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EDITED BY
Rui Zhao,
Southwest Jiaotong University, China

REVIEWED BY
Andreea Nita,
University of Bucharest, Romania
Xiaojun Yu,
Gansu Agricultural University, China

*CORRESPONDENCE
Kejia De,
1162157948@qq.com

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Visual analysis of alpine meadow research trends and hotspots based on VOS viewer

Weishan Lin[1], Kejia De[1,2]*, Xijie Wei[1,2], Wei Wang[1,2], Lin Zhang[1,2], Xuemei Xiang[1,2] and Fei Li[1]

[1]College of Agriculture and Animal Husbandry, Qinghai University, Xining, China, [2]Qinghai Institute of Animal Husbandry and Veterinary Medicine, Qinghai University, Xining, China

In order to reveal the overall research progress in the field of alpine meadows. In this study, a visual clustering analysis of the literature was conducted using VOS viewer software. The English literature related to alpine meadow was searched in the Web of Science database with publication dates limited to 2020–2021, and 3,607 papers were retrieved from the Web of Science using Excel software. By analyzing the basic profiles of annual publication volume, publication country/region, publication journal, publication institution, publication author, and keywords, the hot spots and development trends of alpine meadow research were derived. The data show that China is the top global country for alpine meadow research in the world, the institution with the most publications in Chinese Acad Sci, and the most publications are by Huakun Zhou from China (81 articles); "enzymes", "climate change" and "microorganisms" are the current hot spots for alpine meadow research. This study analyzes the publication situation, research hotspots and research trends in the field of alpine meadow research to provide a reference for the academic research on alpine meadows for those related to this field.

KEYWORDS

alpine meadow, modular cluster analysis, geographical visualization analysis, Qinghai-Tibet Plateau, bibliometric method

1 Introduction

Alpine meadows are one of the most important components of terrestrial ecosystems (Wang et al., 2019). The unique "high" and "cold" natural environment of the Alpine meadows has resulted in extremely fragile alpine meadow ecosystems that are sensitive to local climate change and anthropogenic disturbances (Chen et al., 2018). Therefore, over the years, many scholars have focused on alpine meadows and conducted a lot of research on them. The research hotspots (subject terms) of alpine meadows have changed over time, showing an evolution from simple to complex and from macro to micro; all studies are centered on alpine meadows. For example, at the beginning of the research, the main focus was on vegetation biomass (Li, 1998; Li et al., 2003; Wang et al., 1995; Zhong et al., 1992) and vegetation community characteristics and soil physicochemical factors (Zhou et al., 2005; Zhang et al., 2014; Sun et al., 2016); as the research progresses, alpine meadows are more extensively studied. For example, grazing (Dong et al., 2002; Zhang et al., 2010; Zhang, 2014; Zhang et al., 2014; Li et al., 2019) soil microorganisms (Jiang et al., 2017; Zhao, 2019; Ma et al., 2020); degradation of alpine meadows (Wei and Li, 2012; Lin et al., 2013); permafrost (Yang et al., 2020; Ma et al., 2022); soil enzymes (Huang et al., 2019; Mi

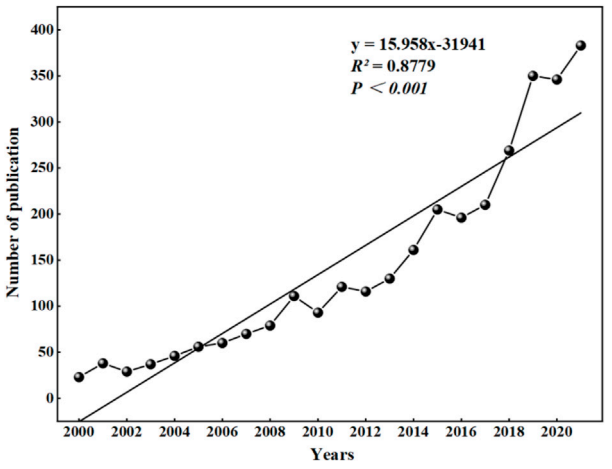

FIGURE 1
Trends in the number of articles published in the field of alpine meadow research.

et al., 2021); and climate change (Luo, 2020; Luo et al., 2021). These studies on the subject of alpine meadows have focused on specific objects, using specific methods to analyze alpine meadows at spatial and temporal scales. Using bibliometrics to analyze national, institutional, and academic articles on alpine meadow research has not been published in the database, and it is not clear which country/institution is the main force in the field of alpine meadow research and what are the scientific results in the field of alpine meadow research. Therefore, it is necessary to review, summarize and analyze the relevant literature to clarify the research progress and trends and to provide a comprehensive reference for researchers in the field of alpine meadows.

Bibliometrics is a popular interdisciplinary scientific field that analyzes literature data through mathematical and statistical methods (Broadus, 1987). Bibliometric mapping focuses on the publication itself rather than the content contained in the publication (Catillon, 2019; Zhong et al., 2019). It analyzes and assesses the quality and interest of research and represents the current status and development of a specific field (Perrier et al., 2016; Luo et al., 2022). Up to now, bibliometrics has been widely used for specific research field analysis (Huang and Chang, 2011), co-citation analysis (Jiang et al., 2015), and analysis of the development of trends across the subject area (Zhong et al., 2019). In this study, we searched the literature on alpine meadows in Web of Science database since 2000, and used bibliometric analysis and cluster analysis to explore the research directions and hotspots of alpine meadows, aiming to help domestic and foreign scholars accurately grasp the current research status of the field and guide the further research directions of alpine meadows.

2 Materials and methods

2.1 Literature sources and search strategies

All articles published in the Web of Science database with the search subject words "(alpine meadow OR alpine meadows OR alpine-cold meadow OR high-cold meadow)" and “alpine meadow research”. The literature search period was set as “1 January 2000 to 31 December 2021". After we cleaned the data and removed duplicates, we obtained a total of 3,607 articles in the field of alpine meadow research. The citation data of these documents were obtained from the Web of Science collection, saved in “plain text” txt format, and then imported into the VOS viewer (Version 1.6.13) software.

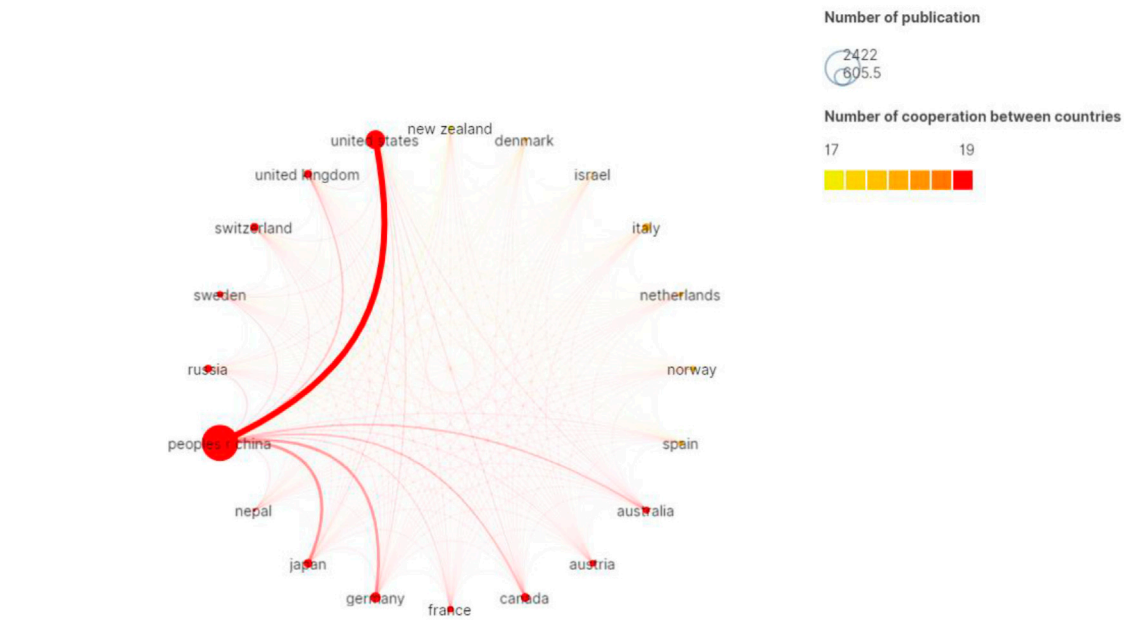

FIGURE 2
Top 20 countries/regions with the largest number of research publications on alpine meadows.

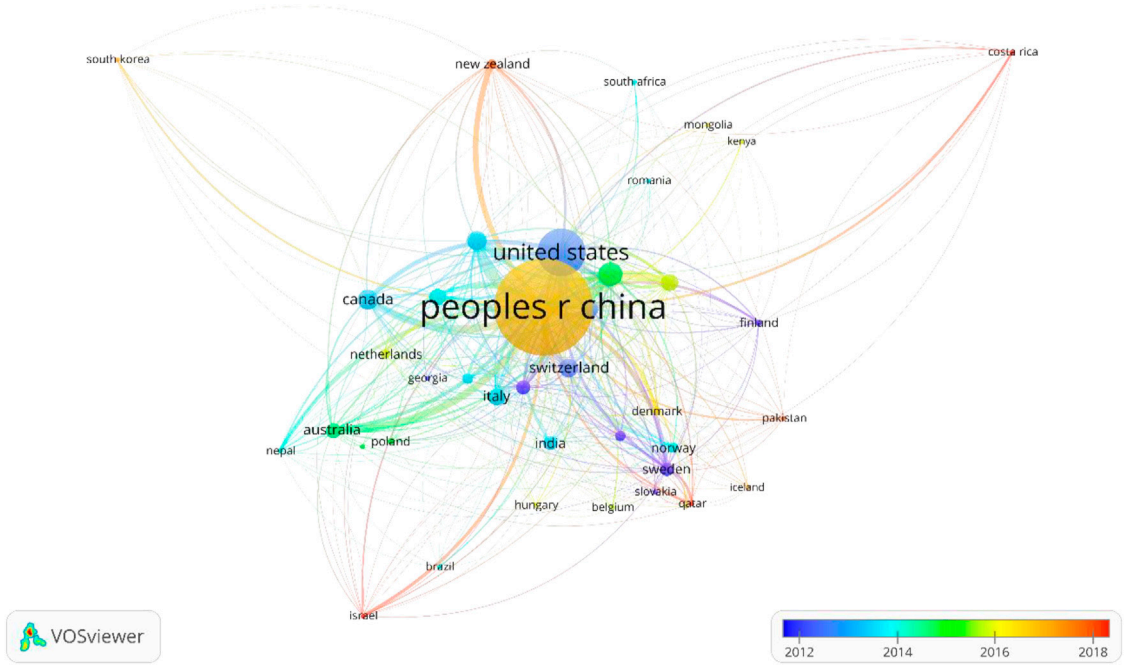

FIGURE 3
Analysis of the cooperation network among various countries/regions in the field of alpine meadow research.

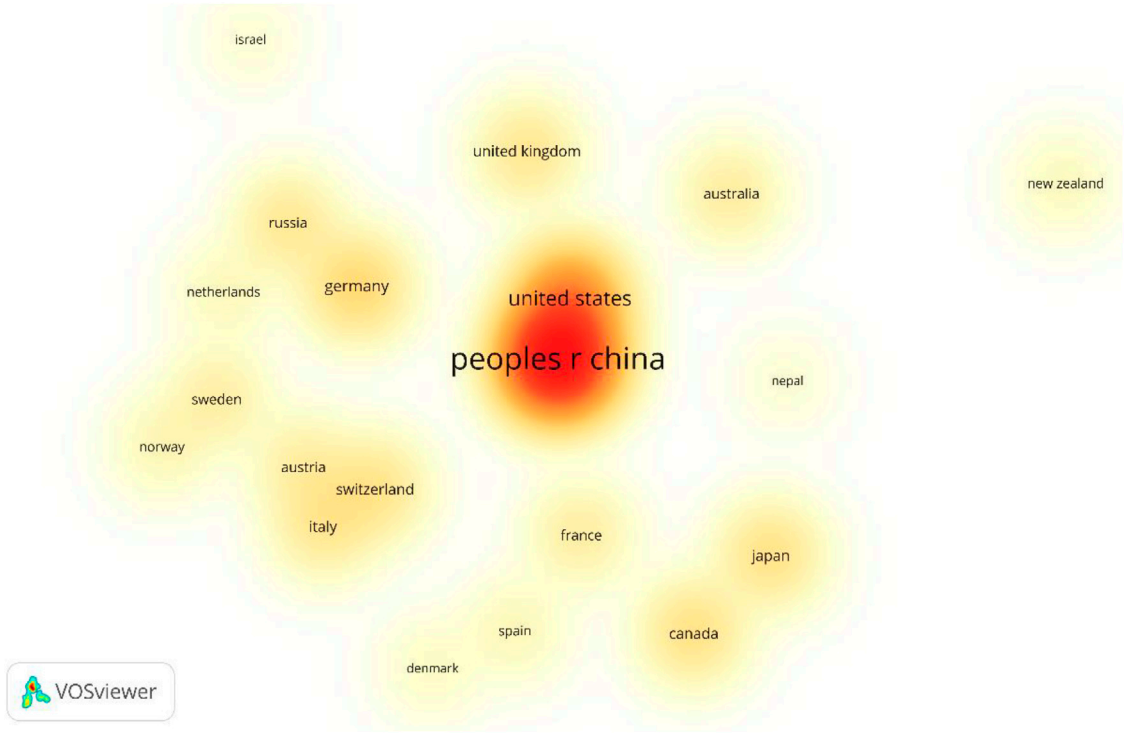

FIGURE 4
Top 20 countries/regions in terms of cooperation density in alpine meadow research.

TABLE 1 Top 15 published authors in the field of alpine meadows.

Rank	Author	Documents	Citations
1	Zhou, huakun	81	1,136
2	Du, guozhen	80	2,195
3	Wang, shiping	74	2,709
4	Cao, guangmin	69	1,418
5	Dong, shikui	52	1,262
6	Zhang, xianzhou	52	1,286
7	Zhang, zhenhua	51	1,582
8	Li, yingnian	47	1809
9	Luo, caiyun	46	1,556
10	Zhao, xinquan	45	2,497
11	Wang, yanfen	44	1845
12	Shi, peili	43	1,046
13	Tang, yanhong	42	1,655
14	Yu, guirui	30	1903
15	Duan, jichuang	21	972

2.2 Methods

VOS viewer software constructs and presents bibliometric maps of distance, size and density differences between nodes based on the co-citation and high-citation principles of the literature. It evaluates the research direction and hotspot of the literature by cluster viewing, overlay viewing and density viewing (Van Eck and Waltman, 2010). VOS viewer runs in Java environment and can import The VOS viewer runs in Java and can import literature in Web of Science format. By clicking "Create" in VOS viewer, the literature is imported into the software, and objects are selected and thresholds are set according to the analysis objectives (Gao et al., 2021). The distance between nodes indicates the closeness and similarity of the subject terms, and the node size represents the frequency of occurrence, and the higher density means the closer the connection and the stronger the relevance (Ling et al., 2020). In this study, the Type of analysis was selected as Co-occurrence, and the Unit of analysis was selected as Keywords, Authors, Organizations and Full counting. The frequency of co-occurrence of keywords is more than 25 times, which is a high frequency word and shows the research hotspots.

In order to make the clustering effect of the network mapping produced by VOS viewer more obvious, the results of VOS viewer were

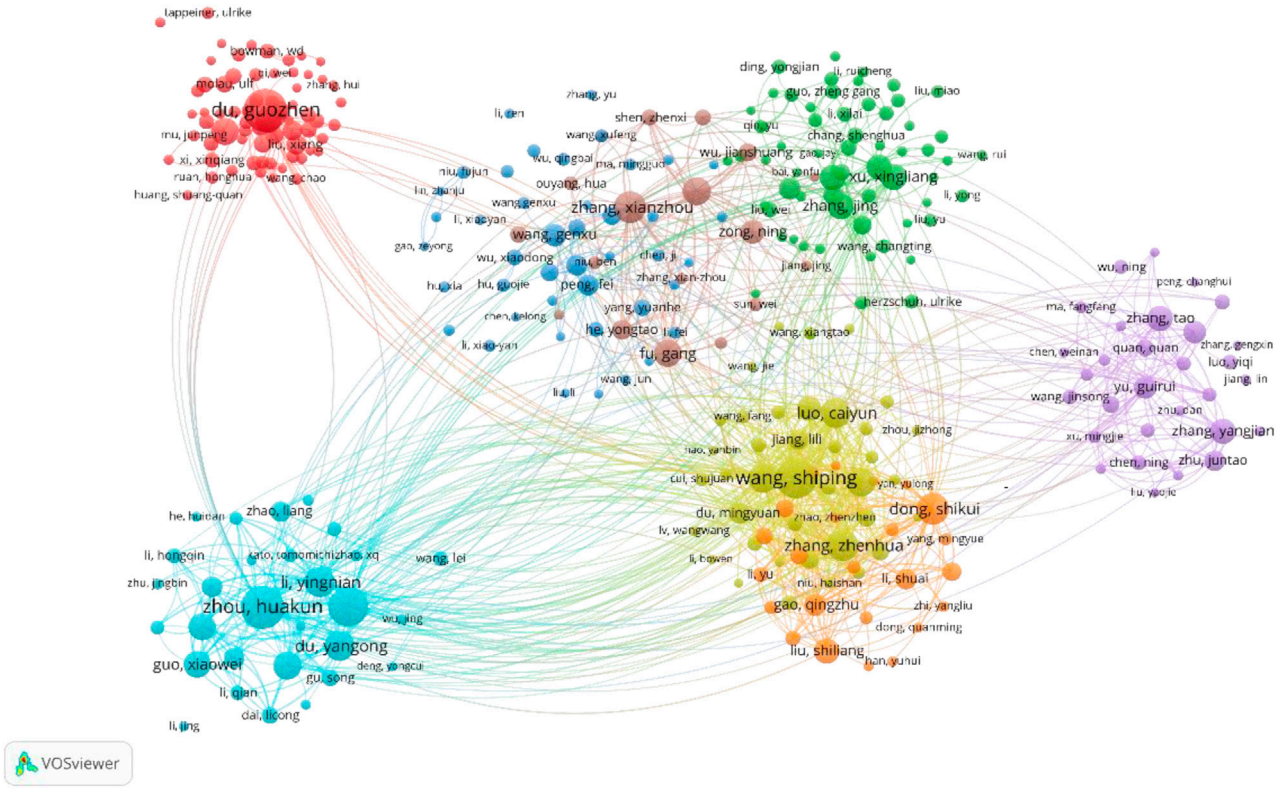

FIGURE 5
Collaborative network of researchers in the field of alpine meadow research.

TABLE 2 Top 15 ranking of scientific institutions in the field of alpine meadow research in terms of number of publications.

Rank	Institution	Country	Documents	Citations
1	chinese acad sci	China	1,514	33,416
2	univ chinese acad sci	China	575	8,863
3	lanzhou univ	China	459	9,068
4	beijing normal univ	China	166	3,710
5	peking univ	China	119	4,827
6	qinghai univ	China	99	725
7	nanjing univ	China	86	1739
8	chinese acad agr sci	China	65	1,470
9	beijing forestry univ	China	64	687
10	northwest a&f univ	China	63	615
11	natl inst environm studies	USA	54	2,674
12	qinghai normal univ	China	53	777
13	cas ctr excellence tibetan plateau earth sci	China	50	995
14	tsinghua univ	China	32	1,428
15	natl inst agroenvironm sci	USA	26	1,231

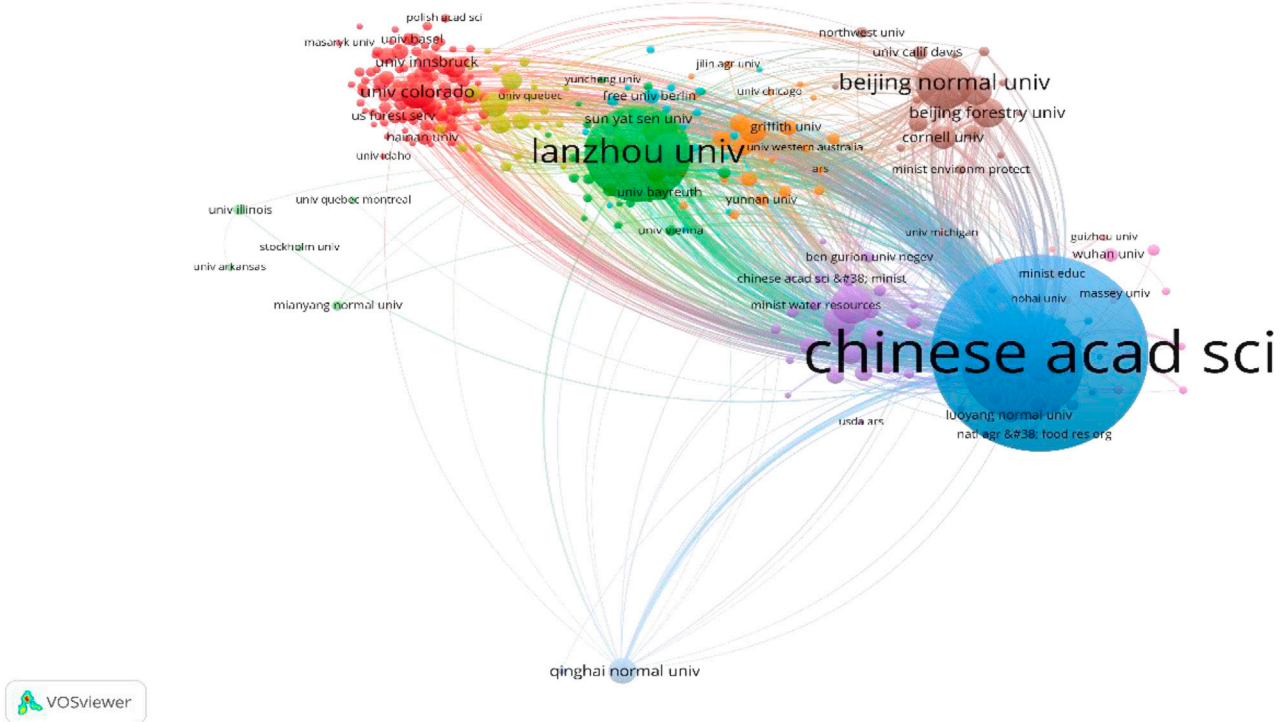

FIGURE 6
Mapping analysis of institutional cooperation network in the field of alpine meadow research.

saved in Pajek format, named net., clu. and vec. files respectively. The saved files were then imported sequentially into Pajek software (Pajek software large complex network analysis tool is a powerful tool for studying various complex non-linear networks that exist today. pajek runs in a Windows environment and is used for analysis and visualization operations of large networks with thousands or even

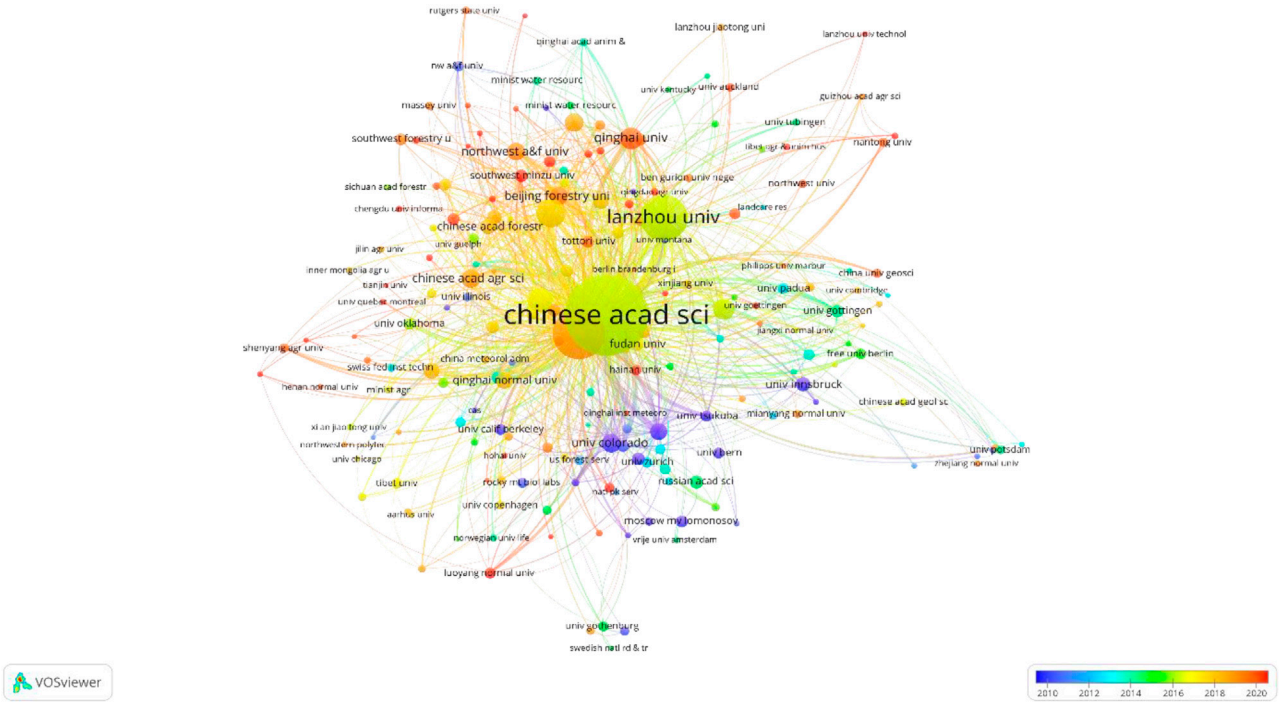

FIGURE 7
Clustering analysis of the temporal overlay mapping of papers published by institutions in the field of alpine meadow research.

millions of nodes (De Nooy et al., 2018) that performs reordering clustering followed by importing into VOS viewer software. The co-cited national geographic visualization plots in the paper were produced by VOS viewer combined with Scimago Graphica software. Plots of the volume of articles issued by year were made by the software Origin Pro 2021.

2.3 Data analytics

The year, journal, author, institution, country/region, literature citation and keywords of alpine meadow related literature were analyzed using Microsoft Excel 2016 software, and the authors, institutions, country distribution and collaboration, literature co-citation and keywords were systematically analyzed and visualized using VOS viewer software for bibliometric analysis. The authors, institutions, country distribution and collaboration, literature co-citation and keywords were systematically analyzed and visualized using VOS viewer software (Li and Liu, 2020). Considering the rigor and accuracy of the study, the literature search statistics were searched independently by one researcher and proofread by one researcher.

3 Results

3.1 Year of publication, number of literatures

The year of publication of the 3,607 papers counted shows that the overall number of papers in the field of alpine meadows is on the rise, especially in the last decade with more increments, and the maximum number of papers published in 2021 is 383 (Figure 1). The overall trend of linear growth of the paper issuing articles was demonstrated by linear regression using origin Pro 2021, and the equation was obtained as y = 15.958x-31941 with R^2 = 0.8779, indicating into an extremely significant linear relationship. After 2000, alpine meadow research entered the exponential growth stage, that is, alpine meadow research has a mature theoretical foundation and enters the stage of theoretical application.

3.2 Distribution of the most published countries/regions

Analyzing Figure 2, we found that the countries with high publication volume are China, United States, Germany, Japan, France, Australia, and Canada. These countries not only have strong research strength, but also have extensive research cooperation networks, and most of the alpine meadow research results come from these countries. China is the top country in the field of alpine meadow research, far ahead of other countries, because China has the "Qinghai-Tibet Plateau", which is known as the third pole of the world, and alpine meadows account for 47% of the Qinghai-Tibet Plateau, which facilitates Chinese scholars to conduct research; it also reflects the importance of China in the field of alpine meadow research sideways.

The inter-country cooperation in alpine meadow research was analyzed using VOS viewer software, and the thicker the

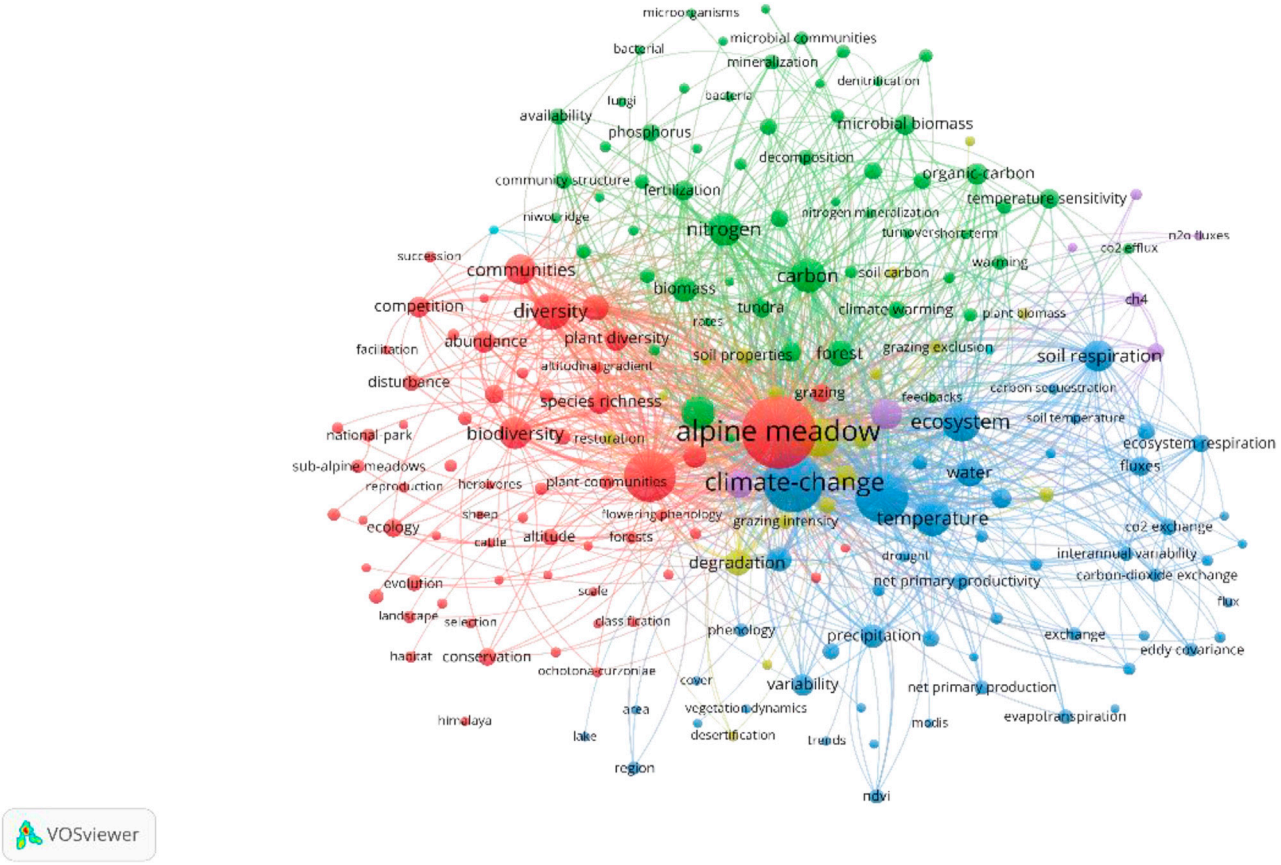

FIGURE 8
Cooccurrence network mapping of keywords related to alpine meadows.

connecting line, the greater the number of country cooperation. The results show that China has established international cooperation with many countries, and the closest cooperation is with the United States, followed by New Zealand, Japan, and Australia. The results show that countries such as Sweden and Finland have researched in the field of alpine meadows before 2012, countries such as Norway, India, Canada, and Italy acted to research alpine meadows in 2014, and countries such as People r China, New Zealand, and Mongolia researched alpine meadows mainly after 2016 (Figure 3). The density analysis can be found that China and United States have more concentrated research in the field of alpine meadows (Figure 4).

3.3 Analysis of paper authors, institutional distribution and cooperation network

The top three authors with the largest number of publications were Zhou, Huakun (81), Du, Guozhen (80) and Wang, Shiping (74) (Table 1), all from China. Meanwhile, the top 15 authors in the field of alpine meadows were all from China according to the study authorship collaboration. The map shows that in the field of alpine meadows, several collaborative sub-networks have been formed with the above authors as the core, and there are strong academic ties among scholars within the sub-networks, but there are collaborative relationships of varying strengths outside the sub-networks. This indicates that Chinese scholars in the field of alpine meadow research have strong ties within their respective teams, and that cooperation between individual teams needs to be strengthened.

The VOS viewer was used to map the co-occurrence of authors to.the trend of close cooperation within teams and lack of cooperation among teams in the field of alpine meadow research, as shown in the study results, is to some extent detrimental to the development of the field (Figure 5), and only through mutual communication and joint learning can we achieve breakthrough results in the field of alpine meadow research in Qinghai-Tibet. Therefore, there is a need to strengthen the cooperation and connection between various teams and scholars in China.

The number of published papers by research institutions can represent the research capability of their fields. 2,158 research institutions were listed in 3,607 papers, and the minimum number of 10 papers per institution was set, and 140 institutions were qualified. Chinese Acad Sci ranked first with 1,514 papers,

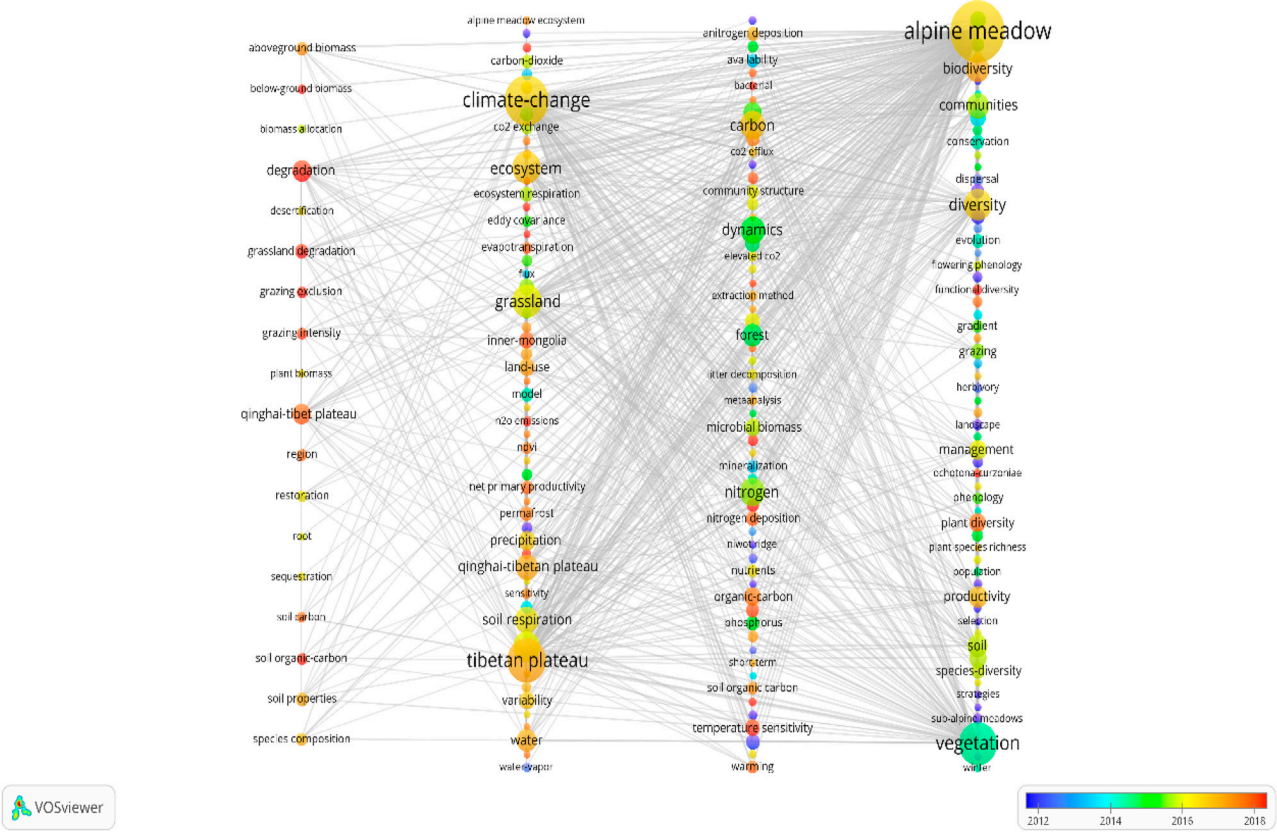

FIGURE 9
Temporal overlapping co-occurrence clustering of keywords in alpine meadow research area.

followed by Chinese univ Chinese Acad Sci (575 papers) and Lanzhou university (549 papers) (Table 2).

The analysis of institutional cooperation network mapping showed that there were more local cooperation among research institutions, but less cross-regional cooperation, for example, there was very little cooperation between Qinghai Normal University and various research institutions, and mainly with Chinese Acad Sci and Lanzhou Univ (Figure 6). By superimposing the time of publication on the co-occurrence network of research institutions to obtain the time superimposition of institutions, i.e., different colors correspond to the average year of appearance of institutions in the literature, we can find the evolutionary trend of research institutions in alpine meadows, and Chinese Acad Sci, Qinghai Univ and Beijing Forestry Univ are the main research hotspots in alpine meadows (Figure 7). The trend of evolution of research institutions in alpine meadows can be found.

3.4 Research keyword clustering and hot topic analysis

A total of 12,919 keywords were obtained in 3,607 documents. The accuracy and frequency of keywords are two important factors that affect the accuracy of the results of the co-occurrence method to identify research hotspots in the field (Pan et al., 2018). In order to make the analysis results more accurate, the keywords in the literature were first cleaned and collated, which mainly included the unification of the case and singular and plural of words, full names and abbreviations and synonyms. The cleaned keywords were counted by VOS viewer, and the keywords with frequencies >25 times were set as high-frequency keywords, and the keywords with the highest frequencies but no analysis significance, such as “response” and “impact”, were eliminated. The keyword co-occurrence network mapping, including clustering map, time superposition map, etc., was drawn.

According to the keyword co-occurrence network analysis, the current directional atmosphere of the alpine meadow research field can be divided into five major categories, which are red area, diversity direction; green area, research direction of microorganisms and nutrients such as carbon, nitrogen and phosphorus; blue area, research direction of climate change and soil respiration; purple area, research direction related to gases such as CO_2 and CH_4; yellow area, research direction related to grazing and grassland degradation (Figure 8). The time of publication was superimposed on the keyword co-occurrence network to obtain the keyword time superimposed map (Figure 9), i.e., different colors correspond to the average year of keyword appearance in the literature, and the research evolution trend of the field can be found.

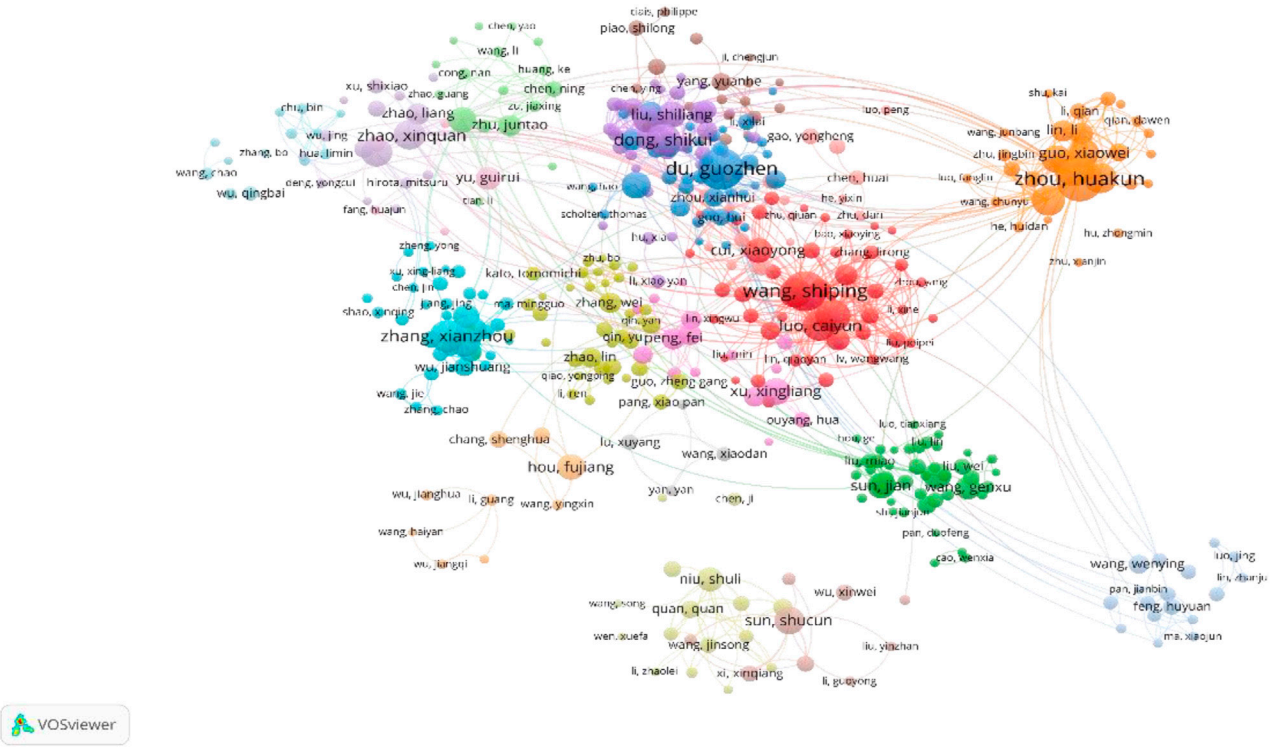

FIGURE 10
Network analysis of authors of co-cited papers.

sensitivity, soil respiration, nitrogen deposition, N_2O emissions, fungi, bacteria, etc. are the latest research hotspots in alpine meadows.

3.5 Analysis of authors of co-cited papers, institutional distribution and national cooperation networks

Smith. (2007) and Ugolini et al. (2015) showed that the number of co-citations indicates the influence, visibility and quality of a publication; however, Walter et al. (2003) noted that the number of citations by others does not indicate the quality of a publication, but rather measures its visibility. Therefore, co-citations of papers can identify scholars and institutions that have made significant contributions to the field or have struggled in the field for a long time, etc.

Analysis of Figure 10 shows that more than ten authors and their teams have certain popularity and influence in the field of alpine meadow research, and there are close collaborations among scholars within their teams; however, there are fewer collaborations among the teams. For example, Huakun Zhou's team cooperates closely with Xinquan Zhao's team, Wenying Wang's team, Shiping Wang's team, and Fujiang Hou's team; and rarely with Xianzhou Zhang's team and Guozhen Du's team. The former teams are all located in northwestern China, on the one hand, because they are near the Qinghai-Tibetan Plateau, which facilitates cooperation among teams; on the other hand, it shows the lack of interaction between Chinese scholars and the need to strengthen cooperation and contact.

Table 3 shows the top ten co-cited articles in the field of alpine meadows, all with more than 120 co-citations, with the top article published in 2009 with 237 co-citations, followed by 170, and 141 co-citations. The most recent article was published in 2012 by Shiping Wang in ecology on the effects of warming and grazing on alpine meadow soils, with 130 citations. Nowadays, with the global climate change and the presence of herders on the Tibetan plateau, grazing and alpine meadows are inextricably linked, so this article is very informative in the study of alpine meadows.

As can be seen from Figure 11, Chinese Acad Sci is the main institution in terms of co-cited articles and far exceeds other institutions in terms of co-cited articles published. univ Chinese Acad Sci, Lanzhou Univ, and Beijing Normal Univ rank second, third, and fourth, respectively. Qinghai Univ (orange part in the figure) also contributes in the contribution of many Universities (institutions) such as Qinghai normal univ in the field of alpine meadow research cannot be ignored. It also shows that China's research in the field of alpine meadow research far exceeds that of other international countries.

There are 15 countries with >48 articles among the 80 countries in the co-cited papers. Analysis of the geographical visualization map of co-cited countries (Figure 12) shows that the clustering results in three categories, the first category is dominated by Austria (the blue area), including Germany, the United Kingdom, and Italy, etc.; the second category is composed of countries such as China, the US, Japan and Australia (the purple area), and the third category is Canada (the red area). The thickness of the lines in the graph

TABLE 3 Top 10 highly cited articles on alpine meadow research.

Rank	Cited references	Author, year	Source	Citations
1	Rangeland degradation on the Qinghai-Tibetan plateau	harris rb, 2010	jarid environ	237
	A review of the evidence of its magnitude and causes. doi 10.1016/j.jaridenv.2009.06.014			
2	Grazing intensity alters soil respiration in an alpine meadow on the Tibetan plateau	cao guangmin, 2004	soil biol biochem	170
	doi 10.1016/j.soilbio. 2003.09.010			
3	Storage, patterns and controls of soil organic carbon in the Tibetan grasslands	yang yuanhe, 2008	global change biol	141
	doi 10.1111/j.1365-2486.2008.01591.x			
4	The impacts of climate change and human activities on biogeochemical cycles on the Qinghai-Tibetan Plateau	chen huai, 2013	global change biol	140
	doi 10.1111/gcb.12277			
5	An extraction method for measuring soil	vance ed, 1987	soil biol biochem	140
	Microbial biomass C. doi 10.1016/0038-0717(87)90,052-6			
6	Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau	klein ja, 2004	ecol lett	137
	doi 10.1111/j.1461-0248.2004.00677.x			
7	Climatic warming in the Tibetan Plateau	liu xd, 2000	int j climatol	135
	During recent decades. doi 10.1002/1,097-0088(2000113020:14 < 1729::aid-joc556 > 3.0.co); 2-y			
8	Experimental warming, not grazing, decreases	klein ja, 2007	ecol appl	132
	Rangeland quality on the Tibetan Plateau. doi 10.1890/05-0685			
9	Effects of warming and grazing on soil N availability, species composition, and ANPP in an alpine meadow	wang sp, 2012	ecology	130
	doi 10.1890/11-1408.1			
10	Temperature and biomass influences on interannual changes in CO_2 exchange in an alpine meadow On the Qinghai-Tibetan Plateau	kato t, 2006	global change biol	127
	doi 10.1111/j.1365-2486.2006.01153.x			

represents the intensity of cooperation, and it can be seen that the first-ranked China and the second-ranked United States cooperate closely, while other countries have cooperation relationships of varying intensity with each other.

4 Discussion

Bibliometric analysis is an effective method to identify the spatial and temporal distribution, knowledge structure and evolution of literature (Kou et al., 2021). In this research, the global alpine meadow-related research literature in the Web of science database was analyzed with the help of bibliometric visual analysis software VOS viewer and quantified in the form of visual networks and presented in the form of co-occurrence maps, including the visualization map of literature publishing author groups, the knowledge map of publishing institutions and the co-occurrence map of hot keyword clusters of literature. The results of the study found that China is the first country in the field of alpine meadow research (Figures 2–4, 12). There is little mutual cooperation between research author groups and groups, and the first authors of the published literature are all domestic authors and have collaborative relationships with a few foreign researchers. This study suggests that future researchers should strengthen mutual cooperation, and more importantly, strengthen cooperation with foreign researchers to achieve a higher level of research in line with international standards. The use of bibliometric analysis methods to quantify specific research fields or journals has become more common and gradually developed into a trend (Feng et al., 2022; Li et al., 2022; Wu and Li, 2022). Many disciplines such as medicine (Lin and Zhang, 2020), agronomy (Meng et al., 2023), ecology (Hu et al., 2023), soil science (Jiang and Peng, 2021), psychology (Liu and Gan, 2022), sociology (Li et al., 2015), pedagogy (Xu and Guo, 2011), environmental science (Wang et al., 2023) and physical education (Liu, 2022) have used the method of bibliometrics to comprehensively analyze the literature changes in their respective fields. Also, Zhao et al. (2023) showed that the combination of ecology, physiology, grass science, soil science, geography, biochemistry, mathematics and meteorology with effective cooperation at home and abroad has obvious positive effects on the study of alpine meadows. Li et al., 2022 mentioned in her paper on architecture research that future studies should combine management, politics, mathematics and other majors.

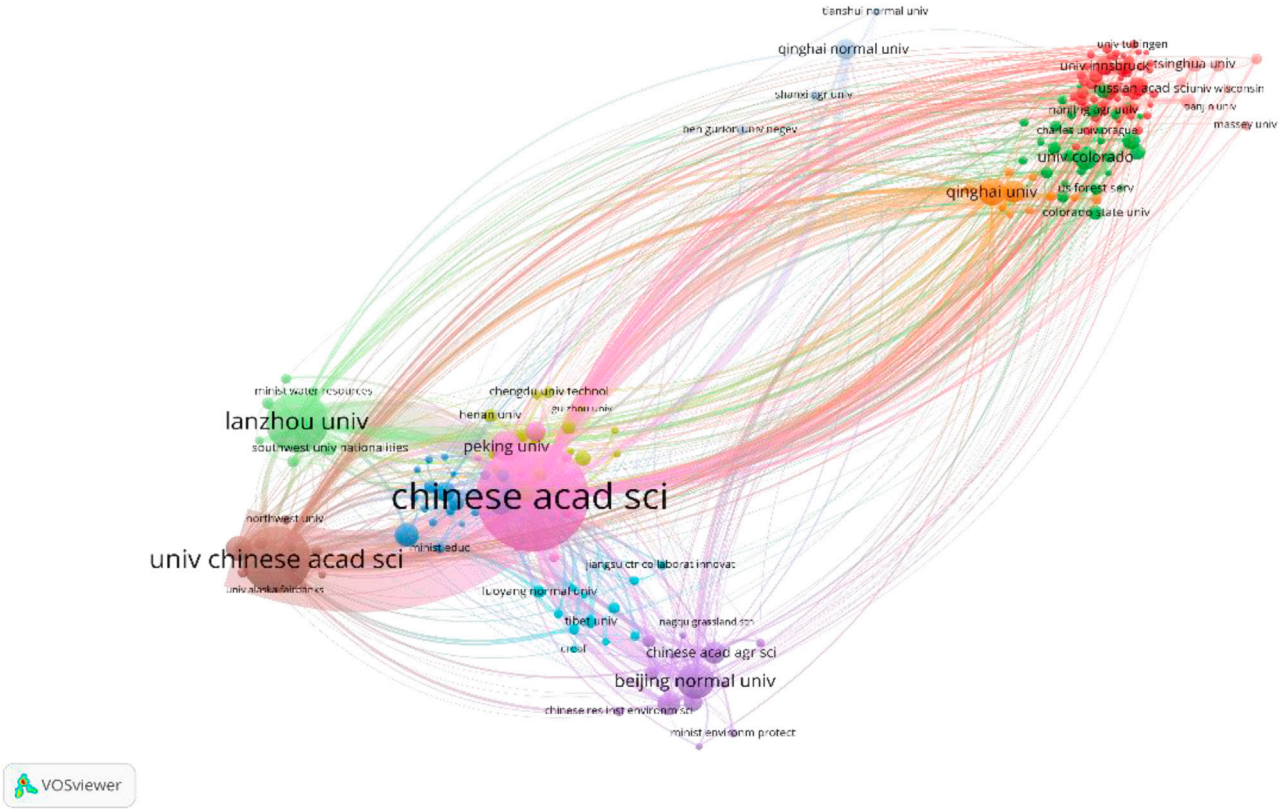

FIGURE 11
Institutional network analysis of co-cited papers.

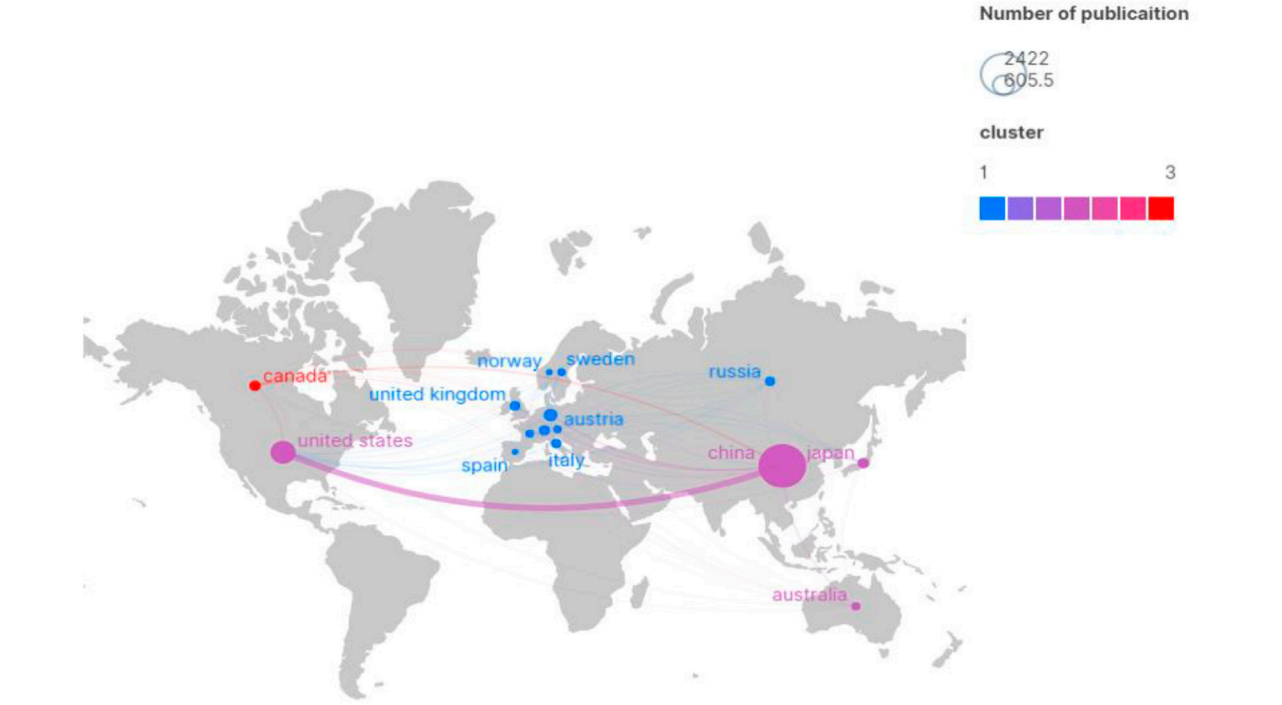

FIGURE 12
Geographical visualization analysis of inter-country cooperation relations of co-cited papers.

High-frequency keywords refer to keywords with high co-occurrence frequency, and a keyword that appears in high frequency within a certain period may be a research hotspot or research focus in a certain field at that time (Xu, 2012), and the resulting high-frequency keywords can reveal the thematic structure and hot issues of a research field through co-occurrence analysis by visual analysis software, which is more conducive to comprehensive analysis of research hotspots in a certain field (An and Zhang, 2014; Zhang, 2016). The results of high-frequency keyword analysis in this study showed that the hotspots of alpine meadow research were "enzymes", "microorganisms", "soil respiration", and "climate change". This indicates that there is a wealth of theoretical knowledge and scientific experiments on alpine meadows, and microscopic research is the main focus of alpine meadows research today. At the same time, the combination of geoinformation technology, remote sensing, meteorology and other disciplines to study alpine meadows may lead to extraordinary results, which are important for global grassland ecosystems and even global ecosystems.

Since this study is the first visual analysis of the relevant literature in the field of global alpine meadow research, there are some limitations in this study. First of all, a single Web of Science database search may omit articles related to the alpine meadow research, and some additional non-English literature may not be included in the analysis, which may contain important research results for this study. Secondly, low-frequency words were not analyzed in this study. According to Zipf's law, some low-frequency terms cannot be excluded as potential research hotspots in the future (Aitchison et al., 2016). For example, "strategy" is a low-frequency word, but it is likely to become the next alpine meadow acting according to the field of theme words, the sustainable development of alpine meadow is closely related to the national and global people's lives. This is similar to the findings of Romanian scholars on the Eurasian steppe (Nita et al., 2019). Third, the search strategy relied on relevant search terms being included in the title or appearing as keywords; therefore, some well-known classic articles may have been excluded (Calatrava Moreno et al., 2016). Fourth, the results for the most cited articles were biased because the earliest articles were cited more often than the most recent ones, which may have influenced the results of this study. Finally, the study of alpine meadows also needs to consider the politics, economy and culture, and the closeness of cooperation between researchers in each country, the ecological conservation policies between developing and developed countries, the laws introduced, and the ecological conservation awareness of local people (Nita, 2019; Nita et al., 2019; Manolache et al., 2020). These are all questions that need to be explored for future research.

5 Conclusion

In summary, this study clustered the research trends and hotspots in the field of alpine meadows using VOS viewer software to further visualize the latest research results in the field of alpine meadows. The results indicate that Chinese scholars are the main force in alpine meadow research, but regional and international multicenter research projects need to be actively pursued, especially the cooperation among domestic teams should be strengthened." Key words such as enzymes, microorganisms, soil respiration and climate change are the focus of alpine meadow research. Research on alpine meadows also needs to consider the global distribution of alpine meadows, grassland conservation policies between developing and developed countries, and cooperative relationships between scholars from various countries. Reasonable ecological conservation policies, reasonable personnel management and appropriate personnel utilization will be of great benefit to the sustainable development of alpine meadows, the stability of grassland ecosystems and even the global conservation of grasslands.

Author contributions

WL conducted experiments, analyzed data, made tables and pictures, wrote a draft of the paper and approved the final draft. KD conceived and designed experiments, reviewed drafts of papers, and approved final drafts. XW, WW, and LZ supervised the writing of the paper and approved the final draft. XX and FL reviewed the draft paper and approved the final draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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