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Quantitative Analysis of the Research Trends and Areas in Grassland Remote Sensing: A Scientometrics Analysis of Web of Science from 1980 to 2020

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Abstract: Grassland remote sensing (GRS) is an important research topic that applies remote sensing technology to grassland ecosystems, reflects the number of grassland resources and grassland health promptly, and provides inversion information used in sustainable development management. A scientometrics analysis based on Science Citation Index-Expanded (SCI-E) was performed to understand the research trends and areas of focus in GRS research studies. A total of 2692 papers related to GRS research studies and 82,208 references published from 1980 to 2020 were selected as the research objects. A comprehensive overview of the field based on the annual documents, research areas, institutions, influential journals, core authors, and temporal trends in keywords were presented in this study. The results showed that the annual number of documents increased exponentially, and more than 100 papers were published each year since 2010. Remote sensing, environmental sciences, and ecology were the most popular Web of Science research areas. The journal *Remote Sensing* was one of the most popular for researchers to publish documents and shows high development and publishing potential in GRS research studies. The institution with the greatest research documents and most citations was the Chinese Academy of Sciences. Guo X.L., Hill M.J., and Zhang L. were the most productive authors across the 40-year study period in terms of the number of articles published. Seven clusters of research areas were identified that generated contributions to this topic by keyword co-occurrence analysis. We also detected 17 main future directions of GRS research studies by document co-citation analysis. Emerging or underutilized methodologies and technologies, such as unmanned aerial systems (UASs), cloud computing, and deep learning, will continue to further enhance GRS research in the process of achieving sustainable development goals. These results can help related researchers better understand the past and future of GRS research studies.

Keywords: grassland; remote sensing; CiteSpace; scientometrics analysis; research progress; network analysis; visualization; Web of Science

1. Introduction

Grasslands are an integral part of the terrestrial ecosystem, and are the most widely distributed form of land cover [1], covering 33% of the world's land surface [2]. They are mainly composed of natural grasslands, semi-natural grasslands, and improved grasslands [2]. For uniform expression, these are hereafter called "grassland". Grassland plays an essential role in providing the function of multi-ecosystem services [3] and supporting people's livelihoods [4]. Grassland ecosystems store 34% of the global terrestrial carbon and account for 30% of net primary productivity [1]. They are of great value in maintaining ecological security, regional economies, and human history [5]. Grassland resources are critical ecological resources in many countries (such as China, Australia, and the USA) and play an essential role in achieving sustainable development goals [3]. Therefore, the dynamic monitoring of global grassland ecosystem health, productivity, biodiversity, real-time assessment, and sustainable health management has become vital research goals. However, the emergence and application of remote sensing technology to grassland ecology research studies has greatly accelerated the process to accomplish these objectives compared to traditional field sampling.

Grassland remote sensing (GRS) research is an interdisciplinary subject. It provides ecological parameters for ecology studies because it utilizes multi-platform, multi-sensor, and multi-temporal satellite remote sensing data sources and ground observation data, through remote sensing inversion and data assimilation. Meanwhile, scale conversion is also important to obtain temporally continuous spatial ecological parameters of the same scale [6–9]. Furthermore, based on these ecological parameters, guided by ecological theories and combined with ecological models, many new ecosystem monitoring, evaluation, and management methods have been developed [10–13]. Besides, development in remote sensing technologies and resolutions (spatial/temporal/spectral) allows extending the scope of grassland studies, e.g., monitoring, etc. [10–12]. Through comprehensive analysis of high spatiotemporal resolution remote sensing data and ground survey data, the macro surveying speed of grassland resources has been significantly accelerated [14], and the accuracy and timeliness of grassland dynamic change monitoring have been improved [15]. The advantages of remote sensing technology are not only reflected in the active monitoring of grassland resources at a sizeable regional scale [6,8,9,16–19], but also play an essential role in the adequate description of ecosystem structure [9], function [20], process [21], and dynamic cascade relationships [12,22]. Therefore, they facilitate revealing the mutual feedback relationship between ecosystem functions and services, achieving the optimization of ecosystem services and promoting sustainable development management of grassland ecosystem [3,16,23]. GRS research has become a necessary technical means to scientifically configure grassland production and ecological functions, and promote the coordinated development of production, life, and ecology in grassland research areas [8]. Due to these characteristics, GRS research is an area of intense scientific interest, and numerous studies have been conducted focusing on this area. However, few studies have focused on GRS research from the perspective of bibliometric or scientometric analysis [11]. Among these, Reinermann et al. (2020) analyzed 253 documents on grassland production traits and management using literature research [21]; Zhang et al. (2019) adopted a bibliometric measurement method to analyze the remote sensing literature published in the journal *Remote Sensing* from 2009 to 2018, and used methods such as high-frequency keyword analysis to determine the research area [24]. Hu et al. (2017) used a scientometric visualization method to analyze night-time light remote sensing research from 1991 to 2016 [25]. In contrast, bibliometric or scientometric research methods have been widely used in other research fields related to remote sensing, such as water environmental processes [26], forest management [27], marine protected areas [28], human–environment interactions [29], human health [30], and crop growth monitoring [17].

Bibliometrics and scientometrics are important quantitative tools for analyzing the progress of a certain research topic from a macro to a more micro perspective (the macro perspective is based on analysis of the whole research as several papers, categories, research countries, institutions, journals, authors, while micro perspective interprets the keywords, co-cited literature and highlighted literature) based on the scientific peer-reviewed literature [24,25,31]. They integrate computer engineering, big data applications, and statistics, and are used in many fields. Those applications are becoming more extensive, and rich evaluations can be provided at different levels [32]. Compared with bibliometrics, the advantage of scientometrics is reflected in keywords analysis, research topic evolution, frontier dynamic analysis, and other aspects with strong analysis efficiency. Scientometrics provides in-depth qualitative features in the form of a knowledge map and analysis of citations or cited references [32,33]. The scientometrics method is the best approach to discover research trends and key areas, and to help researchers understand the evolutionary characteristics of studies over time [28,34–36]. Therefore, it can provide a systematic and comprehensive judgment of the progress of a scientific research field. It is also referred to as scientific science [37]. Generally, the more documents or references obtained, the deeper the understanding of the research topic [32].

We reviewed the development status and determined the development trend of GRS research. Thus, we undertook a comprehensive scientometrics review of the development of GRS research and searched all documents relevant to global GRS research from 1900 to 2020. The study was carried out using CiteSpace and R software (Biblioshiny package), and we produced a map of the scientific knowledge and visualized the overall development process of GRS research. The results of these analyses (1) reveal the document pattern of GRS research at the global scale; (2) provide an accurate overview of the scientific evolutionary path for GRS research; (3) provide the current research status and popular research areas; (4) strengthen future strategies for GRS research.

2. Data and Methods

2.1. Literature Search Strategy

The ISI Web of Science core database was selected as the data source, and the search subject was determined through expert consultation and a literature investigation. The search formula of the advanced method selected according to the GRS research subject after repeated tests were: TI = (grassland* or rangeland* or meadow* or meadowland* or campo grassland* or pampas near/2 grassland or savanna* or steppe* or prairie* or pasture or grazing land) AND TS = (remote sensing or RS or SPOT or NOAA or AVHRR or Landsat or TM or ETM or SAR or Moderate Resolution Imaging Spectroradiometer (MODIS) or RADASAT or ALOS or "Quick bird" or TRMM or Hyperion or IKONOS or CBERS or ASTER or ENVISAT or Normalized Difference Vegetation Index (NDVI) or "big data" or microwave remote sensing or radar remote sensing or Sentinel-2A or "China Cover" or CASA near/2 model). The database was derived from the retrieval period of 1900–2020, updated to 24 November 2020, and a refined selection of its articles. The document type was article and documents reviewed were written in English. Additionally, each record contained the author, title, source document, abstract, and cited references.

2.2. Scientometrics Analysis Method

We used Microsoft Excel, R 3.6.2 software (Biblioshiny package), CiteSpace5.7.R2, and VOSviewer to mine, analyze, process, and visualize the literature data.

Biblioshiny was developed by Dr. Massimo Aria of Federico II University of Naples, Italy, based on Bibliometrix's shiny software package using the R language. Biblioshiny allows relevant scientific measurement and visualization using an interactive web interface [38]. The research countries and institutions, influential journals, and important authors are systematically analyzed using online analysis. Important index methods used in Biblioshiny should be noted. The total local citation score (TLCS) represents the total frequency of the literature cited by the current literature list. "Web of Science Research Areas" are assigned by Clarivate Analytics and were used to classify the research papers. Each paper can be divided into at least one research field using the network science database.

According to Bradford's Law which can reveal journals' distribution, provides a theoretical basis for choosing periodicals. This law can help researchers to seek the core influential journals. Furthermore, according to Price's law, which pertains to the relationship between the literature on a subject and the number of authors in a specific subject area, the core group of authors can be analyzed to explore the number of papers published by authors. The calculation formula is as follows: $N_{min} = 0.749 \times \sqrt{N_{max}}$, where N_{min} refers to the number of papers with the least number of documents published among the core authors and N_{max} represents the number of records with the largest number of published articles [39]. If the number of articles published is greater than N_{min}, then the author is the core author [40].

CiteSpace was developed by Dr. Chaomei Chen, a professor at the School of Information Science and Technology of Drexel University in the United States, for dynamic complex network analysis and data visualization [36,41]. Like cameras, CiteSpace takes snapshots of specific fields based on time series and connects them to infer the changing process and development trends of the field [42]. The specific visualization has two main modes: the cluster view and the timeline graph. The timeline graph can cluster and display the evolution of knowledge (i.e., trends) in different periods using mutation detection [36]. The most powerful function of CiteSpace software is the cited references analysis of documents. By analyzing the clustering and key nodes in the co-cited network, the knowledge structure of research can be revealed [32,33]. This can help researchers identify research frontiers from the clustering of many literature knowledge bases and reveal the important knowledge nodes contained in research frontiers. Clustering tags are usually extracted from the relevant citation literature using the Log-Likelihood Ratio (LLR) algorithm to represent the research frontier corresponding to a certain knowledge base. The unique feature of the timeline graph is that it can sketch the relationship between clusters and the historical span of documents in a cluster. Another function is citation burst analysis, and it refers to the number of citations to the article change dramatically over a short period, it is a useful method for exploring the development of research trends [32]. Using the mutation detection algorithm designed by Kleinberg [43] to identify bursts that represent the frontier of research, explosive nodes can be extracted from large quantities of data [43].

VOSviewer is free software based on JAVA and developed in 2009 by van Eck and Waltman from the Centre for Science and Technology Studies (CWTS) of Leiden University in the Netherlands [44]. It is mainly oriented to document data and uses "network data", which allows relationship construction and visual analysis for the document knowledge unit. It can draw scientific knowledge graph to show the relationship between the structure, evolution, and cooperation of the knowledge field [44]. Graphic forms include network visualization, overlay visualization, and the item density visualization. In the item density visualization, the point with more neighboring items and higher weights of the neighboring items is closer to red. Oppositely, its color will be closer to blue [44].

Keywords can reveal the research topic of the literature, and word frequency statistics of keywords can reflect the research hotspots in the field. A research hotspot is the concentrated presentation of a certain field in a specific period and is manifested as the frontier. The analysis of research hotspots is helpful to clarify the development process of the research field, grasp the research context, and provide a reference for the exploration of the starting direction of the research. The keywords are used to condense and refine the core content of the research ideas in each study [39]. Each article has unique keywords. Therefore, every word represents a document in terms of keywords. Keywords are the core generalization of a paper. The analysis of keywords in a paper can reveal the paper's theme. However, some correlation must exist among the keywords in a paper, which can be expressed by the frequency of co-occurrence. It is generally believed that the more that lexical pairs appear in the same document, the closer the relationship between the two topics. Co-occurrence analysis uses the common occurrence of lexical pairs or noun phrases in the literature set to determine the relationship between topics in the subject represented by the literature set. A co-word network composed of these word pairs can be formed by counting the frequency of subject words appearing in the same document [32,33,44]. High-frequency keywords can be used as research hotspots and research topics in a period in the given field. Through the automatic algorithm of the VOSviewer software, these keywords were analyzed by co-occurrence, and clusters were formed that represent the current research area [44]. These clusters can indicate the most current lines of interest among related researchers and find the future direction of GRS research based on keywords co-occurrence.

3. Results and Discussion

3.1. Basic Data Information

After classifying the retrieved document datasets and eliminating irrelevant documents, a total of 2692 documents and 82,208 references were obtained. It was found that the earliest document date of GRS research was 1980. Over the past 40 years, an average of 8.41 documents on GRS research were published per year, and the average number of citations per document was 22.62. These results demonstrate the rapid and high-quality development of GRS research studies (Figure 1). These documents involved 8310 authors, 88 were single-authored documents. They generated a total of 5346 keywords (Table 1).

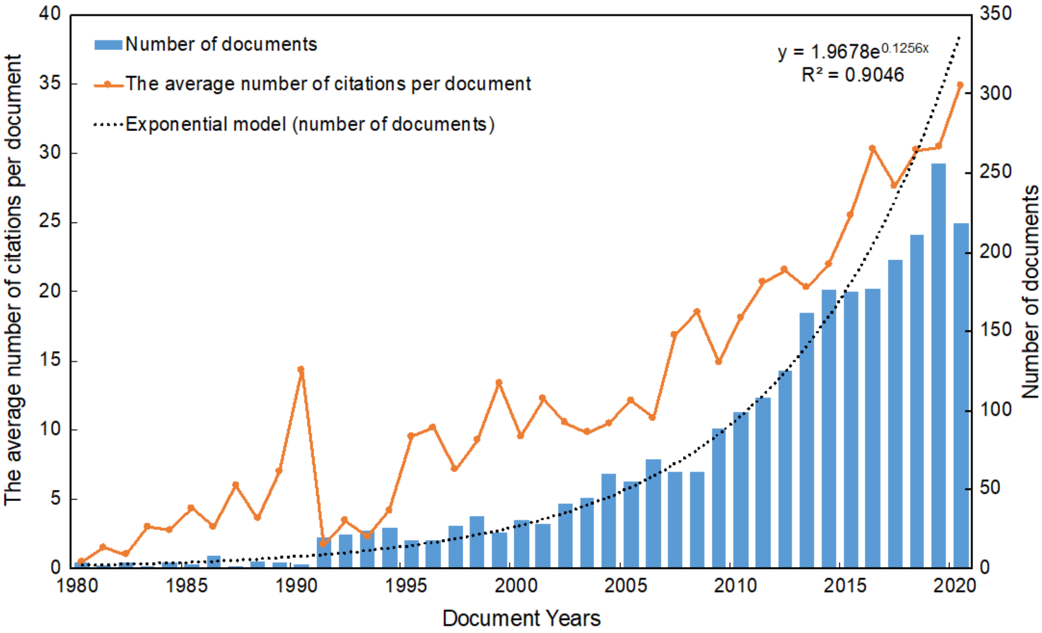


Figure 1. Temporal evolution of documents on grassland remote sensing (GRS) research from 1980 to 2020.

3.2. Temporal Evolution of Documents

Figure 1 shows the number of annual documents related to GRS research from 1980 to 2020. This number increased from 4 in 1980 to 256 in 2019 (due to incomplete data for 2020), with an average annual growth rate of 16.38%. In the past 10 years, the number of articles published each year exceeded 100. Since 1980, the number of GRS studies increased nearly 64 times. The earliest GRS research study is Cipra, J.E. et al. is "Forage production estimates for irrigated meadows from Landsat data" [45], published in *Agronomy Journal*, which officially began the era of GRS research.

3.3. Web of Science Research Areas

According to the Web of Science discipline distribution result of the category field, the areas of GRS research increased from nine fields in 1980 to 97 in 2020. They were concentrated mainly in remoting sensing, environmental science, ecology, imaging science, photographic technology, geosciences multidisciplinary, geography physical, forestry, biodiversity conservation, agronomy, and meteorology atmospheric sciences. The main three research areas represented 2261 of the 2692 documents, accounting for approximately 83.98% of the total (Figure 2). This reveals that the GRS studies have been mainly focused on environmental ecology, although they also covered a wide range of other research areas, such as soil science, water resources, engineering electrical electronics, entomology, and others. Some of the GRS research in the area of water resources concerned the water cycle in grassland ecosystems and root-zone soil moisture variability [46] against the background of environmental stress [47,48]. Studies related to the water surface area of lakes on the steppe [49] were mainly concerned with soil quality [50–52], soil function, and soil organic matter [53]. The engineering electrical electronic area related to the use of yield estimation in grasslands using remote sensing products [17,54,55], modeling based on remote sensing data [8], and machine learning methods or advanced algorithms [9,56,57]. The entomology area was mainly concerned with the relationship between the density of different species and grassland ecosystems [58], for instance, arthropods [59], thrips species [60], spiders and *Auchenorrhyncha* assemblages [61], flies [62], black imported fire ants and other insects [63], and biological control insects [64,65]. Therefore, the disciplinary characteristics of GRS research show a trend of interdisciplinary integration (Figure 2).

Table 1. Basic information of datasets.

Type	Value/Number
Timespan	1980–2020
Documents	2692
Average number of documents per year	9.41
Average number of citations per document	22.62
Average number of citations per year per document	2.13
References	82,208
Keywords plus (ID)	5346
Author’s keywords (DE)	6508
Authors	8310
Author appearances	12,935
Authors of single-authored documents	88
Authors of multi-authored documents	8222
Single-authored documents	100
Documents per author	0.324
Authors per document	3.09
Co-Authors per documents	4.8
Collaboration index	3.17

3.4. Research Countries and Institutions

Results show 135 countries have engaged in GRS research. In terms of research countries, the top five with the largest number of documents are the United States (945), China (617), Germany (272), Australia (248), and Canada (181) (Figure 3a). In addition to the number of documents, the centrality of national cooperation can also be used as one of the indicators to measure a country’s research strength. The top five countries in terms of centrality are the United States of America (USA), Germany, China, Canada, and Australia. The USA has cooperation with more than 20 countries, including China, Brazil, Australia, and South Africa, and China has cooperation with Germany, Canada, Australia, and Japan (Figure 3).

Results show 2341 institutions globally have engaged in GRS research. Five of the most influential research institutions accounted for 833 articles (including cooperation achievements for each institution). The results show that the number of papers in one institution is significantly higher than that in other institutions, which indicates that the research documents of the five most-influential institutions are unbalanced. In terms of studies published from 1980 to 2020, the Chinese Academy of Sciences (CAS) ranked first with the largest number of papers (516), followed by the United States Department of Agriculture (USDA, 165), the Commonwealth Scientific and Industrial Research Organization (CSIRO), and the University of Chinese Academy of Sciences in the top 10 (Table 2). Although Germany ranks third globally in terms of the number of research papers on this topic, no German national research institutions were ranked amongst the top 10 institutions in terms of the number of total documents on GRS research from 1980 to 2020.

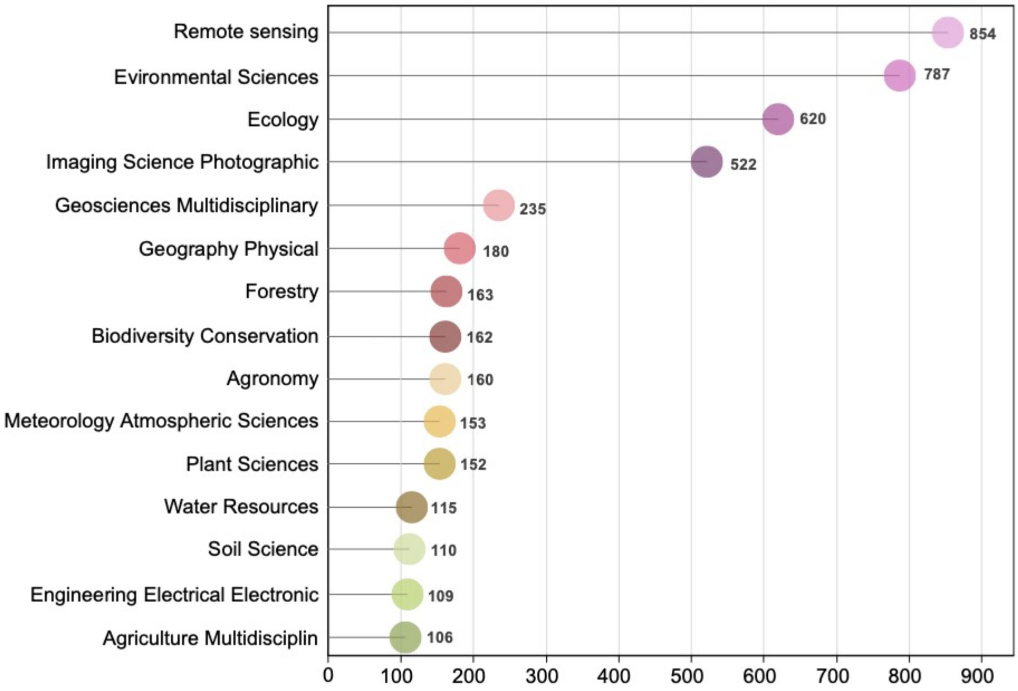


Figure 2. Top 15 main research fields in Web of Science on GRS research studies from 1980 to 2020.

Table 2. Top 10 productive institutions on GRS research from 1980 to 2020.

Institution	TA	Country
Chinese Academy of Sciences	516	China
USDA	165	USA
University of Chinese Academy of Sciences	122	China
CSIRO	95	Australia
United States Department of the Interior	84	USA
University of California	80	USA
Beijing Normal University	76	China
United States Geological Survey	73	USA
CNRS	65	France
NASA	63	USA

Abbreviations: TA, total number of articles; USDA, United States Department of Agriculture; CSIRO, Commonwealth Scientific and Industrial Research Organization; CNRS, Centre National de La Recherche Scientifique; NASA, National Aeronautics and Space Administration.

The Institute of Geographic Sciences Natural Resources Research CAS, the Institute of Botany CAS, and the Institute of Remote Sensing Digital Earth were the top three institutions for research documents on GRS research in the CAS.

3.5. *Influential Journals*

GRS studies have appeared in 526 journals, and the average number of journals per year increased from 4 to 80 since 1980. The distribution of GRS research documents within major journals was examined. The top 20 (3.58%) journals published 1177 (43.72%) of the total number of documents; each journal exceeded 8% of the total number of documents. On the contrary, 256 journals (48.66%) published only one paper, and 158 journals (30.03%) published two to five papers on GRS research. A total of 476 journals (90.49%) published less than 10 papers. As shown in Table 3, the top three journals with the largest number of papers published are *International Journal of Remote Sensing* (201), *Remote Sensing* (185), *Remote Sensing of Environment* (147). According to Bradford's Law, results reveal that the GRS research documents were highly dispersed with a large portion being published in ten journals as shown in Table 3. These journals, such as *International Journal of Remote Sensing*, *Remote Sensing*, *Remote Sensing of Environment*, *International Journal of Applied Earth*, *Observation and Geoinformation*, *Rangeland Ecology & Management*, *Agricultural and Forest Meteorology*, *Ecological Indicators*, and *Journal of Arid Environments* are the core sources in GRS research. These journals play an essential role in the research of GRS. Results of journal dynamics analysis (Figure 4) showed that the journal *Remote Sensing* has had a rapid growth rate and receives increasing attention from GRS researchers. Thus, this journal may become one of the most powerful drivers in GRS research in the future.

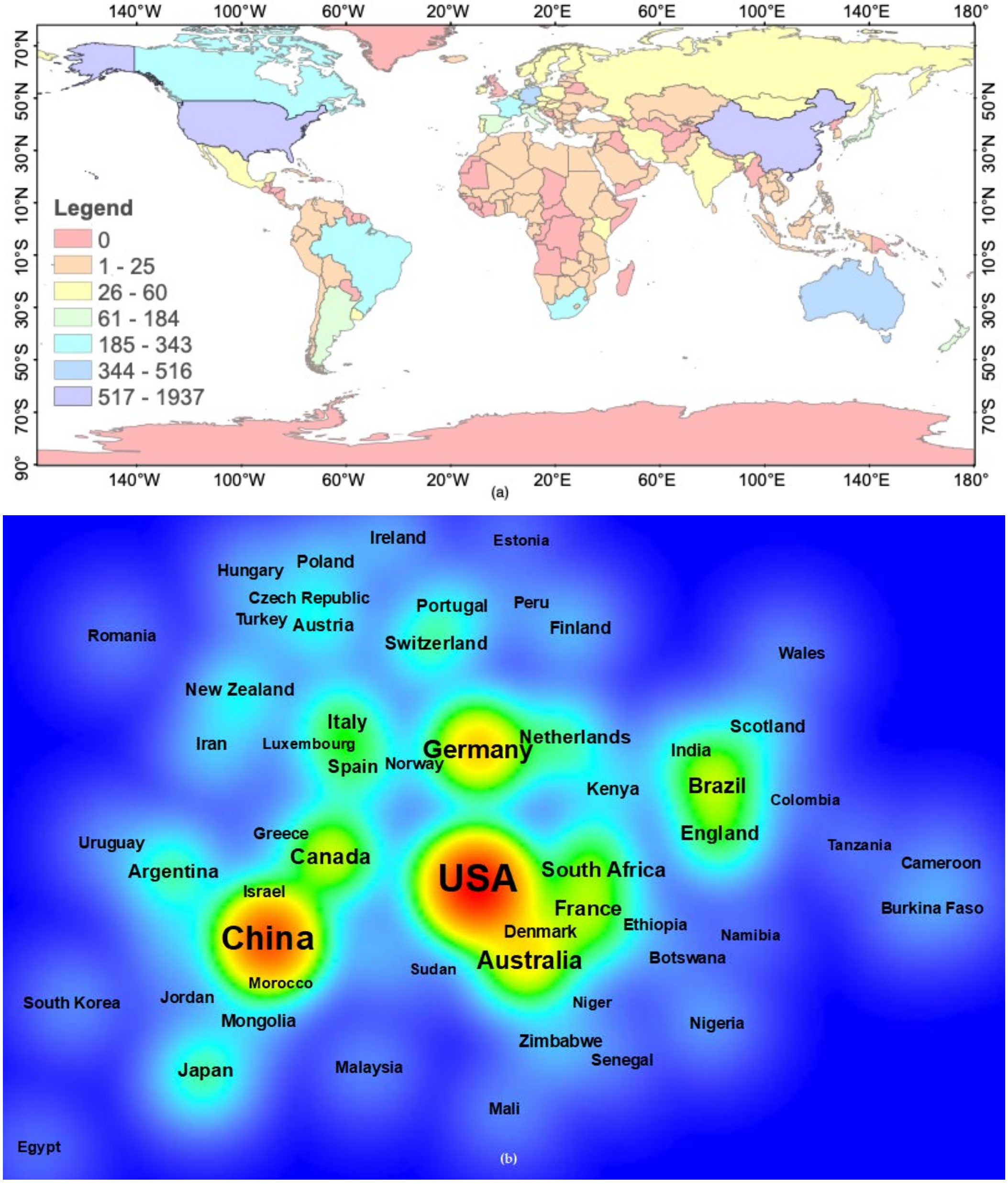


Figure 3. The number of documents per country (**a**) and cooperation density visualization between countries (**b**) in GRS research field.

Table 3. Top 20 journals ranked by the total local citation score (TLCS) in GRS research from 1980 to 2020.

Journal	TLCS	ND	H_i	AC	PY_s	IF
Remote Sensing of Environment *	7261	146	52	50	1980	9.08
International Journal of Remote Sensing *	5586	201	38	28	1986	2.97
Remote Sensing *	2360	185	26	13	2009	4.51
Agricultural and Forest Meteorology *	2282	55	25	41	1994	4.65
Atmospheric Chemistry and Physics	1677	3	3	559	2010	5.41
International Journal of Applied Earth Observation and Geoinformation *	1675	67	25	25	2005	4.65
Journal of Arid Environments *	1619	53	21	31	1984	1.83
Ecological Applications	1256	23	16	55	1994	4.24
ISPRS Journal of Photogrammetry and Remote Sensing	1027	24	15	43	2008	7.31
Agriculture Ecosystems & Environment	958	29	15	33	1991	4.24
Photogrammetric Engineering and Remote Sensing	934	22	15	42	1980	1.26
IEEE Transactions on Geoscience and Remote Sensing	910	28	18	33	1984	5.85
Global Change Biology	888	18	14	49	2004	8.55
Ecology	879	9	8	98	1991	4.7
Rangeland Ecology & Management *	873	61	17	14	2005	2.09
Ecological Indicators *	869	54	19	16	2002	4.22
Journal of Vegetation Science	833	13	10	64	1996	2.69
Biological Conservation	685	14	12	49	2001	4.71
International Journal of Wildland Fire	656	28	11	23	1995	2.62
Ecosystems	647	12	8	54	1999	4.21

Abbreviations: X *, the journal is the core resource of GRS research; TLCS, the total local citation score; ND, the number of documents; H_i, H index; PY_s, published year started; AC, average citation, impact factor (IF) in 2019.

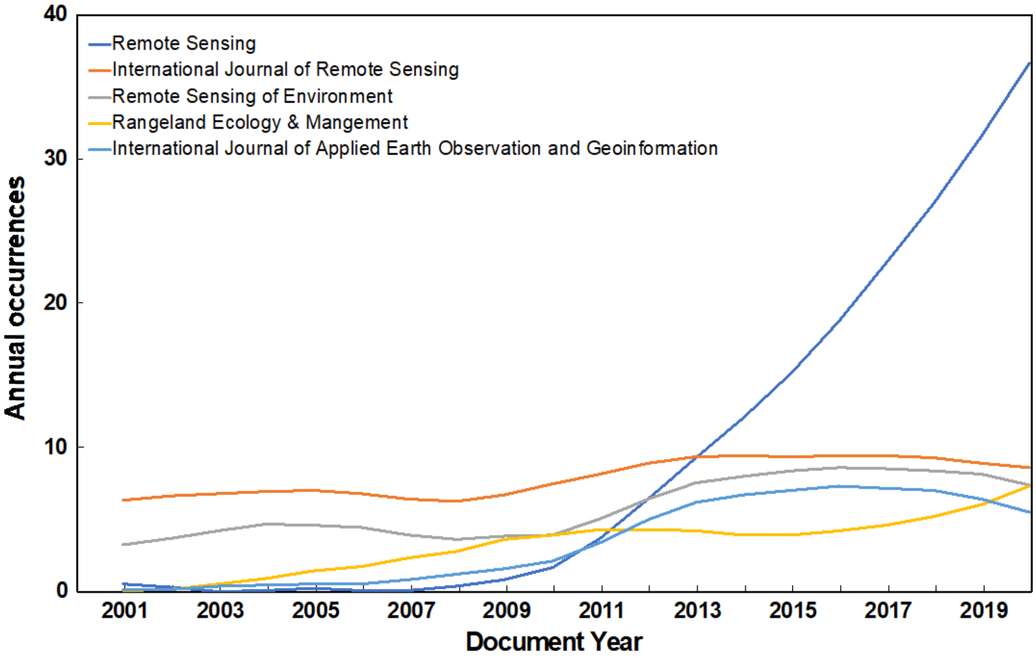


Figure 4. Journal dynamics analysis on GRS research.

Citation statistics have generally been used to evaluate the relative impact of an academic journal. The journals *Remote Sensing of Environment*, *International Journal of Remote Sensing*, *Remote Sensing*, *Agricultural and Forest Meteorology*, and *International Journal of Applied Earth Observation and Geoinformation* also ranked in the top five in terms of citations in these local data. These results indicate a large contribution of document quantity published in a journal to its TLCS value [66]. These results show that these journals not only have a large number of documents but also have an important impact.

3.6. Core Authors

The results of the analysis of authors can identify those who are more active, productive, or cited in GRS research studies and the researcher networks' contribution to GRS studies. The results indicated that the top five authors with the largest number of articles were Guo X.L. (33), Hill M.J. (25), Zhang L. (24), Asner G.P. (23), Paruelo J.M. (23), Xiao X.M. (23) (Table 4). Paruelo J.M. is ranked first, with an average number of citations of 83.08 per article, which is about 33 times higher than that of the second-ranked author. Paruelo J.M., Xiao X.M., Hill M.J., and Asner G.P. are the top four authors in terms of the H index in this dataset (Table 4). According to Price's law, authors who published more than four papers on GRS research are defined as the core authors, of which there are 315. The top 10 core authors are shown in Table 4.

Table 4. Top 10 research authors' local impact ranked by total documents.

Author	TD	TLCS	AC	H_i	TS	Institution	Country
Guo X.L.	33	469	14.21	13	2002–2020	University of Saskatchewan	Canada
Hill M.J.	25	868	34.72	16	1994–2020	CSIRO/University of North Dakota	Australia/USA
Zhang L.	24	575	23.95	12	2007–2020	Chinese Academy of Sciences	China
Asner G.P.	23	1077	46.82	16	1998–2018	Carnegie Institution for Science	USA
Paruelo J.M.	23	1911	83.08	17	1995–2020	University of Buenos Aires	Argentina
Xiao X.M.	23	525	22.82	16	2008–2020	University of Oklahoma System	USA
Xu B.	22	397	18.04	11	2003–2019	Tsinghua University	China
Jin Y.X.	20	348	17.40	10	2013–2019	Chinese Academy of Agricultural Sciences	China
Mathieu R.	20	992	49.60	15	2010–2019	Council for Scientific & Industrial Research	South Africa
Mutanga O.	20	567	28.35	12	2004–2020	University of KwaZulu Natal	South Africa

Abbreviations: TD, total number of documents; TLCS, the total local citation score; AC, average citation score; H_i, H index; TS, time span. TLCS refers to the citation in the data set, not Web of Science.

These 12,935 documents involve 8310 authors. A total of 88 independent authors published 100 studies. The remaining documents have 4.8 co-authors per document on average. The cooperation index is 3.17. Overall, each author contributed 0.324 documents on average, and each document had an average of 3.09 authors. This also indicates that GRS research is typically a multi-author cooperative field (Figure 5). It should be noted that we do not distinguish between the order of authors in their list of names, the calculated document, and the citation; rather, we recorded a name if it was on the list of authors.

3.7. Analysis of the History and the Current Research Hotspots

In this study, there are 11,854 keywords detected in the 2692 documents on GRS research from 1980 to 2020. These keywords were analyzed by co-occurrence, and seven clusters were formed. These clusters are shown in Figure 6 according to the relationship between the weights of the attributes of the links and the total link strength in different keywords. Table 5 lists the top 30 high-frequency keywords detected in the 2692 articles, ranked by the number of occurrences in articles in which they appeared.

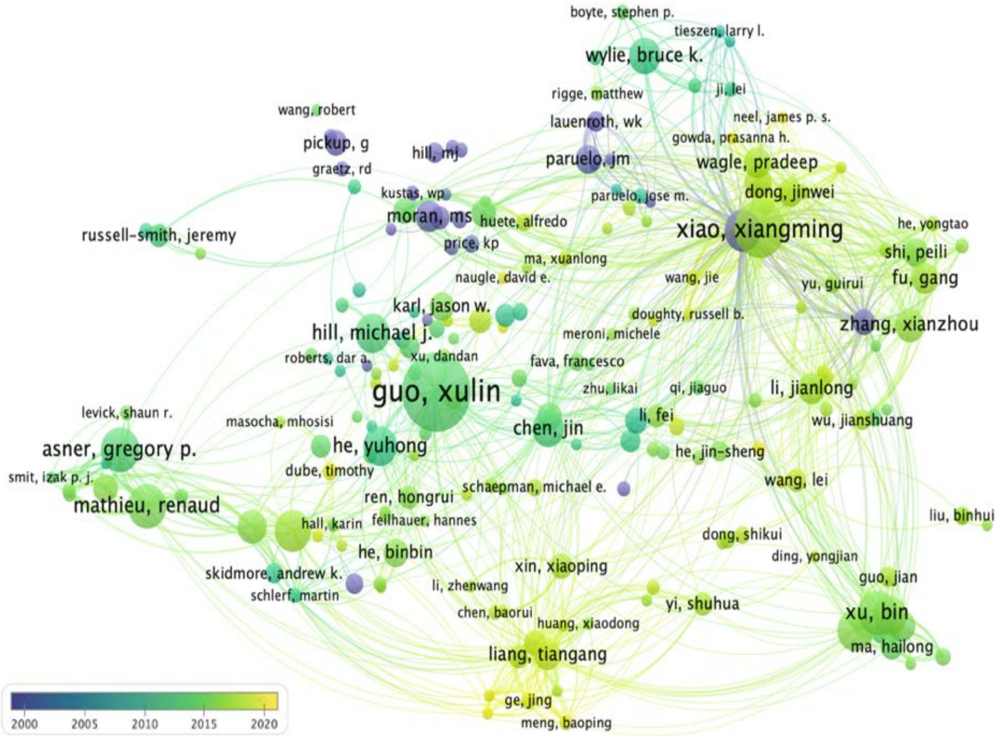


Figure 5. Evolution of authors' network based on the co-occurrence method on GRS research from 1980 to 2020.

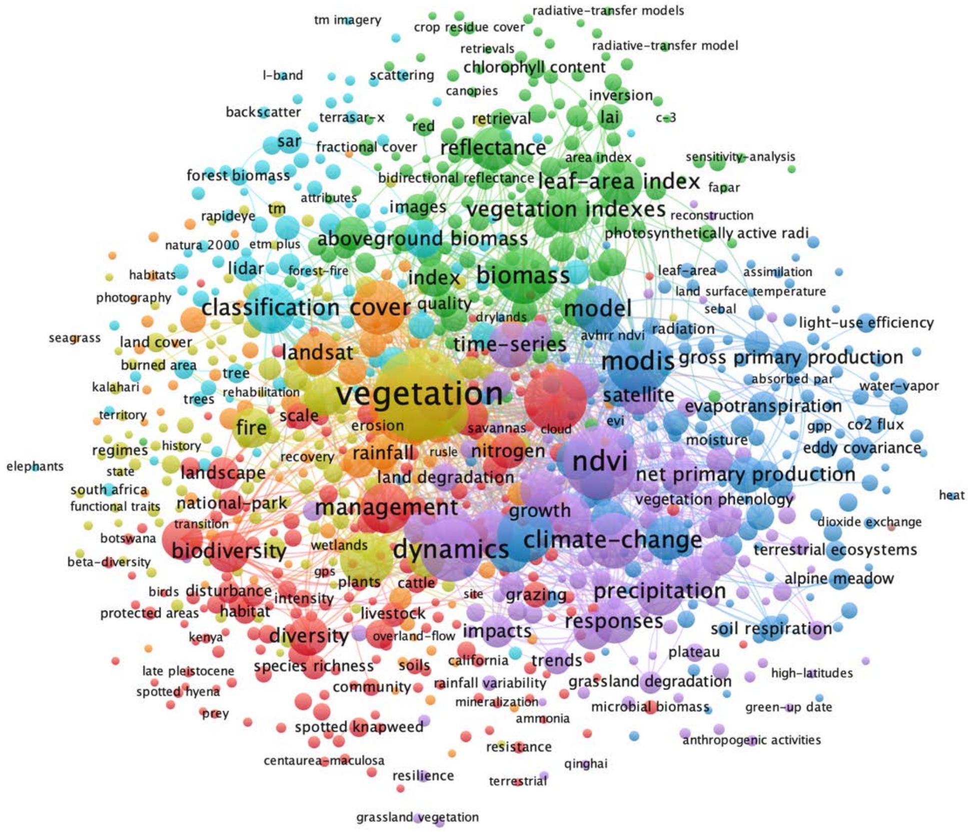


Figure 6. Network of keywords based on the co-occurrence method on GRS research from 1980 to 2020.

Table 5. Top 30 keywords on GRS research studies from 1980 to 2020.

R	Keyword	N	C	L	TLS	R	Keyword	N	C	L	TLS
1	vegetation	476	4	761	3819	16	precipitation	134	5	367	1229
2	Remote sensing	350	7	685	2785	17	Leaf-area index	121	2	352	1050
3	NDVI	306	5	586	2719	18	Time series	119	5	368	1063
4	MODIS	233	3	525	2102	19	Landsat	118	7	413	1079
5	dynamic	229	5	522	1913	20	temperature	114	3	343	960
6	grassland	226	1	583	2005	21	degradation	113	5	344	1020
7	biomass	185	2	485	1568	22	reflectance	113	2	349	925
8	Climate change	179	5	454	1527	23	response	111	5	363	959
9	cover	171	7	483	1430	24	biodiversity	108	1	337	854
10	pattern	164	4	460	1402	25	productivity	107	5	388	1001
11	variability	148	5	429	1302	26	conversion	100	1	315	734
12	classification	146	6	414	1179	27	carbon	98	3	378	884
13	management	146	1	457	1165	28	satellite	95	5	344	861
14	Vegetation indexes	146	2	388	1030	29	savanna	93	4	374	883
15	model	143	3	436	1164	30	phenology	89	5	316	841

R: Rank position; N: number of articles; C: Cluster; L: Weight Links; TLS: Weight Total Link Strength.

The top 30 keywords associated with GRS research studies associated with four variables: remote sensing (NDVI, MODIS, vegetation indexes, model, leaf-area index, time series, Landsat, reflectance, satellite); grassland ecosystems structure (vegetation, grassland, classification, biodiversity, savanna); grassland ecosystems process (dynamic, pattern, cover, variability, management, precipitation, temperature, conversation, phenology), and grassland ecosystems function (carbon, degradation, response).

Figure 6 shows the network of keywords that were selected from the total documents based on the co-occurrence method. The seven clusters of the keywords and their links were grouped, and each group was identified with a different color. The size of each cluster represents their relative contribution to the group with keywords, and the thickness of the tie line between two clusters refers to the number of interactions established between two different communities.

Table 6 shows the seven clusters that were examined. These were labeled using the keyword with the most occurrences and ranked by the percentage of keywords they included, as follows: cluster 1, red: Grassland; cluster 2, green: Biomass; cluster 3, deep blue: MODIS; cluster 4, yellow: Vegetation; cluster 5, purple: NDVI; cluster 6, light blue: Classification; cluster 7, orange: Remote sensing. The weight of the link and the total link strength contributed by each representative keyword are included, and the 10 most important keywords are provided.

Next, Figures A1 and A2 in Appendix A present the keywords with the most links and the highest link strength, which coincide with the terms used in the search of Web of Science to obtain the sample of 2692 articles. Therefore, Figure A2 in Appendix A shows 25,638 links and link strength of 1695 for the keywords “Remote Sensing” and “Vegetation”, which represent the centrality of the study, that is, the most prominent keywords in these studies. The links of five of the strongest keyword links (cluster7) were formed, during the analyzed period, with “Forest” (cluster4-430), “Landsat” (cluster7-413), “soil” (cluster1-411), “time-series” (cluster5-386), and “savanna” (4-376).

Figure A3 in Appendix A shows the 581 links and the link strength of 2719 of the keyword “NDVI”, which represents the third keyword with the greatest number of links and total strength. The five strongest links in “NDVI” (cluster 5) were examined, namely, “Vegetation” (cluster4-476), “Remote Sensing” (cluster7-350) “Grassland” (cluster1-583), “Climate change” (cluster 5-454, “Dynamic” (cluster 5-522), and “MODIS” (cluster 5-522).

Table 6. Identified clusters of keywords on GRS research from 1980 to 2020.

ID	M	C	Name	O	L	TLS	Top 10 Keywords
1	192	Red	Grassland	226	583	2005	Management, biodiversity, conversation, soil, national park, landscape, restoration, livestock, species richness, nitrogen
2	146	Green	Biomass	185	485	1568	Vegetation indexes, Leaf-area index, reflectance, resolution, spectral reflectance, retrieval, imagery, algorithm, regression, hyperspectral
3	145	Deep blue	MODIS	233	525	2102	Model, temperature, climate, carbon, ecosystems, respiration, net primary productivity, water, drought, evapotranspiration
4	123	Yellow	Vegetation	476	761	3819	Pattern, savanna, Land-use, fire, Africa, land cover change, Cerrado, Australia, tallgrass prairie, wildfire, Brazil
5	107	Purple	NDVI	306	586	2719	Dynamic, climate change, variability, precipitation, degradation, productivity, satellite, phenology, responses, time series
6	103	Light blue	Classification	146	414	1179	Land-cover, aboveground biomass, Radar, SAR, random forest, rapid eye, lidar, time series, models, machine learning, unmanned aerial vehicle (UAV);
7	89	Orange	Remote sensing	350	685	2785	Cover, Landsat, rainfall, area, rangelands, impacts, big plains, indicators, encroachment, accuracy

ID: cluster ID; M:O: cluster members; C: color in Figure 6; Occurrences; L: Weight Links; TLS: Weight Total Link Strength.

These key clusters are important forms of visualization for many studies and are highly important for understanding the current research (Figure 6). Next, we introduce and further discuss each research area.

Grassland: During the study period, GRS research studies were focusing on resource monitoring, biodiversity protection, grassland restoration, and precise management of grassland ecosystems using remote sensing technology. The research focuses on soil physical and chemical indicators, the cycles of carbon and nitrogen chemical elements, species richness, and landscape patterns and processes. For example, the main ecological resources in the Three River Resources National Park are alpine grassland and alpine meadow. The habitat is fragile, the terrain is complex, and the grassland ecological environment is heavily degraded [4]. GRS research provides important support for scientific management and dynamic monitoring [56,67,68].

Biomass: The biomass research methods have also undergone tremendous changes from 1980 to 2020. The change in remote sensing techniques, from aerial remote sensing to satellite remote sensing [12,22], has achieved a significant advance in the continuity of research scales and temporal and spatial integrity, and the monitoring accuracy and timeliness have improved considerably [28]. For the model inversion method [18,56], many explorations have been carried out in terms of empirical statistical methods (e.g., image processing algorithm), physical model methods (e.g., radiative transfer model, geometrical optics model), and data modeling methods (e.g., data-intensive scientific discovery, space earth observation data model) [14]. In particular, the widespread application of model inversion methods, such as the vegetation index (NDVI) [8,48,52,67] and leaf area index (LAI) [58,68–70], has greatly promoted the development of grassland quantitative remote sensing [71–74]. The application of vegetation indexes [12,75–77] can reflect the characteristics of different ground features, such as primary productivity (or net primary productivity, NPP) [78,79] and coverage, and has become a research topic of grassland resources [80].

MODIS: Since the development of satellite remote sensing technology and computer technology, the number of satellites, and the spatial and spectral resolution of the payload, have been greatly improved [8,12]. The ability to distinguish and recognize the details of ground features, ecological elements, and their changes, in addition to monitoring accuracy, has also been greatly enhanced. The level of quantitative remote sensing monitoring of grasslands has also been significantly improved [8,12]. Applications are mainly qualitative in GRS research before 2000. One of the important landmark events was that the US Earth Observation System satellite provided MODIS global quantitative remote sensing products in 2000. This enabled GRS research studies to develop more remote sensing physical models [14]. The application of MODIS moved GRS research into the era of quantitative remote sensing [5,19].

Vegetation: The research area is transformed from regional to global, with a critical zone becoming a new focus. Popular research areas include South Africa, China, America, Africa, Canada, and Australia. At present, the key research area is the alpine grassland ecosystem in the Qinghai–Tibet Plateau [71]. From 1980 to 2020, the field of GRS monitoring, and monitoring of objects, gradually expanded. The application of the field is no longer limited to monitoring grassland resources [8,56]. Grassland utilization, land cover change, and qualitative environmental monitoring have gradually expanded to quantitative monitoring of water, soil, and ecological parameters. As a result, significant attention has been paid to the coupling study of ecosystem structure, process, and function [69], particularly for grassland fire and degradation monitoring [19,81].

NDVI: The results from 1980 to 2020 indicated that GRS research has changed from traditional pasture management to placing more emphasis on dynamic monitoring of grassland ecosystems under the conditions of disturbance due to climate change and human activities, particularly current research, which is based on grassland degradation. In recent decades, global climate change and anthropogenic activities have affected the structure and function of ecosystems, and limited sustainable development [82,83]. Fragility, typicality, extensiveness, and sensitivity are important characteristics of grassland ecosystems. Due to these features, NDVI is the most effective indicator to measure the response to climate change and reflect the development process of sustainability [12,84]. Grassland degradation is a major ecological threat [85]. The emergence of keywords, such as phenology and time series, indicates that more attention has been paid to research into the coupling of global climate change and anthropogenic activities and other disturbances, long-term monitoring data, and quantitative inversion processes to achieve grassland degradation management [4,5,35,71,86].

Classification: From 1980 to 2020, the selection of data sources has undergone drastic changes. Due to the development of machine learning technology [20,56], the applications of GRS research have greatly increased. GRS research data sources have developed from a single type of multispectral data (such as MODIS and Landsat TM) to the currently widely used hyperspectral data [12,87], multi-angle data [8,17,74], laser radar data [18], high-resolution data [88], unmanned aerial vehicle (UAV) data [89], and multi-source data. The acquisition of remote sensing data is the vital link to the quality of GRS monitoring and management research.

The acquisition of data can be roughly divided into three key categories: (1) Satellite remote sensing access to information. GRS research monitoring mainly uses satellite remote sensing data [12], such as Landsat TM, SPOT, Landsat MSS, MODIS, and ENVISAT. It is widely used in the estimation of grassland area, monitoring of grassland growth, and remote sensing of pests and diseases. Low-resolution NOAA data is used for large-scale GRS monitoring research [12,90]. High-resolution satellites, such as Quick Bird, IKONOS, and Sentinel-2A [9,12], have been launched successively to provide powerful remote sensing information, thus ensuring that GRS research has more potential opportunities to achieve all-weather grassland monitoring, pest monitoring, etc. They play an important role in coordination with other data (such as microwave remote sensing data) to form the multi-source remote sensing data. Hyperspectral remote sensing has the characteristics of high resolution, strong band continuity, and a large amount of spectral information. It directly allows quantitative analysis of weak spectral differences in ground objects and has developed rapidly in the research of vegetation remote sensing. The use of hyperspectral reflectance data [57] in research on the physiological characteristics of vegetation, such as grassland type identification and classification, the vegetation leaf area index, coverage and biomass estimation, and disaster assessment, has become a necessary condition for vegetation dynamic monitoring and remote sensing yield estimation. (2) Information acquisition by UAVs. Due to the rapid development of remote sensing, the global satellite positioning system, geographic information systems, microcomputers, communication equipment, and other technologies, the remote sensing technology platform of micro-UAVs has made great progress [11,89]. These developments have provided the technology for further development of accurate grassland management using UAVs, effectively overcoming the limitations of traditional satellite remote sensing in data acquisition [11,12,89]. (3) Acquisition of integrated GRS research information from space and ground. The development of related information technologies, such as the Internet of Things, big data, and cloud computing [11,14,15], provides an effective means to quickly obtain grassland ecological information for the construction of a sky–ground integrated information-acquisition technology system for GRS research.

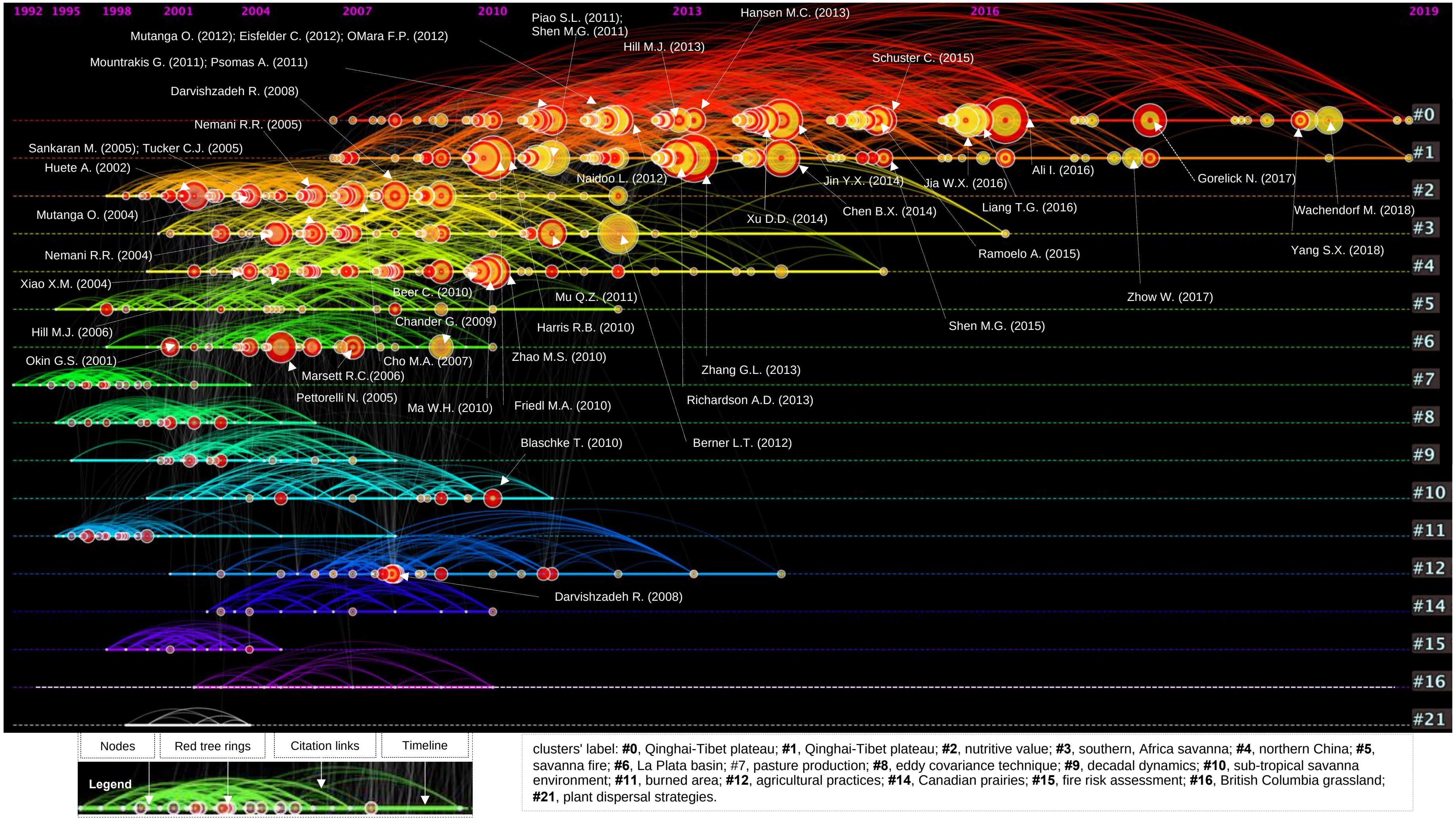
Remote sensing: Before 2000, the key components of grassland remote sensing were atmosphere ecosystem exchange, nitrogen allocation, photosynthesis, primary productivity, glyphosate, and external interference [52,55,63,79,91,92]. Evapotranspiration has been the focus of grassland remote sensing research since 1980, and the word frequency is still very high. From 2002 to 2015, the key research contents were the themes soil moisture, productivity, nitrogen, carbon, water cycle process and soil recovery, *Centaurea maculosa* Lam. and other invasive species monitoring and management [64,65,93]. After 2016, due to the acknowledgement of global climate change and proposal of sustainable development goals 2030 [94], GRS research has paid more attention to grassland sustainable development management, ranging from simply focusing on grassland ecological elements to monitoring and dynamic assessment of grassland ecosystem structure, function, and process [11,12].

3.8. Research Frontiers

The temporal evolution of cited references in GRS research is shown in Figure 7. Using the LLR algorithm, a total of 17 visual clusters were formed, with each representing a future direction according to their activeness in Table 7. The more active the current cluster is, the more it can represent the research frontier. In Figure 7, the color curves represent the co-citation links added in the corresponding color year. Large nodes or nodes with red tree rings are particularly worth exploring because they are either highly referenced, have cited emergencies, or both. Based on their size from Table 7, the clusters are numbered, with cluster #0 being the most massive cluster placed at the top of the graph. The different clusters' timeline has different colors. As the timeline overview shows, the persistence of research content clusters is different. Some clusters last more than 15 years, while others have a relatively short lifespan. Some clusters have stayed active until 2019, the latest year for which references have been cited in this study. The clusters with the top five frequencies and activeness were selected for further analysis. The largest cluster #0 (labeled Qinghai–Tibet Plateau) containing 189 references across a 21-year period from 2007 till 2019 (Table 7). This cluster's silhouette (silhouette is a measure of the similarity between a node and other clusters. The value range is—1 to 1. The larger the value is, the better the node matches its cluster rather than its neighbor. If most nodes have a high silhouette value, clustering is good. As usual, a silhouette value greater than 0.5 indicates the visualization is good) value of 0.84 is the lowest among the major clusters, but this is generally considered a relatively high level of homogeneity. The most active citer to the cluster is Reinermann et al. (2020) [21]. This paper mainly reviewed the literature on grassland production characteristics and management by satellite remote sensing, systematically describes and evaluates the existing research methods and results and reveals the spatial-temporal pattern of the existing research [21]. The second-largest cluster #1 (labeled Qinghai–Tibet Plateau) has 144 members and a silhouette value of 0.854. The most active citer to the cluster is Pan et al. (2017). This study proposes a two-step method (1, the impact of land use change on grassland distribution; 2, the difference between the observed NDVI and the simulated NDVI based on the general linear model) to determine the contribution of climatic and non-climatic driving factors to grassland change in the Qinghai–Tibet Plateau [95]. Although cluster #0 and cluster #1 were both labeled Qinghai–Tibet Plateau by the LLR, the research focuses were different. Cluster #0 refers to the classification and production, and cluster #0 refers to alpine grassland's response to climate change. Unlike other clusters, these two clusters full of high impact contributions—large citation tree rings and periods of citation bursts colored in red. Since 2007, the first reference document of the cluster appeared in both clusters. Since 2010, the results of the two clusters have increased, and there are a lot of red tree rings. In the process of cluster development, many landmark documents appeared in 2010, which need to be focused on. To date, this kind of research remains active. This indicates that GRS research on Qinghai–Tibet Plateau has received increasing attention from scholars, ranging from traditional vegetation classification, dynamic monitoring, and risk assessment, to remote sensing research with grassland degradation as the core, particularly in the context of global climate change. The study of the grassland ecosystem response is a hotspot of current research. The third-largest, cluster#2 (labeled nutritive value), has 131 members and a silhouette value of 0.83. The 10-year period from 2001 through to 2010 is a highly active period of the cluster. The literature of this cluster increased from 2002 to 2009, and many articles were presented in a short period. After 2010, the cluster showed a declining trend, and the active time was up to 2012. This cluster was mainly mentioned in the mapping of grass nutrient element concentrations and vegetation index. The fourth-largest, cluster #3 (labeled southern Africa Savannah), has 103 members and a silhouette value of 0.84. Through the co-occurrence statistics of keywords, it was found that many scholars are paying attention to the grassland ecosystem dynamics in this area, mainly in response to drought climate stress, and prediction and management. The fifth-largest cluster, cluster #4 (labeled northern China), has 102 members and a silhouette value of 0.85. The grassland in northern China is mainly concentrated in Inner Mongolia. In addition to the arid climate, high grazing intensity is also an important feature of the region.

Table 7. Temporal properties of all clusters.

Cluster ID	Size	Silhouette	From	To	Duration	Mean (Year)	Sustainability	Activeness	Label (LLR)
0	189	0.84	2007	2019	13	2013	++++	Active	Qinghai–Tibet plateau
1	144	0.85	2007	2019	13	2012	++++	Active	Qinghai–Tibet plateau
2	131	0.83	1998	2012	15	2004	+++++	Active	nutritive value
3	103	0.84	2001	2016	16	2007	+++++	Active	southern Africa savanna
4	102	0.85	2000	2015	16	2007	+++++	Active	northern China
5	78	0.93	1995	2012	18	2003	+++++	Inactive	savanna fire
6	77	0.85	1998	2010	13	2004	++++	Inactive	La Plata basin
7	70	0.94	1992	2004	13	1997	++++	Inactive	pasture production
8	64	0.96	1995	2006	12	2001	+++	Inactive	eddy covariance technique
9	50	0.91	1996	2008	13	2003	++++	Inactive	decadal dynamics
10	44	0.90	2000	2011	12	2006	++++	Inactive	sub-tropical savanna environment
11	41	0.96	1995	2008	14	1999	++++	Inactive	burned area
12	39	0.91	2001	2014	12	2007	+++	Inactive	agricultural practices
14	23	0.99	2003	2010	8	2006	++	Inactive	Canadian prairies
15	22	0.99	1999	2005	7	2002	++	Inactive	fire risk assessment
16	12	0.99	2002	2010	9	2005	++	Inactive	British Columbia grassland
21	6	1	1999	2004	6	2002	++	Inactive	plant dispersal strategies



clusters' label: **#0**, Qinghai-Tibet plateau; **#1**, Qinghai-Tibet plateau; **#2**, nutritive value; **#3**, southern, Africa savanna; **#4**, northern China; **#5**, savanna fire; **#6**, La Plata basin; #7, pasture production; **#8**, eddy covariance technique; **#9**, decadal dynamics; **#10**, sub-tropical savanna environment; **#11**, burned area; **#12**, agricultural practices; **#14**, Canadian prairies; **#15**, fire risk assessment; **#16**, British Columbia grassland; **#21**, plant dispersal strategies.

Figure 7. Visualization of clusters in terms of timeline view of the document co-citation analysis (DCA) in GRS research from 1980 to 2020. The horizontal axis represents the year, each node represents a popular cited reference, and the size of each node is proportional to its cited frequency, red tree rings mean the burst. The line between each node represents the temporal evolution of the cited reference, and the line thickness represents the co-citation strength; these lines reflect the relationship between transfer and inheritance among cited references [32,33,36].

Based on the analysis of the burst literature (Figure 8), the results indicated that the current GRS research focuses on alpine grassland in China and temperate grassland in northern China (Inner Mongolia). These studies were carried out against the background of global climate change and intensified grazing. The data sources were mostly multi-satellite remote sensing data (WorldView-2 data, satellite-derived NDVI), based on the Google Earth Engine [96]. The research methods mainly used the Carnegie–Ames–Stanford approach based on remote sensing [18], MODIS vegetation indexes, the random forest or random forest regression algorithm, modeling, and WorldView-2 imaging [97,98]. The research focused on the biophysical characteristics, phenological processes [12,74], and grassland management characteristics (degradation and grazing effects), and differentiated between the contributions of the influences of climate change and anthropogenic activities to NPP [99–102]. These can better predict future climate to help cope with the impact of global climate change on humans and to more quickly achieve sustainable development goals.

References	Year	Strength	Begin	End	2000 - 2020
Ali I, 2016, J PLANT ECOL, V9, P649, DOI	2016	**16.13**	2017	2020	
Huete A, 2002, REMOTE SENS ENVIRON, V83, P195, DOI	2002	**13.84**	2005	2010	
Harris RB, 2010, J ARID ENVIRON, V74, P1, DOI	2010	**13.5**	2014	2018	
Gorelick N, 2017, REMOTE SENS ENVIRON, V202, P18, DOI	2017	**11.9**	2018	2020	
Chen BX, 2014, AGR FOREST METEOROL, V189, P11, DOI	2014	**11.31**	2016	2020	
Richardson AD, 2013, AGR FOREST METEOROL, V169, P156, DOI	2013	**10.59**	2017	2020	
Liang TG, 2016, REMOTE SENS ENVIRON, V186, P164, DOI	2016	**9.81**	2018	2020	
Ramoelo A, 2015, INT J APPL EARTH OBS, V43, P43, DOI	2015	**9.51**	2018	2020	
Zhang GL, 2013, P NATL ACAD SCI USA, V110, P4309, DOI	2013	**9.37**	2015	2020	
Jin YX, 2014, REMOTE SENS-BASEL, V6, P1496, DOI	2014	**9.17**	2017	2020	
Hansen MC, 2013, SCIENCE, V342, P850, DOI	2013	**8.82**	2016	2020	
Poulter B, 2014, NATURE, V509, P600, DOI	2014	**8.55**	2018	2020	
Mutanga O, 2012, INT J APPL EARTH OBS, V18, P399, DOI	2012	**8.55**	2018	2020	
Pettorelli N, 2005, TRENDS ECOL EVOL, V20, P503, DOI	2005	**8.29**	2008	2013	
Jia WX, 2016, ECOL INDIC, V60, P1031, DOI	2016	**8.25**	2017	2020	

Figure 8. Top 15 references with the strongest citation bursts in GRS research. 'V' refers to the journal's volume, 'P' refers to the document's page. The light green line refers to 'sustaining period'. The red line means under the timeline. The length of 'burst' represents 'burst duration'.

From the perspective of document co-citation analysis (DCA) and burst analysis, the integral results show that GRS research mainly focuses on the following three aspects:

(1) Grassland growth monitoring, including grassland coverage, productivity, and biomass [10,17], in addition to grassland classification [8,9] and area monitoring. The current monitoring methods mostly combine remote sensing data and ground-measured data and use a variety of vegetation indices to build models to estimate the growth of grasslands. This is a long-term and basic monitoring task. The results of a literature review of the research hotspots until 2020 showed that the core goals of GRS research would continue to be improving the quality of grassland ecological environment and achieving sustainable development by 2030, focusing on grassland degradation, climate change, and soil properties.

(2) Research on the process of grassland ecosystem management [5,16,50,55,103], including grassland degradation and restoration, stocking capacity estimation, crude protein content estimation, and alien species invasion monitoring. Studies have focused on nitrogen, carbon, and water cycle processes in grassland [4,16,104], and phenology is also an important research topic [5,8,9,22,74,105,106]. Most of the early grassland resource research did not classify grasslands or distinguish dominant species, poisonous weeds, etc. [93], and used the overall coverage, NPP, biomass, etc., for aims such as determining grassland

degradation [16] and estimating grass yield and rough protein content. Due to the wide application of high-resolution and hyperspectral remote sensing data, quantitative analysis of the spectral characteristics of different grassland species, and in-depth research on multi-temporal monitoring of different vegetation indices [107–110], model parameters have been continuously optimized [11,12,14,20]. These parameters can be used to effectively identify different grassland types in the community, and determine the height, coverage, and area ratio of the grassland, thus providing complete monitoring of the succession processes of grassland communities. Therefore, these works can provide more accurate scientific references for grassland degradation monitoring and restoration, stock carrying capacity assessment, and alien species invasion monitoring.

(3) Dynamic monitoring and prediction of grassland disasters, including fires, snow disasters, droughts, and insect disasters. One of the important functions of satellites is monitoring various natural disasters in large areas using, for example, high temporal and spatial resolution remote sensing and satellite radar [8,111]. At present, most research focuses on the causes, early warning systems, post-disaster evaluation, and recovery following fires, snow disasters, and droughts [103,112,113]. Few studies have been conducted on insect disasters [114]. Drought and fire have consistently been grassland research hotspots in arid areas [18,46]. By monitoring the soil water deficit of grassland and changes in grassland productivity, a grassland drought warning evaluation system can be constructed. Topography has large impacts on remote sensing, and thus GRS research, like Qinghai–Tibet Plateau, which is a huge challenge of GRS applications [115,116]. Furthermore, by tracking and monitoring the dynamic process of grassland fires, accurate detection of the location and scope of fires can be used to assess the area affected by the disaster, the loss of the affected biomass, and the loss of property. Due to the future development of satellite remote sensing technology, continuous improvement is inevitable in spectral band sensors, such as ground temperature and brightness. In turn, the capability for soil moisture monitoring and the spectral identification of fire spots, and the ability to prevent and reduce disasters, will continue to be strengthened. In terms of grassland pest monitoring, meter-level and sub-meter-level high-resolution remote sensing images are required to monitor the types and quantities of pests, and the level of disasters can be further determined by the difference in the spectral characteristics of the grassland before and after the disaster.

3.9. Limitations

This study also has some limitations. Firstly, the research documents' scope was limited to the core collection of Web of Science. Thus, a broader scope of analysis was lacking, such as the comparison with Google Scholar. Although an analysis of "competitiveness" without considering the external influence is valid, if a comprehensive competitive judgment is made regarding an organization, journal, or author, more extensive supporting data is required, rather than solely relying on internal data from closed research. Secondly, literature retrieval is the basis for further analysis, using "grass*" retrieved more papers than using "grassland*" due to including agronomic issues and "artificial grass". In fact, most of the "natural grassland" has been experiencing human impact. Semi-natural and "artificial grassland" are major components in some regions or countries. Using "grassland" excludes not only papers on lawns, etc., but also some papers relevant to grassland. Therefore, the definition of "grass" and "grassland" in GRS studies needs to be further explored, and relevant researchers need to give a full explanation, which is also conducive to breaking the disciplinary barriers. Thirdly, there are also limitations in keywords analysis. Keywords were selected to avoid repetition with the title in some journals or by some authors to enhance the opportunity to retrieve. At the same time, they may repeat some words in the title for other articles. Furthermore, there is no common list or formal requirements of keywords, leading to inconsistency in selecting keywords in all the articles. Besides, the number of keywords is not the same for all the articles, though mostly five. Therefore, keyword analysis is only a part of the scientometrics analyses. Lastly, the results of the influential documents and authors detected by the DCA method must be supported by many data from later investigations and applied on a specific time scale. Besides, it is impossible to judge the value of individual studies over a short period. Therefore, this method is not conducive to the evaluation of the latest published research. Finally, only documents were chosen in this study as the research object and extensive data support was lacking. Future investigations should collect more data to yield a more systematic and comprehensive interpretation.

4. Conclusions and Expectations

We presented a comprehensive overview of the GRS research field from 1980 to 2020 using scientometrics analysis. In the past 40 years, GRS research has experienced exponential growth in the number of articles published, from 4 articles in 1980 to 256 articles in 2020. Over the past decade, the number of articles published has exceeded 100 documents each year, maybe due to freely available Landsat data since 2008. Results of the study showed that the United States, China, and Germany were the main research countries; the Chinese Academy of Sciences was the main research institution; influential journals included *Remote Sensing*, *International Journal of Remote Sensing*, and *Remote Sensing of Environment*; and Guo X.L., Hill M.J., and Zhang L. were the core authors.

4.1. Research History

GRS research has experienced nearly 40 years of development. The content of applied research has gradually expanded, the accuracy of grassland resource monitoring has significantly improved, and the timeliness of grassland ecological monitoring has been greatly enhanced. The temporal and spatial resolution of the earth observation satellite system has experienced significant development. The selection of grassland remote sensing data sources from 1980 to 2020 has developed from a single type of multispectral data (such as MODIS and TM) to the currently widely used hyperspectral data, multi-angle data, lidar data, high-resolution data, drone data, and multi-source data.

The extraction of grassland remote sensing information has progressed from the era of digital signal processing, through the era of quantitative remote sensing, to the era of remote sensing big data. The wide application of model inversion methods, such as the NDVI and many other vegetation indices, has greatly promoted the development of grassland quantitative remote sensing. The research content indicates that the monitoring of grassland resources is directed to the structure, function, and process of grassland ecosystems. The development of these functions has focused more on the study of grassland ecosystem structure and response against the background of global climate change [48], and the research area has also moved from large-scale monitoring to key zone management.

4.2. Future Development Trends and Expectation

At present, due to the continuous development of the combination of high-temporal-spatial resolution and hyperspectral remote sensing, advanced sensor technology and a variety of mathematical models are becoming more mature. Microwave remote sensing and UAV technology are widely used in GRS monitoring research. DCA and burst results showed that frontier GRS research using multi-source data and quantitative methods will assist in the study of the structure, function, and process of the alpine grassland ecosystem in the Qinghai–Tibet Plateau under the background of climate change. Topology is also the focus of future research. This research can also better predict the natural disaster risks of the savanna. Cross-regional coupling research and coping with climate change will be the focus of future research.

The accuracy of grassland ecological information based on remote sensing data is the key to grassland ecosystem management decision-making. At present, the models and algorithms for GRS monitoring research mainly rely on regression or data models. Therefore, it is necessary to establish expert systems suitable for the automatic interpretation of remote sensing images. These systems could allow the automatic extraction of thematic information from remote sensing images, establish various new and efficient remote sensing image processing methods and algorithms, increase the combination of artificial intelligence technology and remote sensing technology, and apply deep learning to remote sensing technology to achieve instant and large-scale multi-source heterogeneity. Remote sensing data processing, including correction, fusion, and visualization of remote sensing information, will shorten the time required for interpretation of remote sensing images, improve interpretation accuracy, and transform the application of grassland remote sensing technologies. In turn, this will optimize remote sensing image processing methods, including improvement of various vegetation indices and remote sensing inversion models, and allows the construction of a large area monitoring and service platform (Google Earth Engine) through WebGIS technology. Meanwhile, solar-induced chlorophyll fluorescence as an emerging technique needs more investigation and application in future GRS research. Monitoring systems can be established and improved for different regions and grassland types to create conditions for the development of precise animal husbandry.

Regarding the application of GRS study in the future, quantitative remote sensing will continue to be a research hotspot. To achieve real-time and dynamic evaluation of grassland resources and achieve the sustainable development management of grassland ecosystems, relevant theories should be constantly improved. Empirical research based on these theories should be conducted from the perspectives of optimal management of grassland resources, monitoring of disasters (such as fire and snow), and grassland degradation monitoring and prediction.

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Appendix A

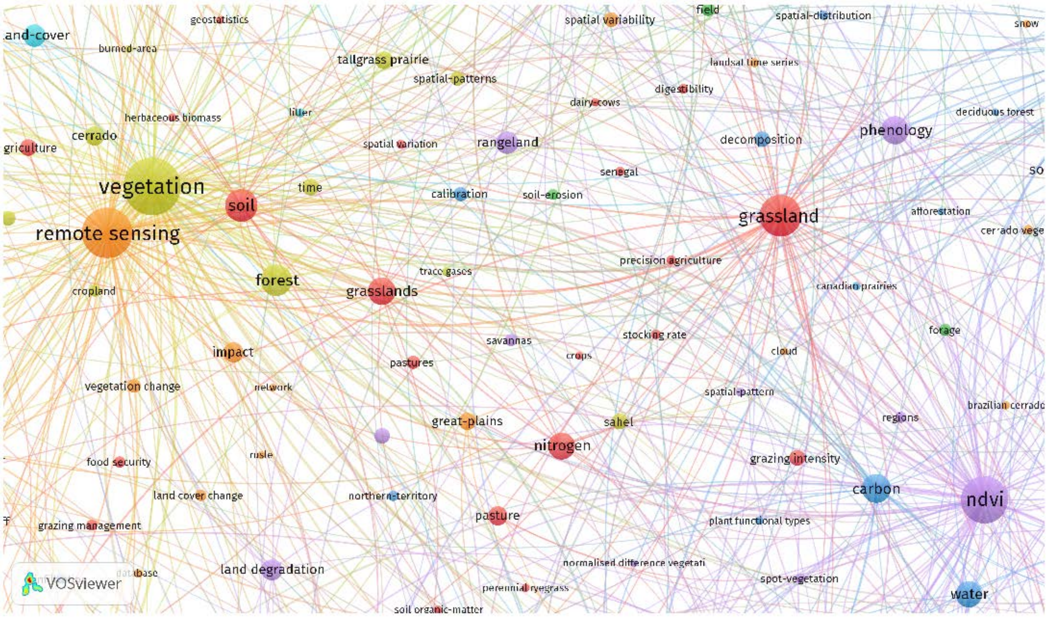

Figure A1. Core links between "Remote Sensing", "Vegetation" and "NDVI" keywords zoomed-in Figure 6 from 1980 to 2020.

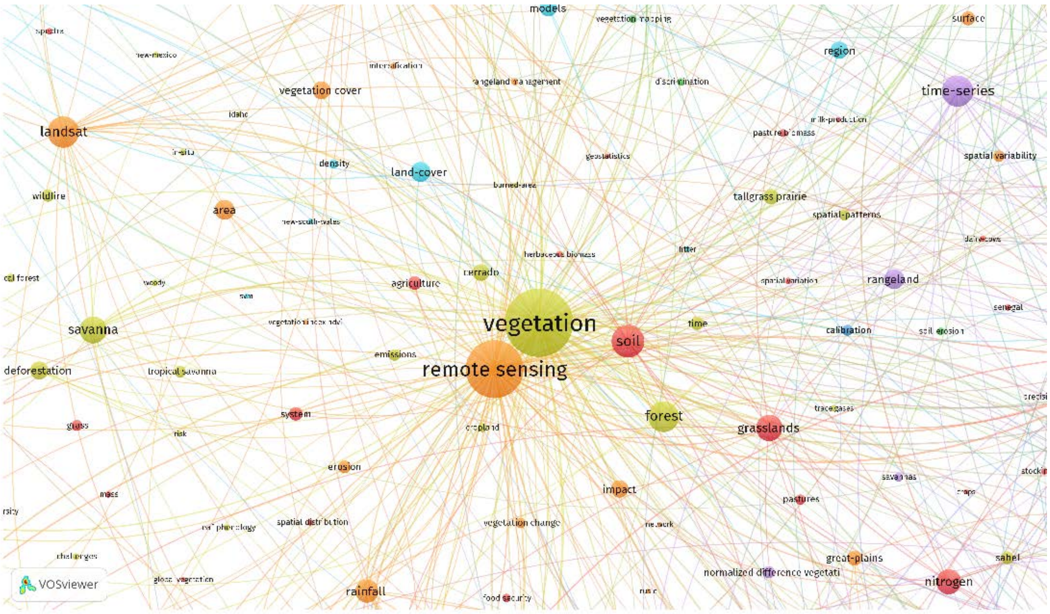

Figure A2. Links of the "Vegetation" and "Remote Sensing" keyword zoomed-in Figure 6 from 1980 to 2020.

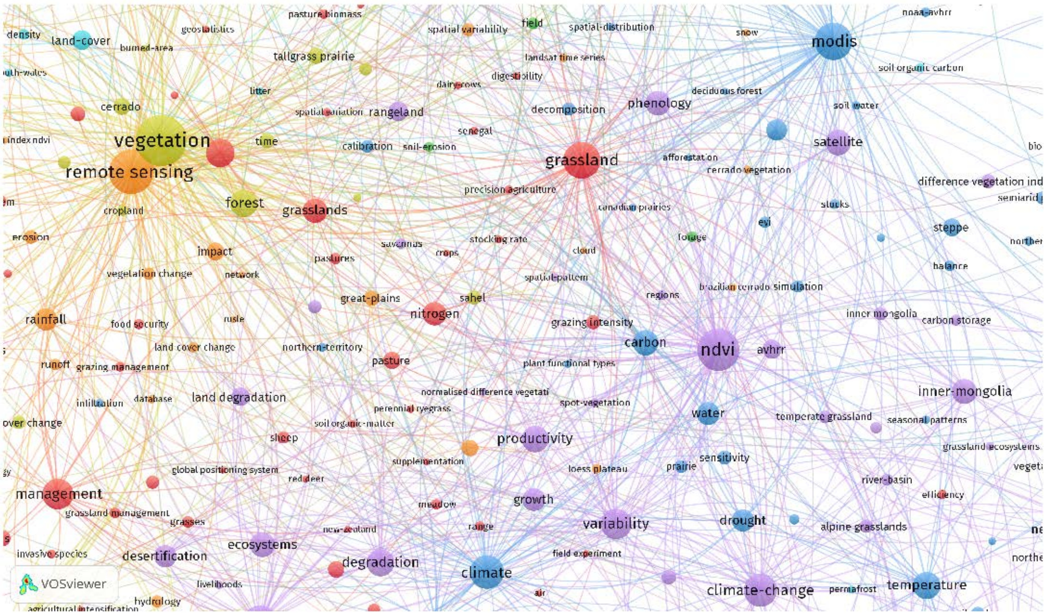

Figure A3. Links of the "NDVI" keyword zoomed-in Figure 6 from 1980 to 2020.

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