environmental, economic, and social dimensions of sustainability.

Diagram 3. Trend Topics



Note. Authors, according to the research

According to analysis of terms related to mountains and their occurrence, cluster affiliation, and centrality measures within a network of sustainability and environmental topics. Below is a detailed breakdown:

Key Terms and Their Occurrences

- **"Mountain region" (365 occurrences)**: The most frequent term in the dataset, linked to Cluster 1 (labeled "sustainable development"), indicating its strong association with this theme.
- Other related terms such as **"mountain environment" (26 occurrences)**, **"high mountains" (7 occurrences)**, and **"mountain" (24 occurrences)** appear less frequently but are still relevant in their respective clusters.

Cluster Affiliation

- **Cluster 1 ("Sustainable Development")**: Focuses on broader environmental sustainability topics, with "mountain region" as the dominant term.
- **Cluster 2 ("Environmental Protection")**: Includes terms such as "mountain," "mountain regions," and specific geographic locations like "Hengduan Mountains" and "Qilian Mountains," suggesting a focus on localized ecological and conservation concerns.

Centrality Metrics

Centrality measures help identify the importance of terms in the network:

1. **Betweenness Centrality**:
   - High betweenness values for terms like "high mountains" (154.734) and "mountain" (174.599) indicate their critical role as connectors between other terms or clusters in the network.
2. **Closeness Centrality**:
   - Uniformly low closeness centrality values (0.002) across terms suggest a broad but less direct influence within the network. This might reflect the dispersed focus of mountain-related terms in the overall dataset.
3. **Pagerank Centrality**:
   - "Mountain region" has the highest pagerank (0.057), underscoring its dominant position in the network. Other terms have significantly lower pagerank values, highlighting their comparatively smaller influence.

Geographic Focus

- Terms like **"Hengduan Mountains," "Taihang Mountains,"** and **"Qilian Mountains"** in Cluster 2 emphasize region-specific studies or discus-

sions within the broader context of environmental protection.

Insights and Implications

- **Dominance of "Mountain Region"**: Its high frequency and centrality metrics solidify its importance in sustainability discussions, particularly in relation to **Cluster 1** (sustainable development).
- **Localized Emphasis in Cluster 2**: The focus on specific mountain ranges within the **environmental protection** cluster suggests targeted research or policy discussions tailored to unique geographic conditions.
- **Connectivity**: Terms like "mountain" and "mountain regions" serve as bridges between clusters, reinforcing their integrative role in linking sustainability and conservation topics.

This analysis demonstrates the significance of mountainous regions in sustainability discourse, balancing both broad global frameworks (Cluster 1) and specific ecological challenges (Cluster 2).

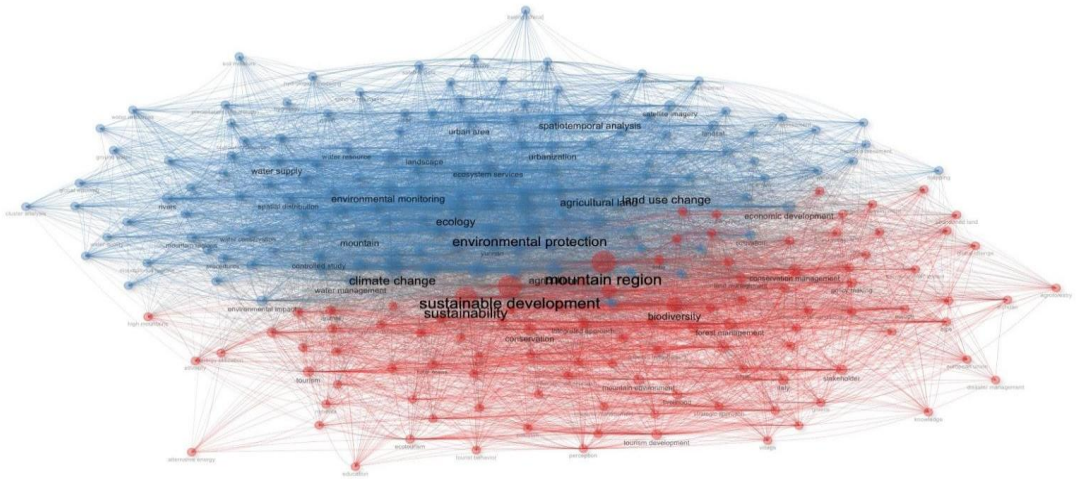


Image 1. Network Map

Note. Authors, according to the research

Image 2 represents a **network analysis** visualization, illustrating the interconnections and relationships among key terms related to sustainability and environmental topics. The nodes (individual terms) and edges (connections) signify the frequency of co-occurrence and the strength of their associations within the dataset.

Key Observations:

- **Central Nodes**: Terms like "sustainable development," "mountain region," "environmental protection," "sustainability," and "climate change" are prominent at the center of the network. Their central placement and larger node size indicate high relevance and strong connectivity with other terms.
- **Clusters and Themes**:
  - The **red cluster** highlights terms associated with socio-economic and ecological factors, such as "biodiversity," "agriculture," "land use change," and "sustainability."
  - The **blue cluster** emphasizes environmental monitoring, natural resources, and related concepts like "ecosystems," "forests," and "environmental management."
- **Dense Connectivity**: The extensive web of connections between nodes reflects the interdis-

ciplinary and integrated nature of research on sustainability, showcasing how different topics are interlinked.

• **Geographical and Contextual Terms**: Some nodes represent geographic or specific contexts, such as "mountain region," signaling a focus on unique environmental challenges or opportunities.

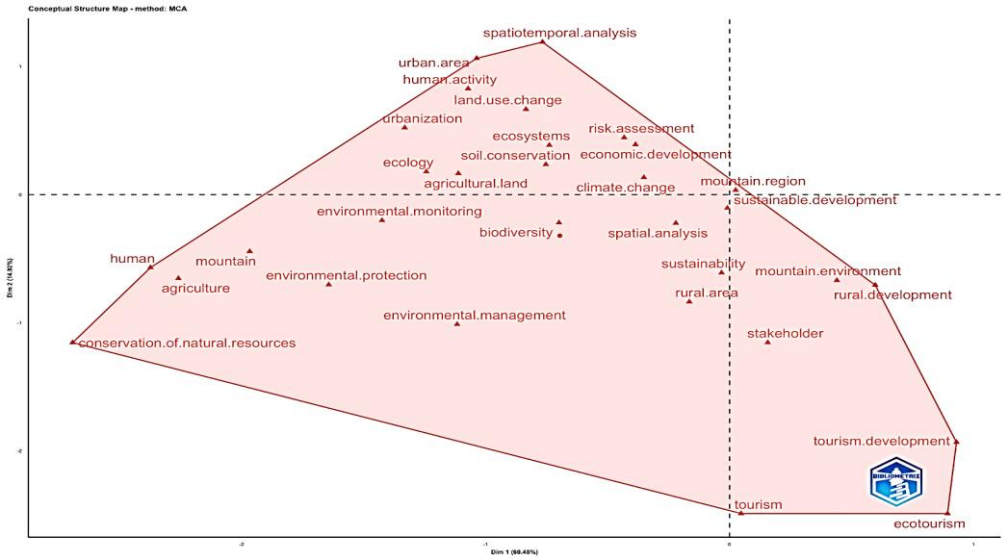


Image 2. Factorial Analysis

Note. Authors, according to the research

This network map effectively conveys the complexity and interconnectedness of sustainability-related discourse, demonstrating how various dimensions such as ecological conservation, socio-economic factors, and climate change interrelate to form a cohesive research or thematic framework

This **Conceptual Structure Map (image 3)** visualizes the relationships between key concepts using **Multiple Correspondence Analysis (MCA)**. The map organizes terms along two dimensions, showing their proximity, clustering, and thematic relationships.

Key Observations

1. **Axes and Dimensions**:

▪ The horizontal axis (**Dim 1**) represents the contrast between global frameworks (e.g., sustainable development, ecotourism) and localized or specific ecological processes (e.g., conservation of natural resources, land use change).

▪ The vertical axis (**Dim 2**) differentiate between environmental protection/conservation efforts (e.g., biodiversity, environmental monitoring) and socio-economic drivers (e.g., economic development, tourism development).

2. **Clusters of Concepts**:

- **Top-Center Cluster (Ecological Analysis)**:

▪ Terms like "spatiotemporal analysis," "land use change," "ecosystems," and "soil conservation" are concentrated here, reflecting an emphasis on spatial and ecological processes.

- **Left Cluster (Environmental Protection and Natural Resource Conservation)**:

- Terms such as "conservation of natural resources," "environmental protection," and "biodiversity" highlight conservation-focused discussions.
- **Right Cluster (Sustainability and Development)**:
- Dominated by terms like "sustainable development," "mountain region," "ecotourism," and "tourism development," this cluster emphasizes sustainability and socio-economic integration.
- **Bottom-Center Cluster (Agriculture and Rural Development)**:
- Terms like "rural area," "rural development," and "agriculture" form a distinct grouping focused on human-environment interactions in rural contexts.

3. **Key Themes**:

- **Sustainability and Development (Right)**: The prominence of terms like "sustainable development" and "mountain region" reflects their centrality to integrated strategies for addressing environmental and socio-economic challenges.
- **Ecological Monitoring (Top-Center)**: Spatial and ecological analysis techniques (e.g., spatiotemporal analysis) align with conservation strategies.
- **Human Impact (Middle-Left)**: Urbanization, human activity, and economic development show a strong connection to environmental degradation or protection efforts.

Insights and Implications:

- Interdisciplinary Nature: The map underscores the interconnectedness of ecological, social, and economic dimensions, reinforcing the need for interdisciplinary approaches in sustainability and environmental management.
- Focus on Mountains: "Mountain region" and "mountain environment" are central in the sustainability-development cluster, underscoring their importance in global sustainability frameworks.
- Tourism as a Development Tool: The distinct cluster around "tourism development" and "ecotourism" indicates its role in sustainable socio-economic progress, particularly in sensitive mountain regions.
- Conservation and Analysis: The clustering of conservation terms with spatiotemporal analysis suggests that data-driven approaches are critical for managing ecosystems and natural resources.

This map provides a comprehensive overview of how key concepts are thematically and structurally related, helping to identify focal areas for research, policy, and action in sustainability and environmental studies.

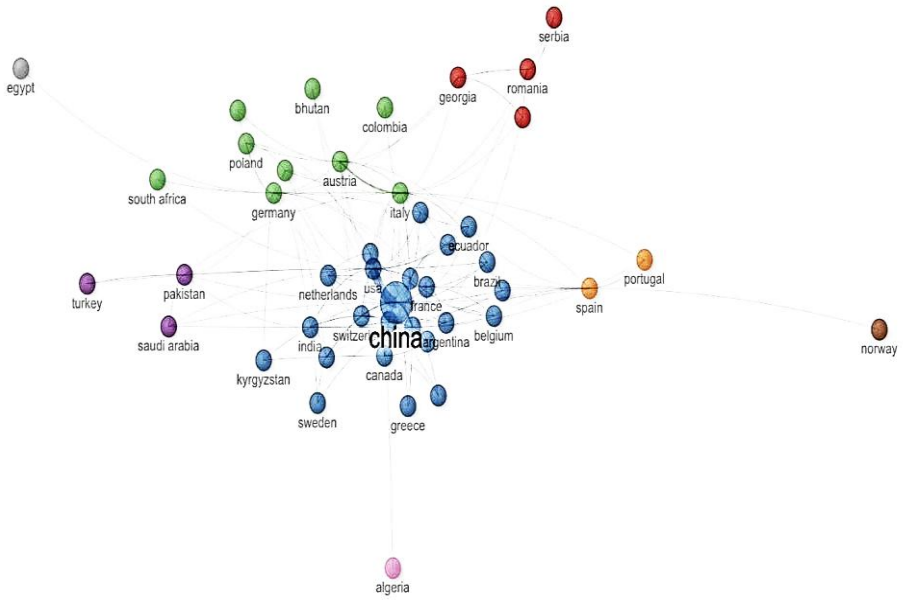


Image 3. Network Graph

Note. Authors, according to the research

This network graph visualizes the **relationships among countries** based on their connections or collaborations in the context of sustainability, environmental studies, or related research. The nodes (representing countries) and edges (representing connections) illustrate the intensity or frequency of interactions, with node size reflecting prominence or influence.

Key Observations

1. **Dominance of China**:
- **China** is the largest and most central node in the network, indicating its significant influence and numerous connections with other countries. This highlights China's leadership or major contribution in the studied field.
2. **Clusters of Countries**:
- **Blue Cluster (Central Collaborators)**:
- Countries like **Switzerland, USA, France, Germany,** and **Italy** are tightly connected around China, reflecting strong collaboration networks, likely driven by global research partnerships or projects.
- **Green Cluster (Peripheral Collaborators)**:
- Countries like **Bhutan, Colombia, Austria, Poland,** and **South Africa** form a distinct grouping, indicating moderate connections within the network, often linked to specific regional or thematic collaborations.
- **Red Cluster (Regional Connections)**:
- **Serbia, Romania,** and **Georgia** are closely connected, suggesting regional collaboration or shared thematic focus.
- **Purple and Isolated Nodes**:
- Countries like **Turkey, Pakistan, Kyrgyzstan,** and **Algeria** are on the periphery, indicating less frequent or less significant connections within the network.
3. **Notable Outliers**:
- Countries like **Norway, Portugal,** and **Spain** are positioned at the edge of the network, suggesting specific, less-centralized collaborations or independent contributions.
4. **Connectivity and Collaboration**:
- The network demonstrates a high degree of connectivity, with central nodes like **China** and **Switzerland** acting as hubs that bridge global partnerships.
- The presence of distinct clusters reflects both regional collaboration and thematic specialization.

Insights and Implications:

- Global Leadership: China's centrality underscores its dominant role in driving research or initiatives in this field, supported by collaborations with major Western nations like the USA and Switzerland.
- Regional Collaborations: Clusters such as the Red Cluster (Eastern Europe) and the Green Cluster (emerging nations) suggest regional efforts in sustainability or environmental projects.
- Peripheral Nodes: Countries at the margins of the network may indicate emerging contributors or those with more specialized or isolated focuses.

This network highlights the global nature of research or initiatives in the studied field, with China playing a pivotal role and other clusters contributing regionally or thematically. It showcases how interconnected global and regional efforts are in addressing shared challenges or advancing knowledge.

Conclusion

This bibliometric review reveals that sustainable mountain development has emerged as a pivotal area of scientific inquiry, encompassing social, economic, and environmental dimensions. Although research output has grown significantly over the past two decades, gaps in geographic representation and interdisciplinary collaboration persist. The prominence of terms such as "sustainable development," "mountain region," and "climate change" reflects the importance of addressing biodiversity loss, climate adaptation, and socio-economic disparities in mountain ecosystems.

The findings underscore the critical role of mountains as biodiversity hotspots, water towers, and socio-economic hubs, with unique vulnerabilities to climate change and urbanization. However, the research reveals that underrepresented regions, particularly in Africa and South America, require greater attention to ensure a

holistic and inclusive approach to sustainable mountain development. Effective strategies must integrate cultural landscapes, traditional knowledge, and innovative technologies, backed by robust policy frameworks and community-driven initiatives.

To advance sustainable mountain development, the study recommends fostering interdisciplinary research, expanding geographic focus, enhancing policy integration, and investing in education, capacity building, and public awareness. Collaborative efforts across global, national, and local levels are essential to address the complex challenges faced by mountain communities and ecosystems, ensuring their resilience and sustainability for future generations.

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UDC 504
SCOPUS CODE 2301
https://doi.org/10.36073/1512-0996-2025-2-310-325

მდგრადობისა და მთის განვითარების თემების გაშუქება თანამედროვე სამეცნიერო ლიტერატურაში

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საკვანძო სიტყვები: მდგრადობა; მთების განვითარება; სამთო ტურიზმი; SDG.

The date of review 03.02.2024
The date of submission 27.02.2025
Signed for publishing 16.06.2025