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Review

Ecological and Environmental Effects of Land Use and Cover Changes on the Qinghai-Tibetan Plateau: A Bibliometric Review

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Abstract: The Qinghai-Tibetan Plateau (QTP), known as the "Third Pole of the Earth", contains fragile ecosystems and is sensitive to global environmental changes. With the intensification of climate change and human activities, the land cover of the QTP is changing significantly, which affects its function as an ecological security barrier. This paper searched 379 papers in the Web of Science core database, conducted a bibliometric analysis, and proposed potential future research directions to gain a macroscopic understanding of the impact of land use and cover change (LUCC) on the regional and global ecological environment of the QTP. The results are as follows. (1) The period from 1995 to 2022 witnessed an overall increase in the number of publications in this field with a high development potential. (2) Climate change, land use, China, impacts, conservation, and management were high-frequency keywords in the field; among these, climate change has received increasing research attention since 2018. (3) The field included three main research directions: the impact of LUCC on biodiversity, the impact of land degradation on ecosystems, and the impact of climate change and land use changes on ecosystem services. (4) The development and evolution of research hotspots were mainly focused on three aspects: the impact of cultivated land expansion and deforestation, the impact of land use management and conservation, and the impact of climate change and human activities on LUCC. (5) Future research should focus on improving the accuracy of land use and cover data on the QTP, assessing and preventing the ecological risks of LUCC, investigating the impacts of human activities on LUCC and the ecological environment, and exploring the interactions between climate change and human activities on the ecological environment. The findings of this paper will help researchers and stakeholders gain a rapid and comprehensive understanding of this research area and thus contribute to the sustainable development of the QTP.

Keywords: bibliometric methods; land use and cover change; ecological and environmental effects; Qinghai-Tibetan Plateau

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1. Introduction

The Qinghai-Tibetan Plateau (QTP) is known as the "roof of the world", the "Third Pole of the Earth", the "water tower of Asia", and the "global gene pool" [1]. Large glaciers, alpine grasslands, and permafrost provide it with an irreplaceable role in mitigating global warming, enabling water conservation, protecting biodiversity, and providing carbon sinks [2,3]. However, this alpine and arid environment has also led to its ecological fragility, and indeed, the area is highly vulnerable to climate change and human activities [4]. Changes to the ecosystem not only affect local surface processes, but may also affect the entire northern hemisphere and even global environmental systems on long time scales and large spatial scales.

Human activities such as urbanization [5,6], commercial logging [7], overgrazing, settlements of herders, the construction of transportation facilities [8,9], tourism [10,11], and hydropower development have intensified on the QTP [12] since the beginning of the Anthropocene epoch. These, together with the fact that the QTP has been experiencing a warming process two times greater than the global warming rate of the past decades [5], have led to drastic changes in land use and cover in the region. Since the 1990s, the urbanization rate of the QTP has risen from 21.26% to 54.95%, with an expansion of the number and size of cities and an almost threefold increase of the areas consisting of urban lands [13]. Grazing intensity has also increased year by year, and nearly 35% of the grasslands have been severely degraded to bare soils [14]. Around 300,000 km^2 of lands have been desertified [15]. Compared with the period from 1981 to 2000, the area covered by permafrost decreased by 10.1% over 2001–2018. It is predicted that another 26.9–80.1% of permafrost will be lost by the end of the 21st century [16].

Permafrost, grasslands, and wetlands are key to the global ecological benefits of the QTP, and once these land uses and covers are altered, they not only weaken the stability of their own ecosystems, but also threaten the livelihood security and community sustainability of downstream ecosystems [16–20]. Therefore, this issue has received extensive attention from scholars. A series of studies have been conducted on the effects of LUCC on climate [21], hydrology [22,23], soils [24,25], biodiversity [26,27], and biogeochemical cycles [7] on the QTP. It has been shown that rapid LUCC on the QTP have led to a reduction of water resources, increased hydrological hazards [21], land desertification [28], an increased frequency of dust storms, excessive soil erosion, and reduced biodiversity [29], with a high potential to threaten the survival and development of nearly 20 countries and 3 billion people locally and downstream [30–33].

Given the enormous ecological challenges of LUCC on the QTP, a consensus has been reached among its neighboring countries to explore a sustainable development path that combines ecological management with mountain development [2]. As the country where the main body of the QTP is located, the Chinese government has developed a series of policies for maintaining the ecological environment of the QTP. For example, it has been implementing large-scale natural forest protection, returning cultivated land to forest, grazing land to grass, soil erosion control, and wetland protection and restoration projects since the 1990s [15], and has established 155 nature reserves with an investment of 90 billion RMB in ecological restoration [34]. In 2013, together with neighboring countries, it launched the "Belt & Road" cooperation initiative to promote the green and low-carbon development of the region's economy [6]. The first national park, the Three Rivers Source National Park, was established in 2016. In 2021, China began to establish the QTP National Park Complex. These initiatives have played an important role in protecting and maintaining the originality, integrity, and stability of the QTP ecosystem [35]. In particular, the establishment of nature reserves has greatly reduced the disturbance of human activities. In fact, Hua et al. [36] found that the pressure of human activities inside the nature reserves was 60% lower than outside the nature reserves. However, ecological restoration is a long process, and human activities such as the mining of mineral resources and construction of hydroelectric facilities still exist in some nature reserves [37]. The fragmentation of wildlife habitats is also still increasing with the construction of roads and other infrastructures [38]. Indeed, the ecological risks of land use changes are predicted to remain widespread on the QTP in the future [30].

Scientific research and national strategies are often closely related and mutually reinforcing. With an emphasis on national strategies, a series of major scientific research projects have been carried out on the QTP, which is frequently perceived as a "natural laboratory" for global change [39]. In 1972, China conducted the first scientific examination of the QTP, which provided the first systematic understanding of multiple elements of the Earth system of the QTP. In 2009, the Chinese Academy of Sciences launched the International Scientific Program for the Third Pole Environment (ISTPE) to collaborate with the international community to assess the risks posed by environmental changes. In 2013, the International

Centre for Integrated Mountain Development Research (ICIMOD) launched a project to monitor and assess the Hindu Kush–Himalayan region. In 2017, China then launched the second Qinghai–Tibet Science Research Project to acquire a better understanding of the environmental changes in water, the ecology of the QTP, and human activities on the latter over the past 50 years and their impacts on human society. In 2018, the Chinese Academy of Sciences launched a Class A strategic pioneering science and technology project known as the "Pan-Third Pole Environmental Change and Green Silk Road Construction" to conduct systematic research on environmental changes in the Pan-Third Pole region. In general, after half a century of exploration, scientific research on the QTP has increasingly focused on the impact of environmental changes on human beings. Relying on these major research projects, scholars have conducted extensive research on the QTP from different perspectives and scales, resulting in a wealth of research results.

Bibliometric analyses can help facilitate the systematic sorting of these research results. This method mainly uses mathematical methods, network analysis, and clustering algorithms to systematically review the research history of a field, classify the research hotspots and their evolution, and build a cooperative network among important countries, institutions, or authors; this allows scholars to acquire an overall grasp of a research field and quickly clarify the current research gaps, and provides insights for finding research directions and ideas [40]. At present, bibliometric analysis methods have been widely used in the construction of knowledge maps for research in the natural sciences. However, systematic combing work related to the QTP is still relatively lacking, and only a few studies providing this are available in the literature. For example, Liu et al. [41] conducted a systematic review of 4315 papers in the field of ecological research on the QTP and found that the research hotspots were focused on ecosystem services, biodiversity, and ecological adaptation, among others. Chen et al. [1] performed a traditional literature review to systematically summarize the progress of the Holocene climate and surface reconstructions on the QTP, suggesting potential future research directions for studying the Holocene evolution of the climate and environment on the QTP.

Land use and cover changes are an important factor threatening the stability of the QTP ecosystem and a comprehensive, macroscopic knowledge map of the ecological and environmental effects of land use changes on the QTP has not yet been constructed. Therefore, this study conducted a comprehensive analysis of 379 papers related to the ecological and environmental effects of land use changes on the QTP based on the Web of Science core set database with the aid of the Bibliometrix and Biblioshiny packages in R tools. This study aimed to address the following questions:

(1) What are the publication trends and major publishing journals in this field?

(2) What are the main researchers, research institutions, and countries involved in the research field, and what are their collaborative networks?

(3) What are the most influential authors, journals, and articles?

(4) What are the research hotspots and themes, and how have they developed and evolved?

(5) What are the future directions of research in this field?

2. Research Methodology

2.1. Research Design and Methodology

The bibliometric approach is considered to be an effective method for quickly acquiring and studying published information [41]. Bibliometric methods were incorporated into this study to construct a systematic knowledge map based on the Web of Science core database to comprehensively organize relevant studies in the field of the ecological effects of LUCC on the QTP. The study design referred to the general steps of bibliometrics, specifically divided into three steps of data collection and cleaning, data analysis and visualization, and interpretation (Figure 1).

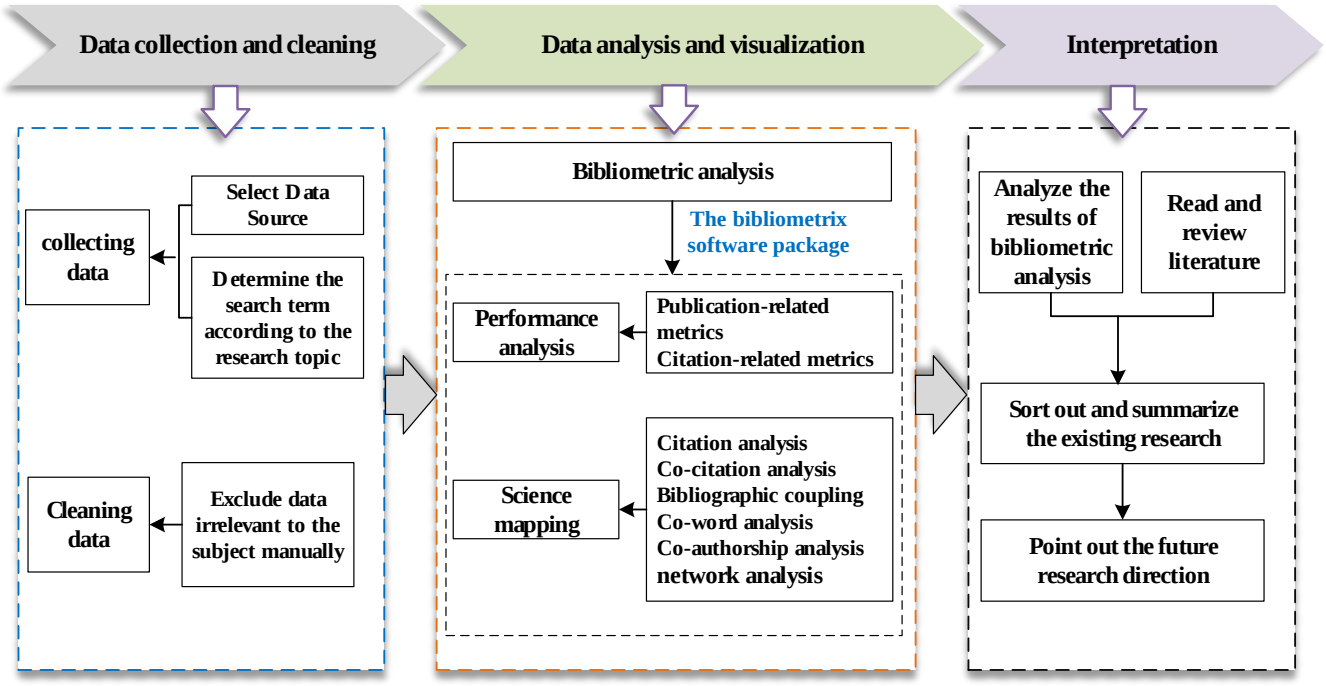

Figure 1. Research design and workflow.

Step 1 consisted of data collection and cleaning, which will be described in detail in Section 2.2.

Step 2 involved the data analysis and visualization. This was achieved with the help of the Bibliometrix and Biblioshiny software packages. Bibliometrix enables a comprehensive analysis and visualization of the literature, compensating for the shortcomings of earlier tools such as BibExcel and CiteSpace that can only perform certain steps of bibliometric analysis. Moreover, the former is an open-source package written in R language, thereby allowing the creation of shared development and the flexibility to integrate with other statistical and graphical packages [42]. The use of Bibliometrix allowed us to describe the current state of research in the field in terms of the annual literature, research power (countries, authors, journals), and research themes.

Step 3 comprised the interpretation. Although the development of bibliometric software has significantly advanced bibliometric studies, it cannot replace the reading of the literature. On the basis of bibliometric results, the retrieved papers were further reviewed. Then, the deficiencies of existing research in this field were summarized and the future development direction was predicted, which will help maximize the key reference role of bibliometrics.

2.2. Data Collection and Cleaning

The data collected in this paper were obtained from the Science Citation Index Expanded and Social Science Citation Index databases in the Web of Science core dataset, which is considered to contain the most comprehensive and influential journals. The data were obtained in September 2022. The database was used to search for papers relating to the ecological and environmental effects of LUCC on the QTP from 1990 to 2022. The data were directly exported from the Web of Science website in a BibTex format and included detailed information such as the DOI, authors, title, year and month of publication, journal, author's contact information, abstract, and references of the literature. The BibTex files were converted into an Excel format in the bibliometric software package to facilitate the data cleaning.

The data collection and cleaning consisted of three steps (Figure 2): the first step was the preparation phase, which focused on identifying the search terms and searching the

database according to the research topic. Considering that this paper intended to study the ecological and environmental effects of LUCC on the QTP, three keywords were considered: (1) land use and cover change, (2) Qinghai Tibet Plateau, and (3) ecological environment impact. Then, relevant research papers in the field were consulted and all of the keywords related to the above three aspects were listed. Finally, after our repeated discussion, experimental search, and consultation with experts in the field, we determined the search terms. The second step consisted of the data processing. Considering the complexity and accuracy of the search, the composite search method was used for the data retrieval, and the search terms identified in the first step were divided into three search formulas: (1) TS = (qinghai-tibet) OR TS = (himalaya) OR TS = (Tibet) OR TS = (qomolangma) OR TS = (mteverest) OR TS = (qinghai) OR TS = (karakorum) OR TS = (kunlun) OR TS = (qilian) OR TS = (hengduan) OR TS = (muztagata) OR TS = (tanggula) OR TS = (qiang-tang) OR TS = (yarlung zangbo) OR TS = (qaidam) OR TS = (pamir) OR TS = (gangdise) OR TS = (gangdese) OR TS = (three river source); (2) TS = (land cover change) OR TS = (land use change) OR TS = (land landscape change); and (3) TS = (environmental impacts) OR TS = (environmental effects) OR TS = (ecosystem impacts) OR TS = (ecosystem change). Then, the intersection of the search results of (1), (2), and (3) was taken as the preliminary search result, and a total of 837 datasets were obtained. The third step involved the data cleaning. A manual screening was performed based on the titles and abstracts with the aim of removing titles that were not relevant to the study content and study area. A total of 458 irrelevant datasets were eliminated and 379 were considered in this paper.

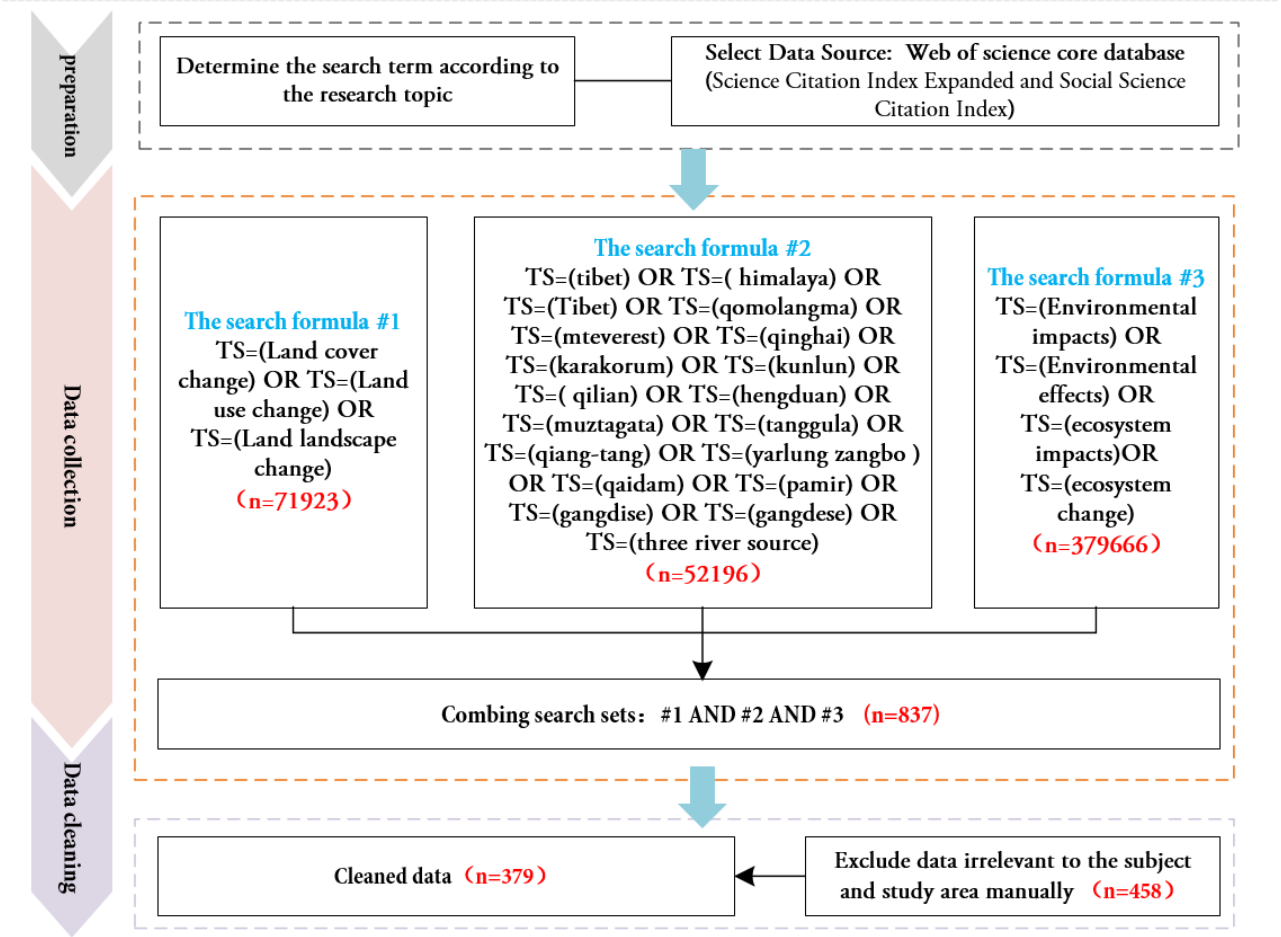

Figure 2. Data collection flow diagram.

2.3. Data Analysis and Visualization

The cleaned data were analyzed and visualized using the Bibliometrix and Biblioshiny software packages, providing the readers with a better understanding of the research status in this field. The data analysis and visualization in this study involved five aspects: the analysis of the number of papers and journals published; the analysis of major researchers, countries, and institutions; the analysis of cited papers; keyword analysis; and the analysis of the evolution of research hotspots. Among them, the number of papers published and the analysis of published journals were good indicators of whether there was research potential in the field through the annual trend of published papers and understand the main published journals. The analysis of the main researchers, countries, and institutions allowed us to identify the main researchers and research teams in this field and draw up the cooperation networks of researchers and research institutions through network analysis. The analysis of the cited papers helped screen out highly cited papers and draw cited networks, as well as enabling us to quickly find the most influential papers among numerous research papers. The keywords were also analyzed to count the keywords of the papers included in the database and to better understand the main research directions in the field through clustering analysis. The analysis of the evolution of research hotspots was finally useful to explore the evolution path of research hotspots by dividing the research field into time periods, so as to provide inspiration for future research directions.

The R language, Excel, and the Tableau software were used in addition to the Bibliometrix and Biblioshiny software packages to draw charts and for better visualization.

3. Results

3.1. Analysis of the Number of Articles Issued and the Publishing Journal

3.1.1. Annual Trends in the Number of Publications

From 1995 to 2022, the number of publications considering the ecological and environmental effects of LUCC on the QTP showed an overall fluctuating growth trend (Figure 3), with an annual growth rate of 17.45% and a large research potential. In this paper, the research was divided into three phases according to the number of papers published: 1995–2007, 2008–2017, and 2018–2022. Among them, 1995–2007 was the budding development stage, with very few publications and an average annual publication volume of less than three. Scholars have mainly focused on the environmental impacts of expanding croplands and deforestation. From 2008 to 2017, the number of publications increased significantly compared with the previous period, which was related to the "International Scientific Program on the Third Pole Environment" initiated by the Chinese Academy of Sciences in 2009. The research during this period focused mainly on the impact of land uses (including land use changes and land management) on the ecological environment. The period covering 2018–2022 was the rapid development phase, with an average annual number of 48 articles. Research during these years focused on the interactive effects of climate change and human activities on LUCC.

3.1.2. Analysis of Publishing Journals

From 1995 to 2022, the journals with more publications relating to the effects of LUCC on the QTP belonged to the fields of ecology and the environment. The top three journals in terms of the number of articles were *Sustainability* (22), *Remote Sensing* (20), and *Ecological Indicators* (16) (Table 1). Among the journals, four, namely, *Sustainability*, *Remote Sensing*, *Ecological Indicators*, and *Science of the Total Environment*, have a higher h-index, which indicates that these journals are more influential in the field.

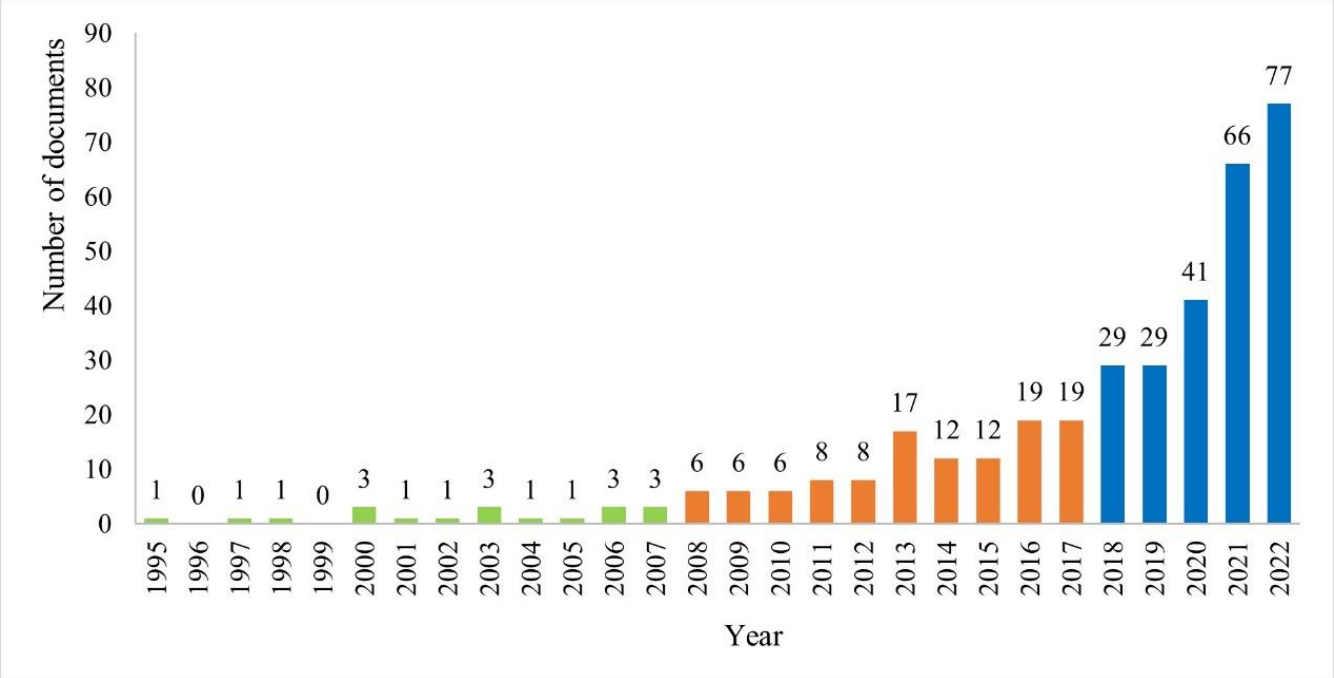

Figure 3. Annual number of documents considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP) from 1995 to 2022.

Table 1. Number of papers issued by the top ten journals and corresponding h-indices considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP) from 1995 to 2022.

Journals	*Articles*	*h-Index*
Sustainability	22	8
Remote Sensing	20	8
Ecological Indicators	16	10
Journal of Mountain Science	13	6
Science of the Total Environment	13	9
Journal of Environmental Management	11	5
Land Degradation & Development	11	5
Catena	10	6
Environmental Monitoring and Assessment	10	5
Journal of Geographical Sciences	8	4

Note: the h-index is a quantitative index used to characterize the number and level of academic outputs, which was proposed by American physicist Jorge E. Hirsch in 2005; the higher the value, the greater the impact of the journal in the field.

A trend analysis of the top five journals in terms of the number of articles (Figure 4) showed that the *Journal of Mountain Science* had paid the most attention to this field and showed a steady increase in the number of related articles since 2008. Although *Sustainability*, *Ecological Indicators*, *Remote Sensing*, and *Science of the Total Environment* started later, the number of articles published was growing faster. Indeed, 22, 20, and 16 articles were published in 2022 by *Sustainability*, *Remote Sensing*, and *Ecological Indicators*, respectively.

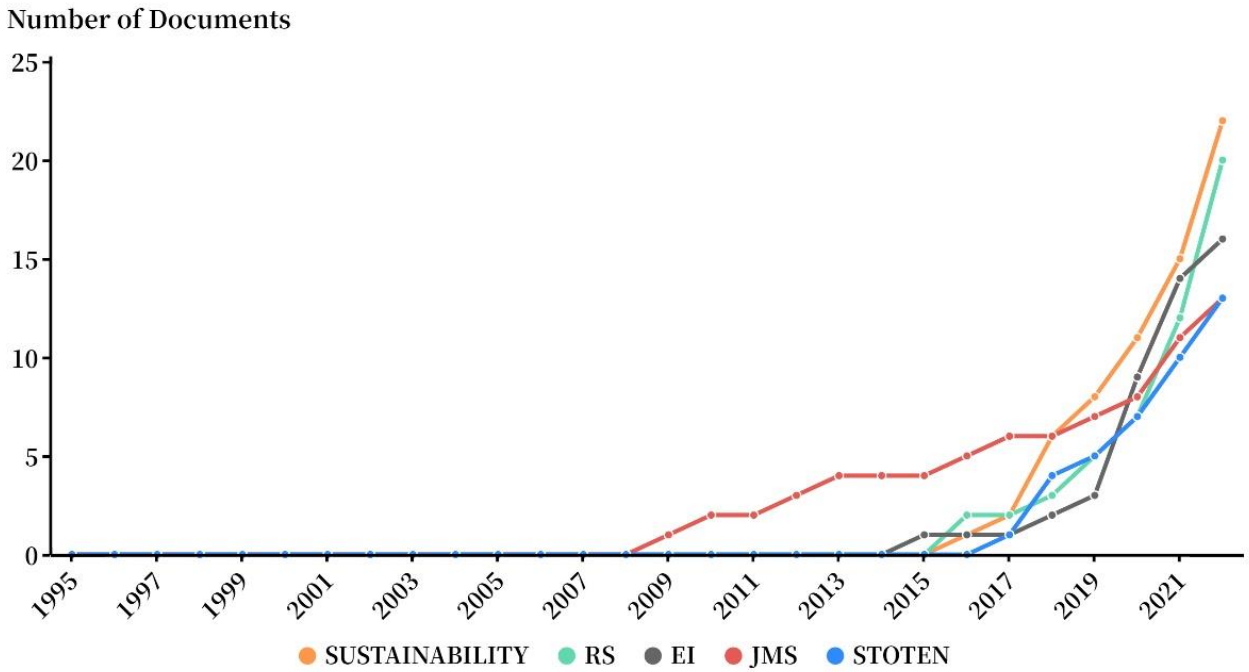

Figure 4. Affiliations' production over time for investigating the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP). Note: RS = *Remote Sensing*, EI = *Ecological Indicators*, JMS = *Journal of Mountain Science*, STOTEN = *Science of the Total Environment*, JEM = *Journal of Environmental Management*.

3.2. Analysis of Key Researchers, Institutions, and Countries

3.2.1. Analysis of Key Researchers

There are a total of 1749 researchers involved in the studied field, and 56 authors have published more than three papers on the topic. There are also 1548 authors who have published only one paper in the field, accounting for 88.5% of the total number. This implies that relatively few experts have paid attention to the field over a long time.

According to the contribution rate of publications in this field, the top ten scholars with the most influence in this field were Zhang Yili, Dai Erfu, Dong Shikui, Yin Le, Li Shicheng, Liu Linshan, Liu Shiliang, Wang Genxu, Wang Yahui, and Wu Tonghua (Figure 5). The author with most publications was Zhang Yili from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences, with eight articles, including three articles with high citation rate published in 2021. Zhang Yili is an influential academic who has been studying LUCC on the QTP for a long time, having been involved in the Second Qinghai–Tibet Scientific Research Project and the LUCC theme of the Pan-Third Pole Environmental Change and Green Silk Road Construction. Liu Linshan, Liu Shiliang, Wu Tonghua, and Wu Xiaodong have all published six articles each. Among them, Liu Linshan is the main collaborator of Zhang Yili. In turn, Liu Shiliang focuses on the impact of grassland degradation and cropland evolution on the ecological environment of the QTP. Wu Tonghua and Wu Xiaodong collaborate closely and focus on the impact of permafrost melting on the ecological environment. Dai Erfu and Wang Yahui studied the impact of LUCC on ecosystem services in the Hengduan Mountains from 2018 to 2021, which resulted in highly cited publications.

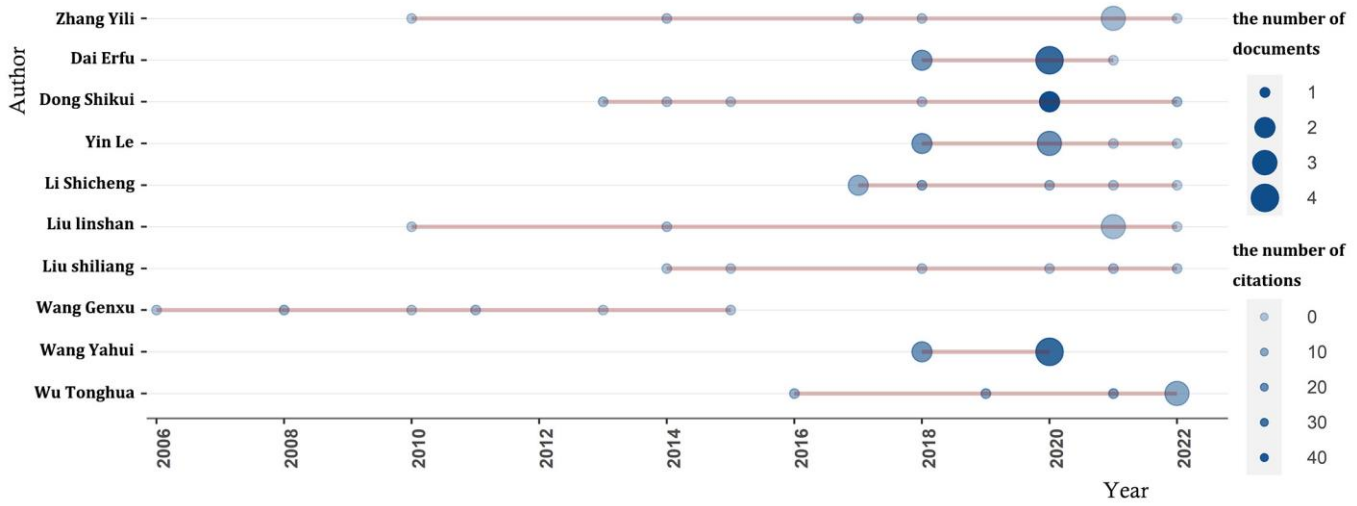

Figure 5. Authors' production over time on the topic of the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP). Note: the size of the circle represents the number of documents, and the shade of the color represents the number of citations.

A total of 11 author clusters were formed in the studied field, each with different research directions and research focuses (Figure 6). Among them, Zhang Yili, Li Shicheng, Liu Linshan, and Wang Zhaofeng from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences formed the most influential and longest-standing research team in this field. Their research has covered remote sensing interpretations of land use and cover data, the analysis of LUCC patterns, assessments of LUCC impacts on the ecological environment, and the impact of human activities on the QTP. The author cluster consisting of Dai Erfu, Wang Yahui, and Yin Le, also from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences, has mainly focused on the impact of LUCC on ecosystem services in the Hengduan Mountains, located on the southeastern edge of the QTP. A cluster of authors comprising Dong Shikui and Liu Shiliang from the Beijing Normal University has also focused on the ecological impacts of grassland degradation on the QTP, while the cluster with Wu Tonghua and Wu Xiaodong from the Northwest Institute of Eco-Environment and Resources of the Chinese Academy of Sciences has concentrated on the ecological impacts of permafrost melting on the QTP.

3.2.2. Analysis of Major Research Institutions

The research institutions in this field were mainly units related to the Chinese Academy of Sciences (CAS) system, which have shown the status and trend of mutual cooperation and formed a preliminary cooperation network with the Institute of Geographic Sciences and Natural Resources Research as the core (Figure 7). The main research institutions in the CAS system are the Institute of Geographic Sciences and Natural Resources Research, the University of Chinese Academy of Sciences, and the Northwest Institute of Eco-Environment and Resources, with 96, 84, and 45 publications, respectively. In addition, researchers from the Beijing Normal University and Lanzhou University have also been paying attention to this field for a long time, with 51 and 79 publications, respectively. Moreover, Lanzhou University has been publishing in this field since 2003 and is the first institution to have conducted research on the topic; the Beijing Normal University has been publishing in this field since 2009, and the number of publications has increased rapidly over the past three years, with an average of 16 publications per year.

Figure 6. Co-authorship network map of researchers having considered the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

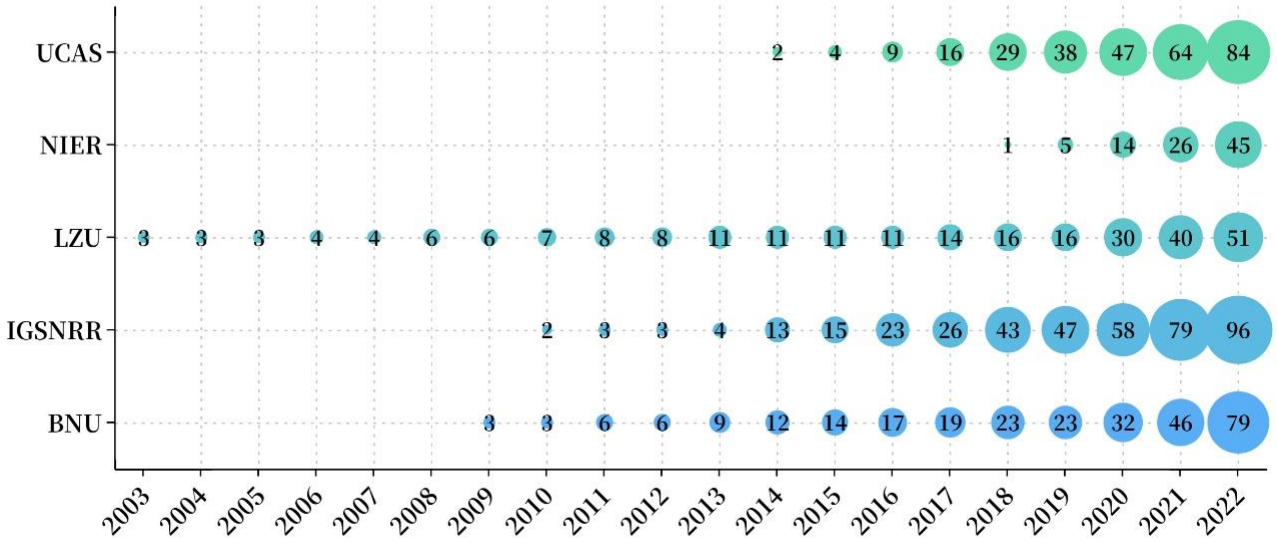

Figure 7. Annual cumulative number of documents issued by the top five institutions in the field of studying the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP). Note: UCAS = University of Chinese Academy of Sciences, NIER = Northwest Institute of Eco-Environment and Resources, IGSNRR = Institute of Geographic Sciences and Natural Resources Research, BNU = Beijing Normal University, LZU = Lanzhou University.

3.2.3. Analysis of the Distribution Characteristics of the Main Research Countries/Regions

China, India, USA, Nepal, UK, and Germany were the main countries studying the ecological and environmental effects of LUCC on the QTP (Figure 8). In terms of the number of articles published by each country, China had by far published the most with 1143 articles and garnered 5534 citations. India and the USA followed with 243 and 98 articles, respectively. Nepal, UK, and Germany had published 34, 30, and 24 articles, respectively. According to the annual trend of the number of publications in each country, the UK was the first country to conduct research in this field, publishing the first article as early as 1995; the number of publications then increased year by year, with an average annual growth rate of 18.96% and 573 citations from 1995 to 2022. India started publishing in 1997, and the number of articles published has been increasing steadily year by year, with an average annual growth rate of 23.26% and 1438 citations amassed from 1997 to 2022. Although China was a little late in publishing, having published its first article in an international academic journal in 2003, the publication growth rate has been rapid, with an average annual growth rate of 35.2% from 2003 to 2022. Nepal and the USA have also shown a steady growth trend in this field, with average annual growth rates of 18.17% and 23.44% from 1995 to 2022, respectively.

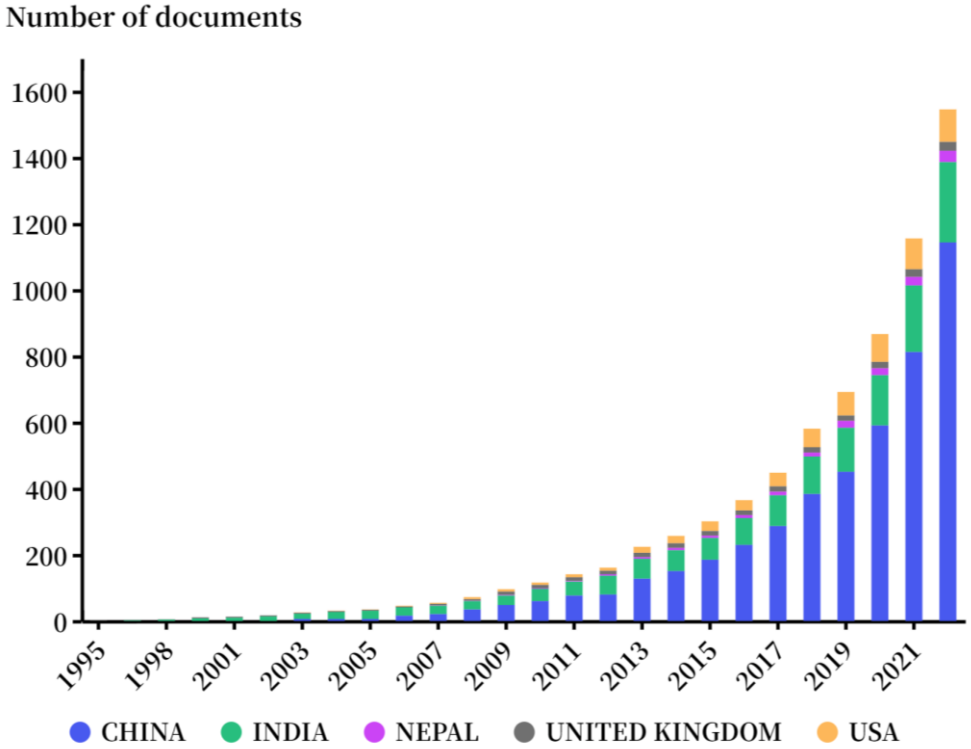

Figure 8. Gradual growth trend of the number of documents issued by the top three countries publishing about the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

3.3. Analysis of Cited Papers

3.3.1. Analysis of Highly Cited Papers

The papers with the highest numbers of local citations were mainly published between 2008 and 2016 (Table 2). The most locally cited paper was published by Li et al. [43] in *Land Degradation & Development*, which found that the patterns of LUCC in the Qinghai Lake basin mainly consisted of conversions of forests to grassland, grassland to cropland, and water bodies to sandy lands, potentially leading to a decline in the lake water level and grassland degradation. The second most locally cited paper was published by Pandit [29] in *Conservation Biology*, which predicted the effects of a planned dam construction on terrestrial ecosystems in the Indian Himalayan basin; the author showed that most dams were located

in species-rich areas and that deforestation due to dam construction could lead to the extinction of 22 angiosperm and seven vertebrate taxa. The third most locally cited local was published in the journal *Biological Conservation* by Brandt [44], which reconstructed the alpine land cover in northwest Yunnan from 1950 to 2009 and showed that at least 39% of alpine meadows were converted to shrublands between 1990 and 2009, potentially threatening endemic grassland biodiversity and people's livelihoods.

Table 2. Top ten local citation scores (LCS) of publications considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

Reference	DOI	Year	Local Citations (LC)	Global Citations (GC)	LC/GC Ratio (%)
[43]	10.1002/ldr.885	2009	9	101	8.91
[29]	10.1111/j.1523–1739.2012.01918.x	2012	8	78	10.26
[44]	10.1016/j.biocon.2012.07.026	2013	8	116	6.90
[45]	10.1016/j.ecoser.2020.101146	2020	8	49	16.33
[46]	10.1007/s00376–008-1029-x	2008	7	32	21.88
[11]	10.1093/biosci/biu152	2014	5	54	9.26
[47]	10.1016/j.scitotenv.2020.137910	2020	5	37	13.51
[25]	10.1016/j.jhydrol.2012.11.058	2013	4	65	6.15
[48]	10.1007/s10661–016-5190-x	2016	4	40	10.00
[49]	10.1007/s11269–011-9825-y	2012	3	36	8.33

Note: the local citations indicate the number of citations by papers in the database of this paper and the global citations indicate the number of citations by all papers.

3.3.2. Analysis of Global Highly Cited Papers

The papers with a high number of global citations were mainly published between 2009 and 2016 (Table 3). The most globally cited paper was published by Xu et al. [17] as a review in *Conservation Biology*, and found that the number of Himalayan glaciers was rapidly decreasing in the context of climate change, thereby affecting local water bodies, biodiversity, and ecosystem boundaries, and increasing uncertainties regarding the water supply of the population and agricultural production in Asia. The second most globally cited paper was published by Chen et al. [7] as a review in *Global Change Biology*; the authors showed that human activities (e.g., grazing, land cover changes) would further alter biogeochemical cycles and that there was a need to improve the predictive accuracy of the effects of climate change and human activities on biogeochemical cycles. The third most globally cited paper was published by Chen et al. [50] in *Agricultural and Forest Meteorology*, and revealed that the impact of human activities on the net primary first productivity of alpine grassland ecosystems had increased significantly from 2000 to 2010.

Table 3. Top ten global citation scores (GCS) of publications considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

Reference	DOI	Year	Total Citations	TC per Year
[17]	10.1111/j.1523-1739.2009.01237.x	2009	527	37.64
[7]	10.1111/gcb.12277	2013	440	44.00
[50]	10.1016/j.agrformet.2014.01.002	2014	346	38.44
[51]	10.1016/j.envsci.2014.01.010	2014	258	28.67
[52]	10.1007/s10584-009-9556-8	2009	254	18.14
[53]	10.1016/j.ecolmodel.2005.07.005	2006	169	9.94
[54]	10.3390/rs8100876	2016	141	20.14
[55]	10.1016/j.ecoinf.2016.03.006	2016	131	18.71
[56]	10.1016/j.geoderma.2007.10.023	2008	127	8.47
[57]	10.1016/S0167-8809(00)00274-7	2001	125	5.68

3.3.3. Analysis of Cited Networks

A total of 15 nodal literatures were extracted in the Biblioshiny package, which were considered to represent seminal research results in the studied field and basically constituted four co-citation networks (Figure 9). Among these papers, Li [53] and Nandy [8] studied the ecological vulnerability of the QTP. Tiwari [49] and Mishra [58] studied the effects of LUCC on food security. Pandit [29], Brandt [44], Rather [48], and Badar [59] mainly studied the impacts of LUCC on hydrology, while Qu [60] and Yin [61] studied the response of vegetation to human activities. In addition, Tiwari had three articles selected in the cited network and Pandit had two articles selected, indicating their large influence in the field.

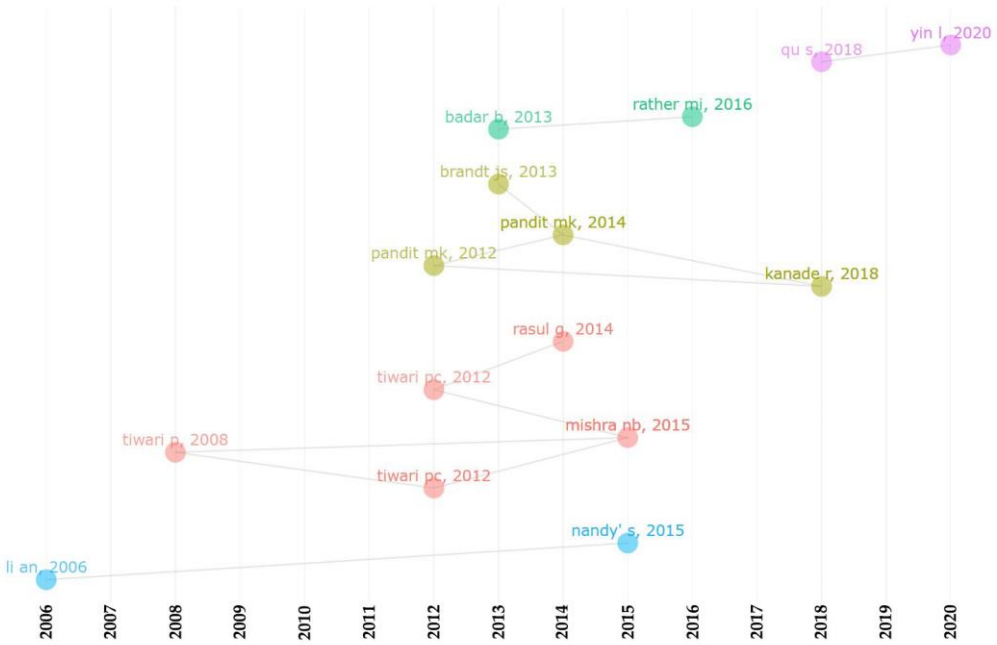

Figure 9. Historical direct citation network of top-cited papers considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

3.4. Keyword Analysis

3.4.1. Analysis of High-Frequency Keywords

High-frequency keywords are usually regarded as the research hotspots of a given field. A tree diagram was used to plot the top 35 high-frequency keywords relating to the ecological and environmental effects of LUCC on the QTP (Figure A1). The top ten keywords and their frequency of occurrence were climate change (98), land use (71), China (65), impacts (55), conservation (44), management (44), dynamics (42), land-use change (41), vegetation (41), and biodiversity (39). This indicates that LUCC dynamics, the response of LUCC to climate change, the impacts of LUCC, and adaptive management were the main points of focus of scholars in this field. As the stability of the QTP ecosystem decreases, vulnerability increases, and service functions diminish [5]; conservation is therefore the main development direction for the region. Moreover, forests play an important role in the stability of the QTP ecosystem [62], but shifting cultivation, farming along steep slopes, and mining and quarrying are still exacerbating deforestation and leading to soil erosion in mountainous areas [63]. Some studies have therefore focused on vegetation (41), NDVI (Normalized Difference Vegetation Index) (20), forests (14), and deforestation (13). In addition, scholars have also paid attention to degradation (38), ecosystem services (27), carbon (21), and NPP (Net Primary Productivity) (15). The risk of ecological degradation on the QTP has always existed under the combined influence of climate change and human activities. For example, driven by economic interests, mountain residents have converted wastelands and agricultural lands into horticultural regions, resulting in compromised soil

health and the degradation of cultivated lands [64]. These degradation phenomena can have negative impacts on ecosystem services and carbon cycling, for example, which in turn may lead to losses of biodiversity, increased water erosion, reduced carbon sequestration, decreased pastoralist productivity, and decreased local human wellbeing [65].

3.4.2. Cluster Analysis and Multiple Correspondence Analysis of High-Frequency Keywords

The combination of cluster analysis and multiple correspondence analysis of high-frequency keywords can help visualize the research directions and research themes of a given research field. Cluster analysis is mainly based on the correlation between keywords to cluster and reflect their closeness in the field, while multiple correspondence analysis considers the cluster results to reflect the similarity between keywords using a plane distance, and the closer the keywords are to the center point, the more attention they have received [66].

Here, the research directions for understanding the ecological and environmental effects of LUCC on the QTP could be divided into three groups by combining the cluster analysis of high-frequency keywords (Figure 10) and multiple correspondence analysis (Figure 11).

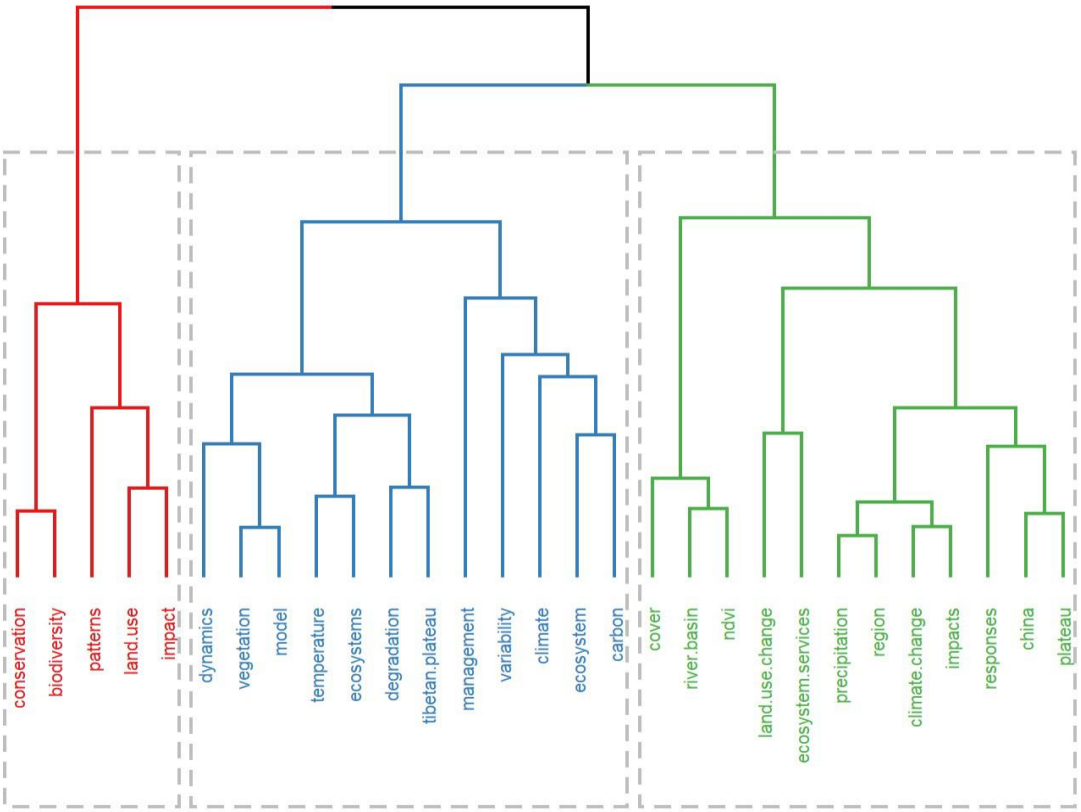

Figure 10. Hierarchical cluster analysis of keywords relating to the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

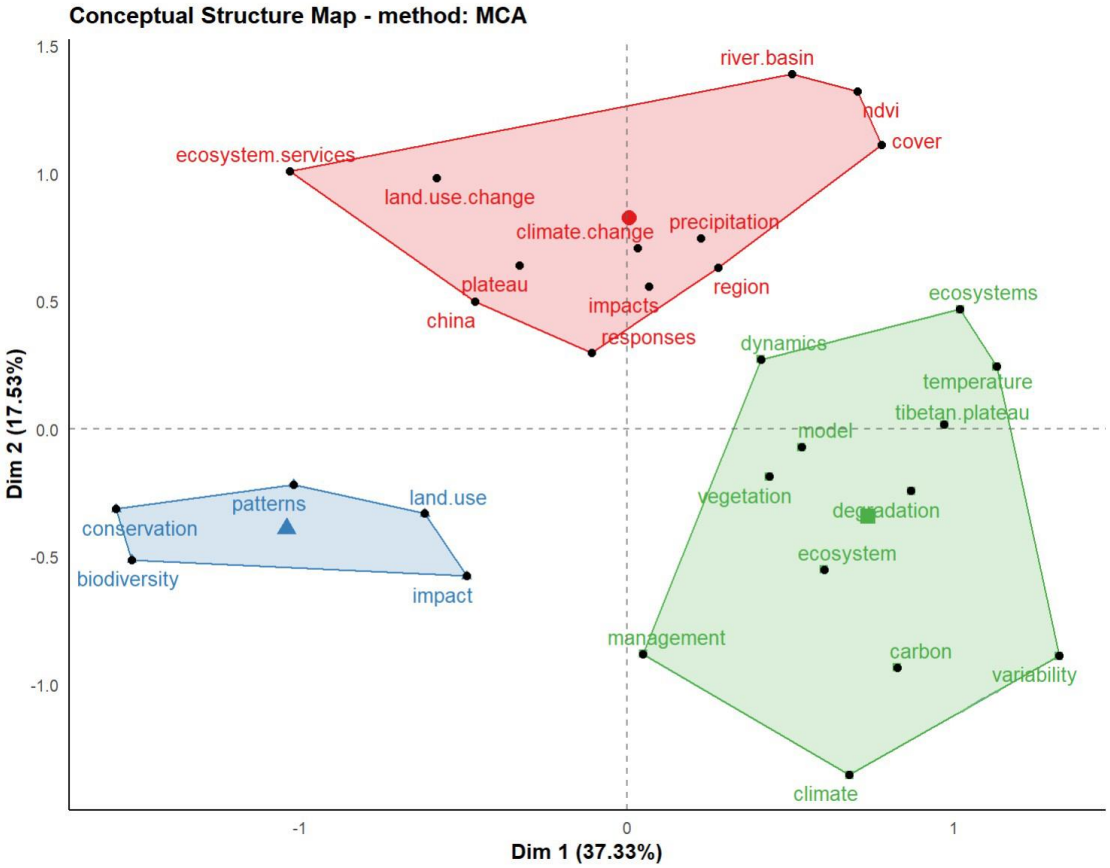

Figure 11. Multiple correspondence analysis of keywords relating to the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP).

The first research direction was concerned with the impact of LUCC on biodiversity. The QTP is one of the richest areas of biodiversity in the world and is known as the "global gene pool". However, due to climate change, LUCC, agricultural intensification, and urbanization, human activities have been expanding [67], habitat loss continuing, forest fragmentation has remained severe, the living spaces of species have changed [68], and the extinction of species has been accelerating [69]. Moreover, anthropogenic disturbances such as infrastructure development, tourism, and trade expansion have introduced invasive plant species to mountain ecosystems [70].

The second group of research directions considered the impacts of land degradation on ecosystems. Land degradation is an important aspect of LUCC. Grassland degradation [71], wetland shrinkage, and land desertification are widespread on the QTP as a result of the interaction between climate change and human activities. The available studies have shown that grassland degradation can reduce carbon and nitrogen concentrations in soils [47], while permafrost degradation may accelerate the risk of mercury release, which in turn affects human health [72]. However, management measures may be adopted to restore degraded wastelands and croplands to grasslands and woodlands and reduce land use intensity, thereby increasing the carbon and nitrogen stocks of soils [73,74].

The third research direction focused on the impacts of climate change and LUCC on ecosystem services. The QTP is an important ecological functional area that provides ecosystem services to about 1/5 of the global population. Numerous studies have attempted to quantify the ecosystem service assessment with the help of InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model and equivalence factor method [75]. Wu et al. [76] found that the value of ecosystem services on the QTP had increased significantly in the 30 years from 1990 to 2020, with grasslands contributing the most to ecosystem services. This is consistent with the findings of Jiang [45]. Qi [77] studied the dynamic

mechanisms of human activities and ecosystem services in the Qinghai Lake basin and found that carbon stocks, habitat quality, and soil erosion on the QTP showed a decreasing trend with enhanced human activities, but the nitrogen and phosphorus loads of soils increased with increased human activities.

3.5. Analysis of the Evolution of Research Hotspots

Considering the growth trend of the number of publications in this field and the large research projects concerning the QTP, the years 2007 and 2017 were used as the time nodes to analyze the thematic evolution of studies considering the ecological and environmental effects of LUCC on the QTP (Figure 12). The period from 1995 to 2007 was the nascent development stage of the field, with mainly descriptive research on cultivated lands, forests, and landscape changes on the QTP. The period from 2008 to 2017 saw the extension phase of the field, which focused on the ecological effects of LUCC and land use management. From 2018 to 2022, the field experienced a rapid development phase, largely prompted by the growing concern with global warming; the research was mainly focused on the impact of climate change on land use and ecology, with a particular focus on land degradation, risk, and organic carbon. The specific research evolutionary paths are as follows:

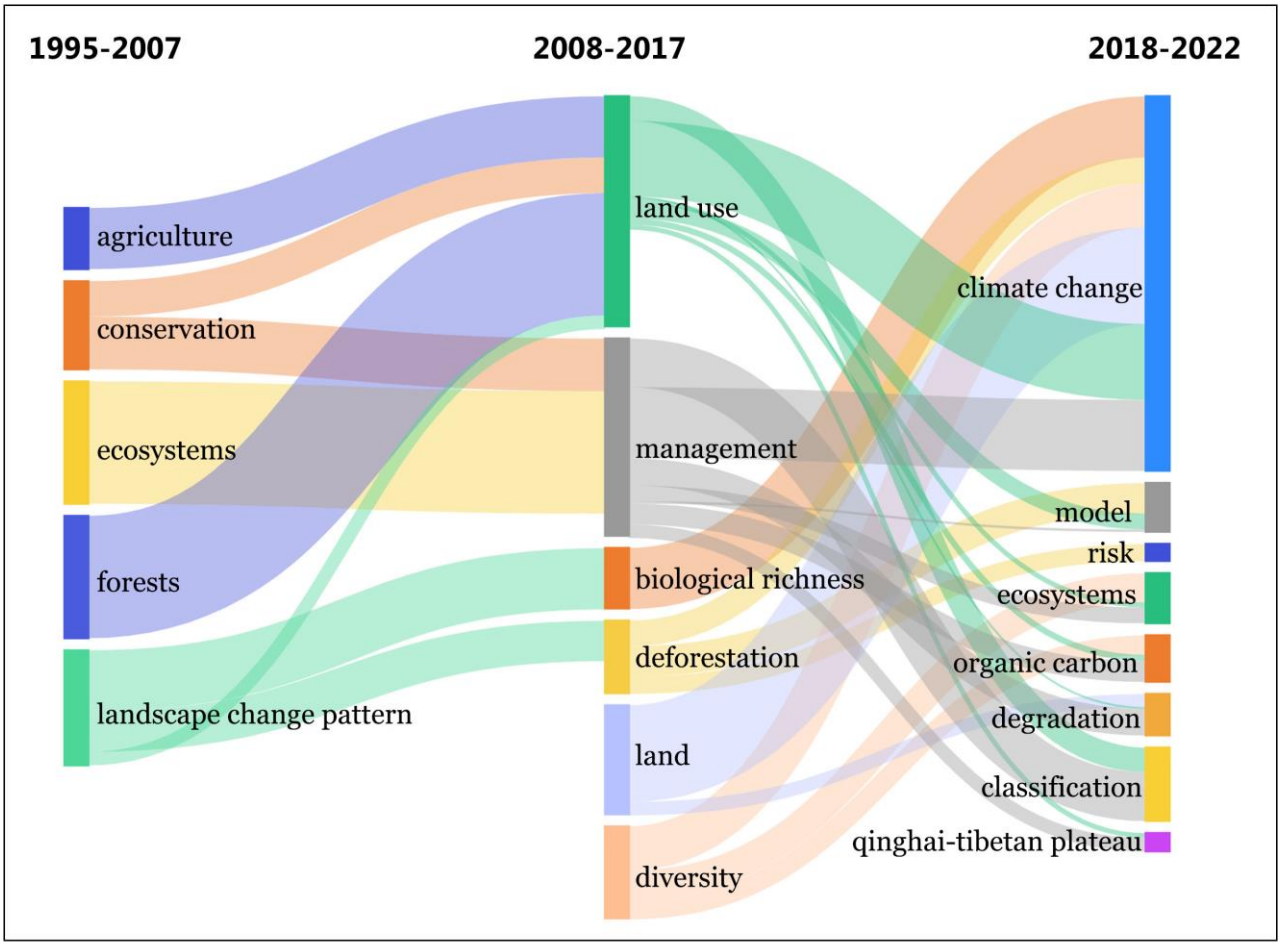

Figure 12. Thematic evolution of studies considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP) from 1995 to 2022.

(1) In terms of the impact of expanding cultivated lands and deforestation, the studied evolutionary pathways included: ① Agriculture → land use; ② forests → land use; ③ landscape change pattern → land use → climate change; ④ deforestation → risk. The QTP is ecologically fragile and economically underdeveloped, and the topographic conditions of the region limit the increase of productivity levels. As a result, irrational land

uses such as cultivation and deforestation have become increasingly common with the increase of human–land pressures and the need to improve the livelihoods of populations residing in the mountains [78,79]. Especially in the Himalayan region within India, where traditional agriculture is highly dependent on forests for livestock fodder and manure, deforestation has continued in order to maintain livestock and farmland soil fertility [80], leading to significant forest fragmentation [3], increased soil erosion [52], losses of soil organic carbon [81], reduced forest biodiversity, and weakened forest ecosystem services, further affecting the sustainability of mountain agriculture [82]. Moreover, large-scale deforestation or forest degradation is also a common problem in Pakistan [78], while in Bhutan, deforestation is being carried out due to infrastructure development, resulting in the browning of the Himalayas [83].

(2) In terms of land use management and conservation impacts, the studied evolutionary pathways included: ① conservation → management → classification; ② ecosystems → management → climate-change; ③ ecosystems → management → degradation; ④ management → ecosystems; ⑤ management → model; ⑥ management → organic-carbon; ⑦ conservation → land use. The QTP represents an ecological security barrier in Asia and the northern hemisphere. As the ecological degradation problem has become increasingly more serious, a series of ecosystem conservation and management policies have been implemented by China. In the Three Rivers Source region of the QTP, overgrazing and the excessive use of yak dung as fuel have led to the serious degradation of ecological services and functions in the high mountain grasslands. The government has slowed down or reversed grassland degradation by implementing ecological migration and clean energy policies [84], and the ecological services and functions of alpine grasslands have been effectively improved [85]. In the Hengduan Mountains, the implementation of the policy of returning farmlands to forests has promoted the transformation of cultivated lands into woodland and grassland, resulting in a significant increase in ecosystem services in the region from 2000 to 2010 [86]. On the other hand, irrational land use management activities have also caused many negative impacts on the environment. For example, the implementation of intensive agriculture and extensive cash crop cultivation in order to increase farmers' livelihoods has improved household income, but at the cost of forest degradation, reduced livestock productivity, and the loss of agricultural diversity [87].

(3) In terms of the impact of climate change and human activities on land use changes, the studied evolutionary pathways included: ① landscape change pattern → biological richness → climate change; ② landscape change pattern → deforestation → climate change; ③ landscape change pattern → land use → degradation; ④ diversity → climate change; ⑤ diversity → ecosystems; ⑥ diversity → organic carbon; ⑦ landscape change pattern → land use → organic carbon; ⑧ landscape change pattern → land use → ecosystems. The two main causes of LUCC are climate change and human activities. The warming trend on the QTP directly affects the melting of permafrost and snow cover [88,89]. Continued climate change in the future will also continue to exacerbate land use changes [90] and have significant cascading effects on river flows, groundwater recharge, natural hazards, and biodiversity, which in turn will affect the composition, structure, and function of the ecosystem as well as human livelihoods [17]. The impact of human activities on LUCC is mainly reflected in tourism, dam construction, agriculture, urbanization, and anthropogenic ecological restoration [91]. However, one region will often be affected by both human activities and climate change, and it can be difficult to completely separate the effects of the two and assess how much human activities and climate change affect LUCC or ecosystems, respectively. Studies have been conducted to tackle this uncertainty [92]. For example, Chen [50] stripped out the influence of climate change and anthropogenic activities on the actual alpine grassland NPP (Net Primary Productivity) changes and found that the impact of human activities on the alpine grassland ecosystem had significantly intensified between 2001 and 2010 compared with the period from 1982 to 2001.

4. Discussion

4.1. Future Research Directions for Understanding the Ecological and Environmental Effects of LUCC on the QTP

The bibliometric analysis conducted here suggests that the study of the ecological and environmental effects of LUCC on the QTP will remain an important topic of future research. Future research should focus on the following aspects:

(1) Improving the accuracy of land use and cover data on the QTP.

Land use and cover data are the prerequisite for studying the ecological and environmental effects of LUCC on the QTP. However, the accuracy of existing LUCC data is relatively poor because of the vast area covered, complex natural environment, and various types of land use and cover on the QTP, which make ground verifications difficult. Moreover, the academic community has not yet formed a land use classification system with plateau characteristics, which further restricts the scientific research in the area. In the future, the accuracy of land use and cover data should be improved in terms of data sources and field verification by using various remote sensing images, unmanned aerial vehicles, and large-scale field trips to further refine land use and cover classification, especially the grasslands, woodlands, and water bodies of the QTP. Considering the difficulty of this work as well as the role of foundations for the research, research institutions in neighboring countries should strengthen their cooperation for scientific investigations and data interpretation.

(2) Assessment and early warning of the ecological risks of LUCC on the QTP.

The ecological environment of the QTP is fragile, extremely sensitive to global changes and human activities, and difficult to recover naturally once damaged. In recent years, climate change and human activities have intensified, and the serious degradation of grasslands, extreme weather, and natural disasters on the QTP have increased the possibility of ecological risks. However, only a few studies have provided assessments and early warnings of the ecological risks of LUCC on the QTP. In the future, the impact of LUCC on the structure and function of ecosystems, including water, carbon, human health, and downstream communities, should be comprehensively assessed from an interdisciplinary perspective to facilitate timely warnings of risk.

(3) Tapping the impact of human activities on LUCC and the ecological environment on the QTP.

The intensity of human activities on the QTP has increased significantly in the last 20 years, having both positive and negative consequences for the region. Various ecological restoration activities carried out by humans, such as the establishment of nature conservation, are usually considered to have a positive effect on the ecological environment. However, influenced by the trade-off–synergistic effects of ecological restoration goals and ecosystem services, such forced human interventions may lead to an increase in one type of ecosystem service, but at the same time threaten others. In addition, the QTP is increasingly becoming a tourist destination due to its beautiful scenery, and the downstream energy demand has therefore led to the need to build large hydroelectric power plants there. Mining activities in the Qaidam Basin are also ongoing. The ecological impacts of these human activities, if further developed, should also be considered in future studies.

(4) Exploring the interaction of climate change and LUCC on the ecology of the QTP.

There are complex interactions between climate change and LUCC that together drive global environmental change. Climate change leads to changes in land use and cover, and LUCC exacerbate the rise of atmospheric temperatures [93]. During this complex process, changes in glaciers, permafrost, lakes, wetlands, grasslands, and deserts will not only produce regional disasters and affect the region's economic development, but also affect the ecological environment and the functional utility of the ecological security barrier of the QTP at a larger scale. Therefore, the mechanism and consequences of climate change and LUCC on the ecological environment of the QTP should be studied in depth in the future.

4.2. Advantages and Uncertainties

This study reviewed and analyzed the available publications on the environmental effects of land use changes on the QTP by means of information technology. This study had three advantages. First, it used the R language to automatically search, select, and analyze publications, but it was not limited to automatically collecting information. Manual checks were also conducted, which ensured the quality of the original data. The quality of the original data determined the accuracy of the research results. Second, this paper actively used graphical methods to describe the research results, which could gather the interest of academics, environmental practitioners, policy makers, and ordinary audiences intuitively. Third, this paper described the research methods in detail, which could also be directly applied to other fields.

However, this paper also had some limitations in that the keywords used in the data retrieval may have had a certain impact on the research results. In order to avoid this problem, the authors repeatedly discussed and tested the keyword selection, referred to published papers, and consulted experts in relevant fields to ensure the reliability of the research results. However, it could not be guaranteed that no omission was made during the data retrieval. This is indeed a common problem of bibliometric methods.

5. Conclusions

With the intensification of global environment changes, the ecological and environmental effects of LUCC on the QTP are a current research hotspot, attracting the attention of government decision makers, scientific institutions, and scholars. In this study, 379 papers related to this field were retrieved from the Web of Science core database, and an econometric analysis of these was conducted using the Bibliometrix and Biblioshiny software packages. The trends of publications in the field and the main publishing journals were clarified and the most influential authors, journals, and articles were identified. The main researchers, research institutions, and national collaboration networks were then visualized. The evolution of the research hotspots and themes was analyzed and the future research directions were discussed.

The number of publications in this field has been increasing since 1995 and the growth trend could be divided into three phases: the 1995–2007 period represented the nascent development phase, 2008–2017 the expansion and promotion phase, and 2018–2022 the rapid development phase. *Sustainability*, *Remote Sensing*, and *Ecological Indicators* were the top three journals in the field in terms of the number of articles published. The high-frequency keywords in this field included climate change, land use, China, impacts, conservation, and management; climate change has been receiving increasing attention as time has gone by. The three main research directions in this field included the impacts of LUCC on biodiversity, the impacts of land degradation on ecosystems, and the impacts of climate change and LUCC on ecosystem services. The evolution of the research hotspots focused on three main aspects: the impact of cultivated land expansion and deforestation, the impact of land use management and conservation, and the impact of climate change and human activities on LUCC. Future research should focus on improving the accuracy of land use and cover data on the QTP, assessing and providing warnings of the ecological risks associated with LUCC, exploring the impacts of human activities on LUCC and the ecological environment, and exploring the interactions between climate change and human activities and their effects on the ecological environment.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

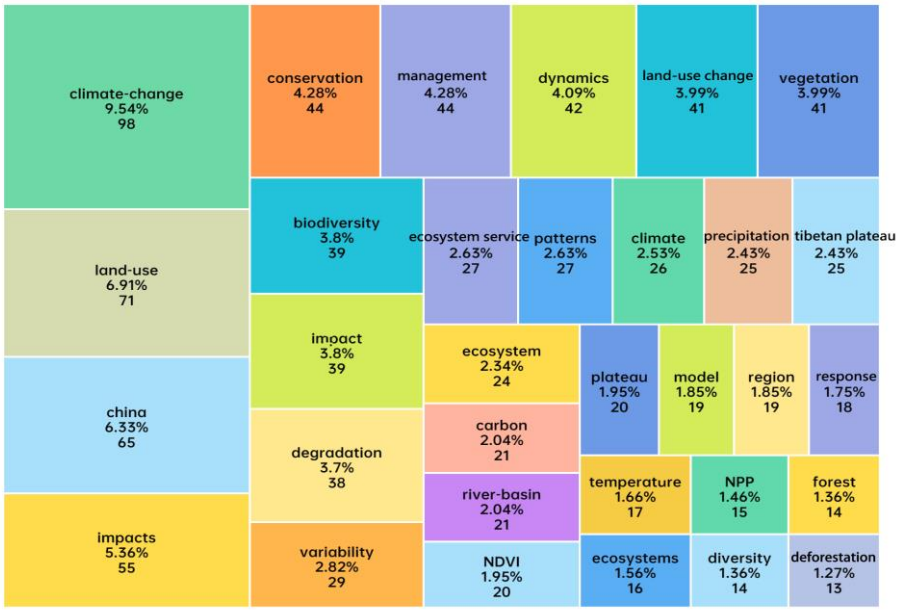

Figure A1. High-frequency keywords and their occurrence frequency in studies considering the ecological and environmental effects of land use and cover changes (LUCC) on the Qinghai-Tibetan Plateau (QTP). Note: NDVI = Normalized Difference Vegetation Index, NPP = Net Primary Productivity.

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