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RESEARCH ARTICLE

A bibliometric review of vegetation response to climate change

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Abstract

Global assessment of vegetation response to climate change (VRCC) studies was conducted to reveal the research evolution, current research hotspots and better understanding of dominant themes in VRCC areas of research from 1992 to 2019 through the use of bibliometrics. A total of 186 articles with the search term "Vegetation response to Climate change" were retrieved using the Web of Science (WOS) database. The annual growth rate of 10.3% connotes that research on VRCC has been increasing over time during the survey period. Average citations per article experienced many fluctuations over the years rather than maintaining the same growth rate, which connotes that this field of research reached was unstable in terms of average total citation per document. Results show that China ranked first followed by the USA and the UK, and this shows the dominance of these countries on VRCC studies over the years in review. Results from corresponding authors' nationalities show that multiple-country publications are relatively low compared to articles from single-country publications which showed a dominant trend. Hence, we can infer that most studies on VRCC were sustained by single-country publications. Results from this study revealed top-cited articles, the top global distribution of documents, academic collaboration, most relevant keywords and Word TreeMap of high-frequency keywords. The findings of this study show that "temperature" is in a central position in all keywords with the largest significant appearance in the field. In conclusion, the findings from this study may be applicable for planning and managing vegetation and forest ecosystem research and provide hints for future development.

Keywords Bibliometrics · Climate change · Precipitation · Temperature · Vegetation

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Introduction

Climate change impacts on vegetation dynamics are expected to increase due to extreme climate events such as increasing temperatures, changes in rainfall patterns, increased solar radiation and other climate-related events (Walther 2010; Pricope et al. 2013; Wang et al. 2018). Vegetation is an integral part of terrestrial ecosystems and crucial to the various roles in ecological cycles, representing the status of ecosystems (Yevide et al. 2016; Pan et al. 2018). Studies have reported that a large portion of the earth's biodiversity is predicted to be susceptible to extermination (Mishra et al. 2010; IPPC 2014). The degree to which vegetation degradation affects the ecological cycle through its response to changing climate is a global issue, receiving little attention, especially in developing nations with particular emphasis on public health and social impact (Turner et al. 2013). The disruption in the pattern of vegetation through climate change, land-use change and other disturbances are derived from those alterations (Dale 1997; Shukla et al. 2019). Vegetation dynamics have undergone extreme climate

change events both in Asia, the USA, Europe and Australia including Africa with agricultural drought hazards, landslides, flooding and drastic decline of vegetation among others (Hou et al. 2015; Afuye et al. 2018; Busayo et al. 2020; Walz et al. 2020). Climate variability and changes in land-use dynamics result in major changes in vegetation, which are among the most influential driving factors for vegetation dynamics under global change (Tucker et al. 2001; de Jong et al. 2012; Afuye et al. 2021).

Globally, the pressure on biodiversity has increased as a result of natural and human disturbances which modify the composition and function of vegetated ecosystems (Dubey et al. 2019). Consequently, climate change interaction with vegetation resulting from land degradation, in turn, affects local climate and surface energy balance (Jetz et al. 2007). The intense human practices such as urbanization, logging, mining and deforestation have significantly altered the functioning of the ecosystems (Zipper et al. 2011; Wang et al. 2017; Orimoloye and Ololade 2020). The culmination of different anthropogenic activities over the years has led to a decline in the supply of resources for vegetation to thrive (Leitinger et al. 2010; Afuye and Ojeh 2017; Orimoloye and Ololade 2021). The "UN-Habitat" affirms its support for the global intervention for human settlements to expand its support for climate resilience, reducing emissions and conservation planning outcomes in the world's habitats and the formulation of policy recommendations on sustainable development for policymakers (United Nations 2015). At the international scene, many organizations are grappling to deal with global environmental issues and to promote and propose policy tools in addressing evolving ecosystem threats from global climate change (Crate et al. 2008; Wheeler 2013). Several existing policies have been counterproductive in effectively responding to climate change with regard to the extent of land-use change patterns in line with vegetation dynamics (Wu et al. 2015; Komljenovic et al. 2016). Therefore, the formulation of local-level policies with regard to vegetation, forest, ecosystems and biodiversity conservation would, in turn, make up on how the global level concerns are strengthened in terms of policy implementation and communication of research outcomes to the final users. Hence, it is important to conduct a bibliometric review that provides the evolution of studies on vegetation response to climate change.

This bibliometric was carried out to determine the research trends and academic collaboration networks. This method has been widely used in different fields of study (Seppelt et al. 2011; Wang et al. 2011; Zhang et al. 2016; Estoque et al. 2019). A review of academic literature has resulted in a new approach called bibliometric or scientometric which leads to a scientific understanding of a research niche area (Wang et al. 2011; Wei et al. 2014). This method can serve as an impetus for researchers to advance studies in their areas of specialization; hence, the findings from this type of review exert influence on productive authors, countries and affiliations among others (Zhuang et al. 2013; Tan et al. 2014; Zhang et al. 2018). Studies have reported that bibliometric review can be used to evaluate the focus of national and international studies and to define possible research goals, funding sources and academic research collaborations (Fedderke and Goldschmidt 2015; Zhang et al. 2019). Literature has linked bibliometric studies with a conceptual-theoretical review based on the existing literature or studies (Sarto et al. 2014; Zhang et al. 2016; Zhang et al. 2018). Furthermore, bibliometric analysis is a methodological approach for evaluating both the quantitative and qualitative scope and the appropriateness of research efforts in an area of expertise (Elango and Rajendran 2012; Ellegaard and Wallin 2015). This study appraised published articles on vegetation response to climate change (VRCC) studies. More so, the study navigates the rich tapestry of VRCC studies, analysis of top-cited articles, the top global distribution of documents, academic collaboration, most relevant keywords and Word TreeMap of high-frequency keywords.

Data identification and methodology

The Web of Science (WOS) Core Collection database was used to systematically mine data for this study on March 14, 2020, as shown in Table 1. The bibliometric analysis was carried out using the bibliometrix R-package (RStudio v.3.4.1 software) and biblioshiny, an application providing a web interface for bibliometrix (Aria and Cuccurullo 2017). The h_index and g_index calculations are captured in the R code using the bibliometric package. These are available open-source software. All publications related to VRCC research were searched using the search terms "Vegetation response to Climate change" in the title field and filtered; 186 articles on VRCC were retrieved from the years 1992 to 2019. Data were obtained in the BibTeX file format and analysed using the RStudio software (Aria and Cuccurullo 2017). R programming was used to import the data and transformed it into a bibliographic data frame and optimized for matching duplicates (Ekundayo and Okoh 2018; Aria et al. 2020). Previous studies show the importance of the author's keywords, and their effectiveness across a specific field of study is key in traversing research trajectories (Zhang et al. 2017; Chen et al. 2019). The high-frequency keywords provided in this study would help researchers to understand the intellectual domain of VRCC and also to provide research hotspots in the field with relevant conceptual guidelines and direction for future studies. However, this paper cannot generalize scholarship on VRCC in other fields other than the core areas of vegetation response to climate change having its limitation using one database as other databases can be integrated to quantify the possible research developments and

improvements. Thusly, it is burdensome to generate a dataset that would capture the whole areas of VRCC research across different disciplines. Hence, the analysis was streamlined and focused on major studies that explored VRCC to accommodate the niche area. The analysis and discussion borders in the interest of vegetation response to climate change studies. The names of authors, the keywords of authors (DE) and Keywords-Plus(ID) were derived for uniformity. Authors' names were derived twice as two separate sets (P and Q) (Aria et al. 2020). The variant author's names were tested for each set and spelling errors and matched to affiliations, and names of normalized authors are obtained when

$$|P \cap Q| \equiv |P \cup Q| \quad (1)$$

Co-occurrence of a term in the keywords (DE set) and keywords-plus (ID set) of authors in the dataset was evaluated as a set made of the two sets intersecting the other and therefore:

$$\left(DE \cap ID \| \right) \quad (2)$$

Results

The analysis of 186 articles published on VRCC during the period of study has been presented in this study. The evaluation of journals, books, etc. involves 114 sources with 937 authors' appearances with 0.235 articles per author (4.25 authors per article) and 5.04 co-authors per article. A collaboration index of 4.42 with 790 authors has been involved among which 782 authors have authors of multiple-authored articles, while 8 authors have authors of single-authored articles published as presented in Table 1. The average annual percentage growth rate was 34.75% of citations per article recorded during the survey period. The annual percentage growth rate was 10.3% with an overall mean of 3.2±16.01, suggesting that global research on VRCC has been increasing over time particularly during the survey period. Research output fluctuated during the survey period with a high peak in 2019 which accounted for 15.1% (28/186) of the total, as a result of more detailed advances in research, followed by the year 2018 with 21 research articles accounting for 11.3% (21/186). The main information on the collection of the database in terms of the number of document counts, authors, sources, keywords and average citations is shown in Table 1. The study employed (WOS) database from 1992 to 2019 to gather scholarly research publications on VRCC studies spanning 27 years using bibliometric analysis. The bibliometric exploration used in vegetation response to climate change studies is, therefore, categorized into themes to reveal the research evolution, current research hotspots and a better understanding of dominant themes in VRCC areas of research.

Table 1 The summary information on retrieved vegetation response to climate change studies

Description	Results
Web of Science (WOS)	Counts and rates
Documents	186
Sources (journals, books, etc.)	114
Keywords-Plus (ID)	793
Author's keywords (DE)	490
Period	1992–2019
Average citations per document	34.75
Authors	790
Author appearances	937
Authors of single-authored documents	8
Authors of multi-authored documents	782
Single-authored documents	9
Documents per author	0.235
Authors per Document	4.25
Co-Authors per Documents	5.04
Collaboration Index	4.42
Document types	
Article	148
Articles, book chapter	2
Articles, proceedings paper	4
Correction	2
Editorial material	5
Letter	1
Meeting abstract	1
Proceedings paper	17
Review	6

Analysis of top-cited articles

The amount of published articles in a field is usually considered an important metric to measure the influence of an author in a particular field of research. The amount of publications by academic scholars indicates their research strength and the quality of their research (Wang et al. 2018). The number of annual cited articles describes the average total citations per year and the annual growth of trends of citation (Fig. 1).

The number of annual cited articles in VRCC shows the annual growth of trends of citation. Average citations per article peaked in around 1995 and 1999 and a high peak in 2001, and an overall decline was observed in 1997 and 2019 suggesting that the average article citation for those periods was significantly low in the field as presented in Fig. 1. The year 2006 has no publication for that particular year; hence, the overall trend continues

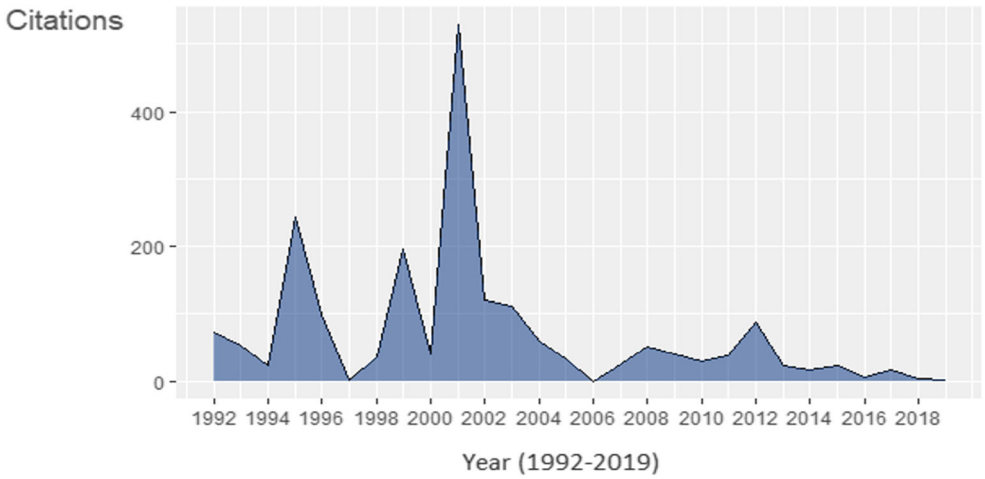

Fig. 1 The number of annual cited articles in VRCC studies

to grow and then fluctuates between 2016 and 2019, respectively. Notably, it can be observed that the average citations per article experienced many fluctuations over the years, rather than maintaining the same growth rate. The average citations per article declined which connotes that the field of research was unstable in terms of average total citation per document (Ellegaard and Wallin 2015). During the survey period, a rapid increase was observed between 1995 and 1999 with an average citation per article, reaching a maximum of 9.78 and 9.3, respectively, while the maximum growth of top-cited articles was noted between 2001 and 2002 with the highest average citations per article reaching 27.8% within the survey period.

Bibliometric measurement of research output

The function Top-Author's Production over the time in the field calculates and plots the top 20 authors' production in terms of the number of publications and total citations per year over the time, publication start year, h-index, and g-index with a large number of published high-quality papers in the field of VRCC studies are presented in Fig. 2 and Table 2.

Information in Table 2 shows the top 20 articles of the most productive authors in the field of VRCC. Zhao Y (China) ranked first with a publication year starting from 2009, co-authoring 6 (3.2%) articles, and M. T. Hoffman 1997 (South Africa) ranked second with 5 (2.7%) articles during the same period of study. The h-index (total citations) was (4, 226) ranked first for Zhao Y followed by Hoffman M. T (4, 141) which ranked second as shown in Table 2. Countries that make up the top 20 list based on citations per country include China (n = 13), UK (n = 2), Sweden (n = 1), Spain (n = 1), France (n = 1) and South Africa (n = 2).

The research articles within the survey period from the perspective of the number of articles published. The top most four authors are Zhao Y, Hoffman M. T, Li C., and Li Q, with 6 articles, 5 articles, 4 articles and 4 articles, respectively. Chinese scholar Zhao Y tops the chart in the

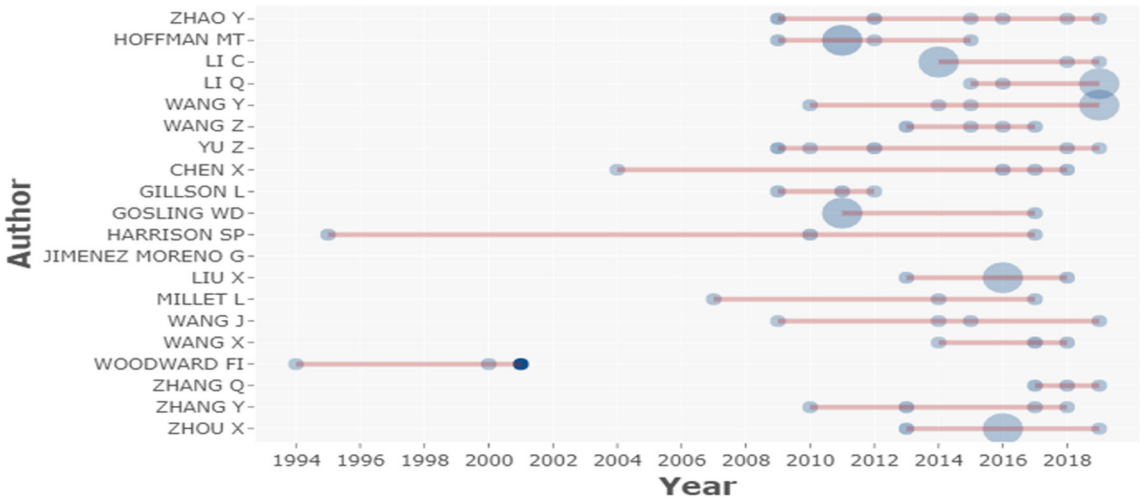

Fig. 2 Top 20 author's production over the time on VRCC studies

Table 2 Top 20 most productive authors

Rank	Authors	Articles	Nation	Percent of 186	h_ index	g_ index	TC	PY_ Start
1	Zhao Y.	6	China	3.2%	4	6	226	2009
2	Hoffman M. T.	5	South Africa	2.7%	4	5	141	2009
3	Li C.	4	China	2.2%	1	4	17	2014
3	Li Q.	4	China	2.2%	2	3	13	2015
3	Wang Y.	4	China	2.2%	1	1	1	2014
3	Wang Z.	4	China	2.2%	4	4	87	2013
3	Yu Z.	4	China	2.2%	3	4	220	2009
4	Chen X.	3	China	1.6%	2	3	28	2004
4	Gillson L.	3	South Africa	1.6%	2	3	104	2009
4	Gosling W. D.	3	UK	1.6%	3	3	47	2011
4	Harrison S. P.	3	Sweden	1.6%	3	3	161	1995
4	Jimenez-Moreno G.	3	Spain	1.6%	2	3	16	2016
4	Liu X.	3	China	1.6%	2	3	18	2016
4	Millet L.	3	France	1.6%	3	3	30	2007
4	Wang J.	3	China	1.6%	1	2	8	2009
4	Wang X.	3	China	1.6%	2	3	46	2014
4	Woodward F. I.	3	UK	1.6%	3	3	1342	1994
4	Zhang Q.	3	China	1.6%	3	3	44	2017
4	Zhang Y.	3	China	1.6%	2	3	77	2013
4	Zhou X.	3	China	1.6%	1	3	67	2013

TC total citation, *PY_Start* publication start year

field of VRCC, in terms of the total number of articles. The h-index, g-index and total citation values for Zhao Y, as presented in Table 2, were 4, 6 and 226, respectively, with a significant number of high-quality published articles that were analysed to measure the author's contribution to the literature on VRCC studies. The circle size in Fig. 2 represents the number of documents, and the colour shade represents the number of citations. Zhao, Y, and Hoffman, M. T started to publish papers in 2009, followed by Li, C in 2014. In particular, the dominance of Woodward, F. I. which started in 1994 has been noted in the author's output over time in the field of the research and ranked first with the largest number of published articles and the highest frequency of average citations per article accounting for (total citation (TC) = 1288, total citation per year (TCpY) = 64.400) in 2001. However, Hoffman, M. T., and Gosling, W. D ranked second which accounted for total citation = 78, total citation per year = 7.800 and total citation = 38, total citation per year = 3.800, respectively, in 2011. It was observed that scholars Li, Q, and Wang, Y both accounted for total citation = 0, total citation per year = 0.000 and total citation = 0, total citation per year = 0.000, respectively, in 2019 with no frequency of average citations per article.

Top Global distribution of documents

The distribution of top documents on VRCC can be found in the journals related to biology, climate, ecology, environment and geology, with some journals categorized in the global biogeochemical cycle such as *Nature Climate Change* and multidisciplinary entities such as *Quaternary International and Science* of the total environment paying attention to this particular field of research (Li et al. 2011).

Information in Table 3 shows the top 20 documents in terms of contribution to the field of VRCC research. The evaluation of these journals and the publications in the top 20 productive documents and their growth trends of publications over time are listed in Table 3. Cramer et al. (2001) paper ranked first in the *Global Change Biology Journal* which produced 1288 citation chains accounting for 64.40% of the total number with very high influence in the field. This connotes that the proportion of publications in this field is not high in the distribution of top documents, which connotes that this field is relatively distributed through large journals and covers research erudition across many fields of study (Li and Zhao 2015). Gottfried M. (2012) in *Nature Climate Change Journal* (n = 488, 54.22%) ranked second while Melillo J. M. (1995) in the *Journal of Global*

Table 3 Top global documents per citation in the field vegetation response to climate change

S/N	Paper	TC	TCperYear
1	Cramer et al. 2001, Global Change Biology	1288	64.40
2	Gottfried M., 2012, Nature Climate Change	488	54.22
3	Melillo J. M., 1995, Global Biogeochemical Cycle	410	15.77
4	Tinner W., 2001, Geology	264	13.20
5	Brauer A., 1999, Quaternary Science Review	196	8.91
6	Hughen K. A., 2004, Science	177	10.41
7	Wu .D., 2015, Global Change Biology	159	26.50
8	Munson S. M., 2011, Proceedings Natl Academy of Science	146	14.60
9	Zhao et al. 2009, Earth-Science Review	144	12.00
10	Lenihan J. M., 2008, Climate Change	133	10.23
11	Williams J. W., 2002, Geology	119	6.26
12	Muller U. C., 2003, Quaternary Research	112	6.22
13	Landhausser S. M., 1993, Journal of Ecology	105	3.75
14	Starfield A. M., 1996, Ecological Applications	98	3.92
15	Smith T. M., 1992, Advance in Ecological Research	92	3.17
16	Harrison S. P., 1995, Quaternary Research	79	3.04
17	Collatz G. J., 2000, Geophysical Research Letters	77	3.67
18	Harrison S. P., 2010, Quaternary Science Review	73	6.64
19	Jiang L., 2017, Science of the Total Environment	71	17.75
20	Brown M. E., 2012, Remote Sensing of Environment	67	7.44

TC total citation, *TCperY* total citation per year

Biogeochemical Cycle (n = 410, 15.77%) ranked third. The top-cited article's publication in this field was published in 2001 in *Global Change Biology*, written by Crammer: *Global response of terrestrial ecosystem structure and function to $CO_2$and climate change using six dynamic global vegetation models*. This article analyses six Dynamic Global Vegetation Models (DGVM) from a regional and global perspective and points out that forest vegetation is often vulnerable to anthropogenic changes and increasing population pressure because this contributes to irreversible degradation and ecosystem changes as a result of systematic interactions between climate impacts and land-use patterns (Crammer et al. 2001). In general, the trends of publications show that Cramer's research and publications in the field of VRCC are continuous, consistent and stable in total amounts of publications.

Academic collaboration and corresponding authors' nationalities

As the adverse effects of climate change on vegetation responses continue to evolve, the problem-assessment measures to mitigate vegetation loss to climate change is a challenging issue that requires coordination and collaboration between various countries including authors from various nationalities to cooperate and collaborate. The strength of scientific collaboration can be used to measure the connection or association of collaboration in scientific research on VRCC and the quality of academic research (Wei et al. 2014).

Most productive countries represent productivity based on the number of articles and citations per country related to VRCC for the top 20 most active countries. There exist connecting or communication lines between the nodes, suggesting that there is a collaborative partnership between the countries (Zhang et al. 2019). The higher the country-to-country collaboration, the stronger the partnership of collaboration. China is at the edge of the connecting network with a wide country to a country node and independent research articles accounting for (n = 82, 44.1%) of all China's publications (Fig. 3), which can be inferred from collective data from representative countries in the field as shown in Table 4. The results show that the UK made notable performance in international collaboration with 10 published articles based on the number of articles status; between them, frequent partnerships were made by China, the USA, Australia and Austria, with collaboration frequency of 28, 10, 8 and 2, respectively. China showed dominance in the network over other countries that have no significant collaboration networks. Furthermore, collaborations by authors in China, the USA, the UK, Australia, France, Germany, South Africa and Spain tend to be multinational (i.e. multiple country publications), which is more profitable for the research development on VRCC studies. More so, China has the

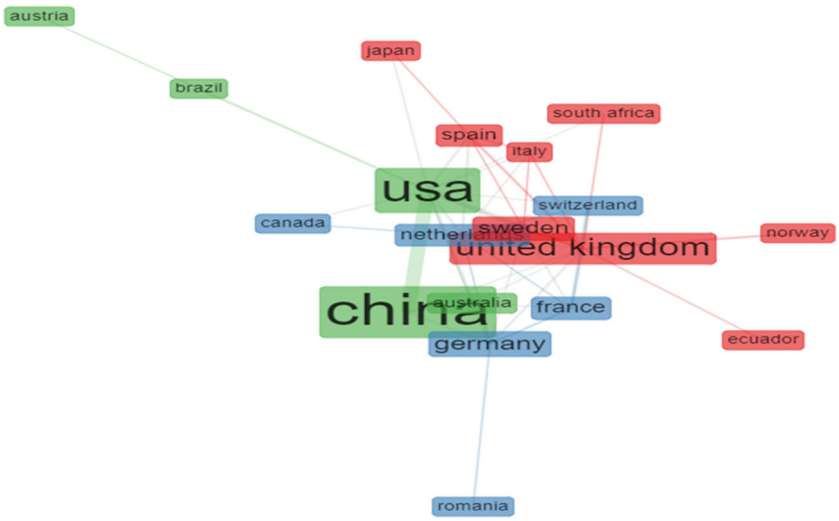

Fig. 3 Countries collaboration for the top twenty 20 networks VRCC studies

largest document number of research articles in the field of VRCC, suggesting that most of the research are self-funded or independent research and had a strong collaboration with the USA, the UK, Australia, France, Germany, South Africa and Spain. South Africa is the only country in Africa that surfaced on the list of the top twenty 20 countries collaboration. In addition to the UK, Sweden, Norway, Brazil, Romania, Netherlands and other countries with multinational collaboration, the rest of the countries focused on autonomous or independent research. This connotes that the amount of research articles from single-publication is greater than that of multiple country publications.

Respective countries authors' affiliations have made a significant contribution from the global perspective to national- and even local-scale collaboration network structure (Elango

Table 4 Most productive countries on vegetation response to climate change during 1992–2019

Rank	Country	Productivity based on no. of articles status				A/MP	Productivity based on no. of citations per countries status			ACC
		Articles	SCP	MCP	Frequency (%)		Rank	Country	TC	
1	China	82	54	28	44.1	0.44565	1	Germany	1689	241.29
2	USA	28	18	10	15.1	0.15217	2	USA	1619	57.82
3	UK	10	2	8	5.4	0.05435	3	China	1230	15.00
4	Australia	7	5	2	3.8	0.03804	4	Austria	489	489.00
4	France	7	4	3	3.8	0.03804	5	Switzerland	273	91.00
4	Germany	7	2	5	3.8	0.03804	6	UK	173	17.30
5	South Africa	6	3	3	3.2	0.03261	7	South Africa	172	28.67
6	Spain	5	1	4	2.7	0.02717	8	Canada	171	42.75
7	Canada	4	4	0	2.2	0.02174	9	France	84	12.00
8	India	3	2	1	1.6	0.01630	10	Sweden	83	41.50
8	Netherlands	3	2	1	1.6	0.01630	11	India	81	27.00
8	Norway	3	2	1	1.6	0.01630	12	Australia	55	7.86
8	Switzerland	3	2	1	1.6	0.01630	12	Korea	55	55.00
9	Brazil	2	1	1	1.1	0.01087	13	Brazil	48	24.00
9	Denmark	2	2	0	1.1	0.01087	14	Netherlands	47	15.67
9	Japan	2	2	0	1.1	0.01087	15	Norway	38	12.67
9	Romania	2	1	1	1.1	0.01087	16	Portugal	29	29.00
9	Sweden	2	1	1	1.1	0.01087	17	Spain	26	5.20
10	Austria	1	0	1	0.5	0.00543	18	Denmark	24	12.00
10	Ireland	1	0	1	0.5	0.00543	18	Japan	24	12.00

*SCP*single-country publication, *MCP*multiple-country publication, *TC* total citations, *A/MP* article per million populations, *ACC* average citation per country

and Rajendran 2012; Koseoglu 2016). Collaborative pathways among Chinese scholars were largely intra-national, as indicated by a large number of articles, but five different country affiliations were mostly significant such as the USA, the UK, Australia, France and Germany. The results revealed that most of the studies were from universities in developed countries while a few came from developing nations. South Africa is the only country in Africa that surfaced on the list with 4.3% published research articles between 1992 and 2019. The Republic of South Africa is one of the emerging countries among the top twenty developed countries indicating that the amount of research output is weak in emerging nations, with low single-country articles and international collaborative articles. In general, the national distribution of the research institute is relatively wide, showing that the response of vegetation to climate change issues is simulating debates from around the world. Among the top 20 institutions as shown in Fig. 4. The University of the Chinese Academy of Sciences (China) has the largest number of publications with the highest h-index of 28 and ranked first with a total of 82 research articles, accounting for 44.1% of the total number of Chinese publications, indicating that it occupies the foremost position on VRCC research, followed by the University of Arizona (USA), University of Exeter (UK), University of Queensland (Australia), Aix-Marseille University (France) and the University of Bremen (Germany). It is worth noting that among the top 20 list of developed countries institution, the University of KwaZulu-Natal (South Africa) has the highest number of publications and h-index of 4 and ranked seventh, with a total number of 6 articles accounting for 3.2% of the total number of South Africa's publications.

Based on corresponding authors' nationalities, the total number of published articles in single-country publications and multiple country publications shows that China has the largest articles, indicating that it occupies the leading position in this field of research among the most active and influential author's countries, followed by the USA and the UK as presented in Fig. 5. Most studies were from developed countries, and a few came from developing nations. The results from corresponding authors' nationalities show that multiple-country publications between countries are not frequent, and articles through single country-publications showed a dominance trend, which is not helpful to research openness of scientific research and productivity. Therefore, South Africa surfaced on the list of corresponding author's nationalities as the only African country on VRCC research.

Information in Table 4 shows the research output of the most productive countries related to VRCC for the top 20 most active countries. Productivity based on the total number of articles status, China ranked first with a total number of articles of $n = 82$ (44.1%) and citations of $n = 1230$), followed by the USA ($n = 28$, 15.1%) and the UK ($n = 10$, 5.4%), indicating that most studies were from developed countries while a few came from developing nations. Although the number of publications fluctuated among the top countries as these countries' rank order changed when the output was measured based on the number of citations per country, with only the USA remaining in the same position. Productivity based on the total number of citation and average citation per countries status, Germany ranked first with a total citation of TC = 1689 (ACC = 241.29), followed by the USA (TC = 1619, ACC = 57.82), China (TC = 1230, ACC = 15.00), Austria (TC = 489, ACC = 489.00), Switzerland (TC = 273, ACC = 91.00), the UK (TC = 173, ACC = 17.3.0) and South Africa (TC = 172, ACC = 28.67). South Africa was the only country among the top 20 to make up for African countries. Consequently, India ($n = 3$) and Japan ($n = 2$) were among the top 20 to make up for Asian countries, while France ($n = 7$), Germany ($n = 7$), Spain ($n = 5$) and Netherlands ($n = 3$) also make up for Europe countries on the list. It is worth noting that

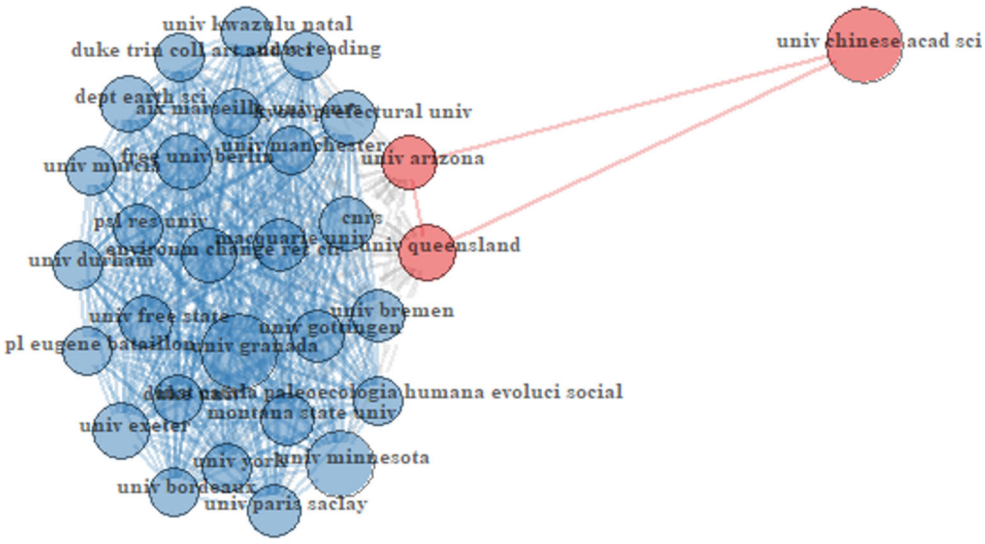

Fig. 4 Top 30 universities collaboration networks on VRCC research

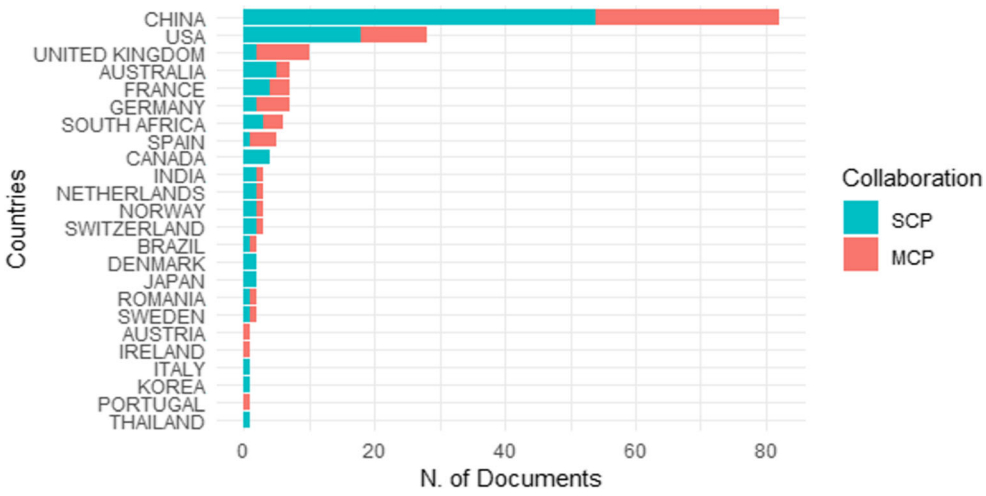

Fig. 5 Top 20 corresponding authors' nationalities on VRCC studies

South Africa (n = 6) is the only African country based on productivity of the total number of articles status and ranked fifth among the developed countries. The outstanding output of South African research among other developed countries shows that the country is performing well in funding research capacity which might contribute to the increase in research productivity on VRCC during the survey period (Fedderke and Goldschmidt 2015). The number of publications by an author reflects the number of scientific research articles either by a single country publication or multiple country publication in a particular field of study. Single-country publication (SCP) is the total number of published articles which represent intra-country collaboration while multiple-country publication (MCP) is the total number of published articles which represent different country publications and tend to be inter-country collaboration.

Information in Table 5 shows the most relevant keywords in Author Keywords (DE) and Keywords-Plus(ID) related to VRCC studies. This includes temperature, precipitation, China and Normalize Difference Vegetation Index (NDVI) as shown in Table 5. Furthermore, the distinct Author Keywords terms associated with the identification methods of VRCC include climate change (n = 54), NDVI (n = 13), temperature (n = 10), precipitation (n = 8), vegetation

Table 5 Most relevant keywords

Rank	Author's keywords (DE)	Freq. and %	Rank	Keywords-Plus (ID)	Freq. and %
1	Climate change	54 (29.0)	1	Temperature	35 (18.8)
2	NDVI	13 (7.0)	2	Dynamics	22 (11.8)
3	Holocene	12 (6.5)	3	Impacts	21 (11.3)
4	Pollen	10 (5.4)	3	Variability	21 (11.3)
4	Temperature	10 (5.4)	4	Growth	19 (10.2)
5	Precipitation	8 (4.3)	4	Precipitation	19 (10.2)
5	Vegetation dynamics	8 (4.3)	5	China	15 (8.1)
6	Tibetan Plateau	7 (3.8)	5	NDVI	15 (8.1)
6	Vegetation	7 (3.8)	6	Carbon	13 (7.0)
7	Paleoclimate	6 (3.2)	6	Drought	13 (7.0)
7	Pollen analysis	6 (3.2)	6	Ecosystems	13 (7.0)
7	Vegetation change	6 (3.2)	6	Trends	13 (7.0)
8	China	4 (2.2)	7	Model	12 (6.5)
8	Climate changes	4 (2.2)	8	Tibetan Plateau	11 (5.9)
8	Climatic change	4 (2.2)	9	Atmospheric CO_2	10 (5.4)
8	NDVI	4 (2.2)	9	Biodiversity	10 (5.4)
8	Remote sensing	4 (2.2)	9	Forest	10 (5.4)
9	Climate variability	3 (1.6)	9	Index	10 (5.4)
9	Diatoms	3 (1.6)	9	Modis	10 (5.4)
9	Evapotranspiration	3 (1.6)	9	Record	10 (5.4)

dynamics (n = 8), vegetation (n = 7), vegetation change (n = 6), China (n = 4), climate changes (n = 4), remote sensing (n = 4) and climate variability (n = 3). The keyword analysis identified "temperature" in ten (5.4%) and thirty-five (18.8%) articles by author keyword and keyword-plus, respectively, while "precipitation" was identified in eight (4.3%) and nineteen (10.2%) articles by keyword and keyword-plus, respectively, across the same time. "NDVI" was identified in four (2.2%) and fifteen (8.1%) by keyword and keyword-plus article, respectively. This result indicates that research on VRCC has consistently identified these climate-related problems and highlighted the process influenced by the responses of vegetation to climate change events, as well as the means or variables. This indicates that forest vegetation is modified by intense disturbances which might lead to permanent loss and changes in the ecosystem, land degradation, environmental degradation, water scarcity and desertification, as a result of structural interactions between climate impacts and patterns of land use (Sivakumar 2006; D'Odorico et al. 2013; Shukla et al. 2019).

Word TreeMap of high-frequency keywords analysis

Word TreeMap of authors' keywords represents the summary of hot themes or the dynamic trends of dominant themes of the author (Cobo et al. 2011; Xie et al. 2020). Word TreeMap is key to investigating hot themes and associated developments within this field of study.

Word TreeMap of keywords shows the dynamic trends of hot themes and the clusters of high-frequency keyword terms on VRCC studies. The frequency of author's keyword on VRCC was summarized within the period of the analysis by a structured scheme to classify the core high-frequency keywords with word frequency greater than or equal to 10 are selected, and 40 high keywords were obtained in terms of their occurrence in the field and drawn as a Word TreeMap as presented in (Fig. 6). This depicts the keywords and areas to identify on VRCC research. For example, temperature, dynamics, impacts, variability, growth, precipitation, MODIS/AVHRR NDVI, carbon, drought, ecosystem, biodiversity, forest, land use and models were identified as some of the prominent key terms in VRCC studies. The quest for policies formulation with regard to vegetation, forest, ecosystems and biodiversity conservation at the local level is essential across the globe because the creation of policies would, in turn, make up how the global level concerns are reinforced in terms of policy implementation, although the dynamic trends of hot themes with different periods are diversified and the evolutionary link in the field is complex (Cobo et al. 2011; Xie et al. 2020). Nevertheless, it is worthy to know that temperature has the most links with other keyword terms because it has the highest appearance and surface repeatedly in VRCC studies.

Discussion

The study carried out a global assessment of vegetation response to climate change studies of published articles indexed in the Web of Science (WOS) database. A detailed analysis was conducted to reveal the evolution and current research hotspots and a better understanding of dominant themes in VRCC research from 1992 to 2019 through the use of bibliometrics. Average citations per article peaked in around 1995 and 1999 and a high peak in 2001, and an overall decline

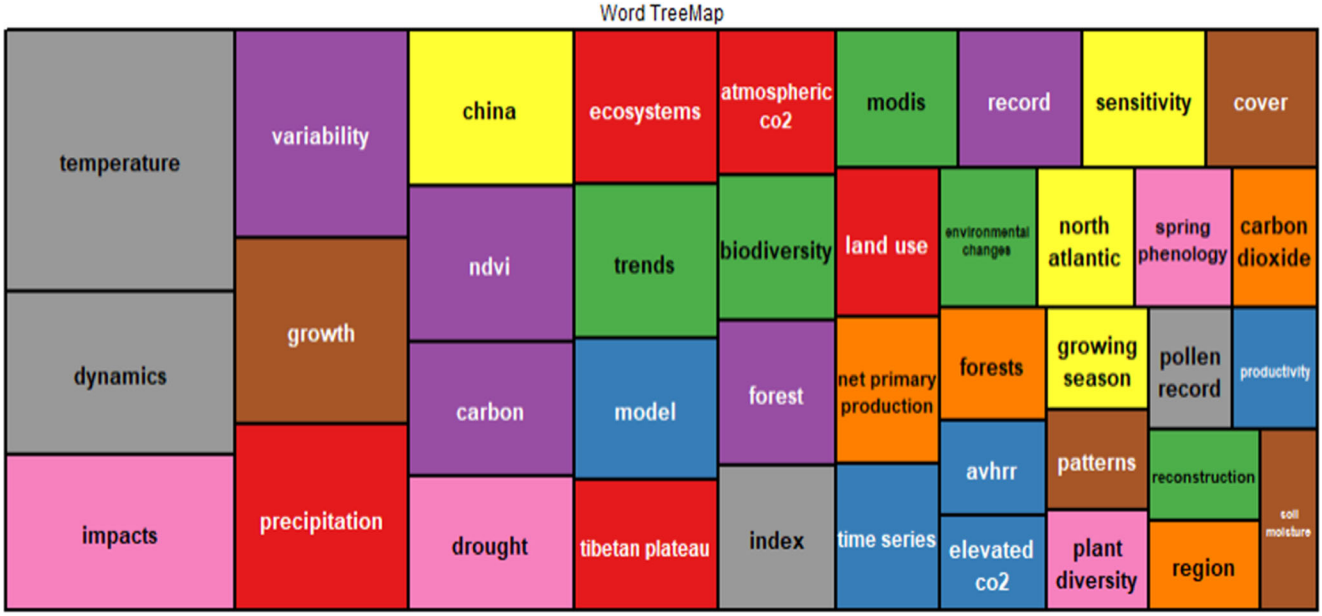

Fig. 6 Word TreeMap of high-frequency keywords in the field of VRCC studies

was observed in 1997 and 2019 suggesting that the average article citation for those periods was significantly low in the field (Ellegaard and Wallin 2015). The annual growth rate was 10.3% which connotes that global research on VRCC has been increasing over time during the survey period. This study navigates the rich tapestry of VRCC studies by the assessment and approach to analyse the top-cited articles, the top global distribution of documents, academic collaboration, most relevant keywords and Word TreeMap of high-frequency keywords. The results show that the UK made notable performance in international collaboration with 10 published articles based on the number of articles between them; frequent collaborations were made by China, the USA, Australia and Austria, with a collaboration frequency of 28, 10, 8 and 2, respectively. Furthermore, collaborations by authors in China, the USA, the UK, Australia, France, Germany, South Africa and Spain tend to be multinational (i.e. multiple country publications), which strengthened the research development on VRCC studies. South Africa is the only African country that surfaced on the list of countries based on the number of articles and citations per country status. Developed countries from Asia, America and Europe are more influential in the field with research strength, strongly suggesting that more research focus on VRCC related studies are needed from other developing countries (Fedderke and Goldschmidt 2015). Besides, the results further revealed the need for more research to be conducted in Africa especially that it has been flagged by the Intergovernmental Panel on Climate Change (IPCC) as one of the continents to be hit by the effects of climate change (Alexander 2016; Kouw and Petersen 2018).

Conversely, the low research output was from African countries which are characterized by a high level of self-funded or autonomous research (Huang et al. 2016). This connotes that motivation for more research output and countries collaboration associated with research productivity and funding of research needs to be implemented across all fields to increase the impact of South African's research output. Hence, the advancement in funding initiative capacity is crucial to increase the number of world-class scholars in South African universities and make rooms for other developing nations' universities. Also, it is worth noting that among the top 20 list of developed countries institution, the University of KwaZulu-Natal (South Africa) has the highest number of publications and ranked seventh, with a total number of 6 articles accounting for 3.2% of the total number of South Africa's publications. The results from the corresponding authors' nationalities show that multiple country publications between countries are not frequent, and articles through single-country publications showed dominance trend which is not helpful to research openness of scientific research and productivity. The literature has revealed that temperature was established to be the main controlling factor accountable for vegetation growth at high latitudes in the Northern Hemisphere (Xiao and Moody 2005) and Western Europe (Forster et al. 2008) while in Central Asia, South America and Southern Africa (Kogan et al. 2012; Wang et al. 2016; Walz et al. 2020) while declining precipitation and rising temperatures were correlated with a decline in vegetation health. Hence, the relationship between the changes in temperature and precipitation might influence the vegetation growth as well as the distribution of plants.

Conclusion

This study appraised studies on VRCC to reveal the evolution and current research hotspots and a better understanding of dominant themes by using bibliometric analysis of published articles from 1992 to 2019. This assessment and approach described in this study would help to advance the understanding of the evolutionary trend of studies by assessing the intellectual domain and identifying research hotspots, top global distribution of documents, most relevant keywords, high-frequency keywords and academic collaboration networks associated with VRCC studies globally. Hence, using these available articles on VRCC, help to identify the research gap; the reviewed studies were used to evaluate and determine the current research hotspots and dominant themes, considering the insights from time-varying trends observed in VRCC during the period of study. The important scientific findings from these reviewed studies show that "temperature" is in a central position in all keywords with the largest significant appearance in the field which connotes that future studies must appraise how far the VRCC has been able to contribute to the advancement of temperature change. Temperature plays a vital role in vegetation growth and development. Therefore, an extremely high temperature is harmful to vegetation growth while moderate temperature tends to support vegetation activity. The key findings are associated with the responses of vegetation to climate change as the temperature variations can impede the length of the growing season. Consequently, bibliometrics has been widely utilized as a methodological approach for evaluating various research niche areas over time. Nevertheless, this study will help government and institutions in the implementation of theory and technologies of restoration, ecological protection guidelines and multi-integrated system research for evolving future research development. Hence, the evolution and current research hotspots of dominant themes and associated influences in VRCC may be expressed in four evolutionary paths, which include monitoring and evaluation of vegetation, a policy-making decision for tree planting, restoration of crumbling vegetation and improved cutting-edge research on VRCC, especially in developing nations. More so, findings from this study are crucial in planning and managing vegetation and forest ecosystem and

an eye-opener for those countries that had little or no research on VRCC and provide hints for future research. This paper recommends that various research databases should be integrated to identify other possible research developments and improvements and hints for future research.

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Author contribution Gbenga Abayomi Afuye conceptualized and wrote the methodology and the first draft of the paper. Ahmed Mukalazi Kalumba and Israel Ropo Orimoloye supervised the study. Emmanuel Tolulope Busayo reviewed and edited the paper.

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Data availability Data used in this study are available on request. Requests for access to these data should be made to Gbenga Abayomi Afuye [afuyeabayomi@gmail.com].

Declarations

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication All authors provide formal written consent to publish this work.

Competing interests The authors declare no competing interests.

References

Afuye GA, Ojeh VN (2017) Temporal variations in ambient carbon monoxide concentrations between weekdays and weekends in Akure Central Business District, South West Nigeria. Phys Sci Int J:1–12

Afuye GA, Ojeh VN, Okunlola BA, Adejokun VF (2018) Heat-sum calculation in forecasting maize phenological stages and harvesting date in Lagos South West, Nigeria. J Geogr Environ Earth Sci Int:1–12

Afuye GA, Kalumba AM, Orimoloye IR (2021) Characterisation of vegetation response to climate change: a review. Sustainability 2021(13):7265

Aria M, Cuccurullo C (2017) bibliometrix: an R-tool for comprehensive science mapping analysis. Journal of Informetrics 11(4):959–975 11(4), Elsevier

Aria M, Misuraca M, Spano M (2020) Mapping the evolution of social research and data science on 30 years of social indicators research. Soc Indic Res:1–29. https://doi.org/10.1007/s11205-020-02281-3

Alexander LV (2016) Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. Weather and Climate Extremes 11: 4–16

Busayo ET, Kalumba AM, Afuye GA, Ekundayo OY, Oriomoloye IR (2020) Assessment of the Sendai framework for disaster risk reduction studies since 2015. International Journal of Disaster Risk Reduction: 101906

Chen K, Zhang Y, Fu X (2019) International research collaboration: an emerging domain of innovation studies? Res Policy 48(1):149–168

Cramer W, Bondeau A, Woodward FI, Prentice IC, Betts RA, Brovkin V, Young-Molling C (2001) Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. Glob Chang Biol 7(4):357–373

Crate BSA, Einarsson N, Ford JD, Lahsen M, Paolisso M, Schlee G, Crate SA (2008) Gone the bull of winter? Grappling with the cultural implications of and anthropology's role (s) in global climate change. Curr Anthropol 49(4):569–595

Cobo MJ, López-Herrera AG, Herrera-Viedma E, Herrera F (2011) An approach for detecting, quantifying, and visualizing the evolution of a research field: a practical application to the fuzzy sets theory field. Journal of Informetrics 5(1):146–166

Dale VH (1997) The relationship between land-use change and climate change. Ecol Appl 7(3):753–769

de Jong R, Verbesselt J, Schaepman ME, De Bruin S (2012) Trend changes in global greening and browning: contribution of short-term trends to longer-term change. Global Change Biol 18(2):642–655

D'Odorico P, Bhattachan A, Davis KF, Ravi S, Runyan CW (2013) Global desertification: drivers and feedbacks. Adv Water Resour 51:326–344

Dubey A, Malla MA, Khan F, Chowdhary K, Yadav S, Kumar A, Khan ML (2019) Soil microbiome: a key player for conservation of soil health under changing climate. Biodivers Conserv 28(8-9):2405–2429. https://doi.org/10.1007/s10531-019-01760-5

Ekundayo TC, Okoh AI (2018) A global bibliometric analysis of Plesiomonas-related research (1990–2017). PLoS ONE 13(11): e0207655

Ellegaard O, Wallin JA (2015) The bibliometric analysis of scholarly production: how great is the impact? Scientometrics 105(3):1809–1831

Estoque RC, Togawa T, Ooba M, Gomi K, Nakamura S, Hijioka Y, Kameyama Y (2019) A review of quality of life (QOL) assessments and indicators: towards a "QOL-Climate" assessment framework. Ambio 48(6):619–638

Elango B, Rajendran P (2012) Authorship trends and collaboration pattern in the marine sciences literature: a scientometric study. International Journal of Information Dissemination and Technology 2(3):166–169

Fedderke JW, Goldschmidt M (2015) Does massive funding support of researchers work?: evaluating the impact of the South African research chair funding initiative. Res Policy 44(2):467–482

Forster S, Kuhlmann B, Lindenschmidt KE, Bronstert A (2008) Assessing flood risk for a rural detention area. Nat Hazards Earth Syst Sci 8(311–322):2008

Huang J, Tang J, Qu Y, Zhang L, Zhou Y, Bao S, Mu D (2016) Mapping the knowledge structure of neonatal hypoxic-ischemic encephalopathy over the past decade: a co-word analysis based on keywords. J Child Neurol 31(6):797–803

Hou W, Gao J, Wu S, Dai E (2015) Interannual variations in growing-season NDVI and its correlation with climate variables in the southwestern karst region of China. Remote Sens 7(9):11105–11124

Hoffman MT (1997) Human impacts on vegetation. In: Cowling RM, Richardson DM, Pierce SM (eds) Vegetation of southern Africa. Cambridge University Press, Cambridge, pp 507–534

IPPC (2014) Climate change 2014–impacts, adaptation and vulnerability: regional aspects. Cambridge University Press

Jetz W, Wilcove DS, Dobson AP (2007) Projected impacts of climate and land-use change on the global diversity of birds. PLoS Biol 5:1211–1219

Kogan F, Salazar L, Roytman L (2012) Forecasting crop production using satellite based vegetation health indices in Kansas, USA. Int J Remote Sens 33(9):2798–2814

Komljenovic D, Gaha M, Abdul-Nour G, Langheit C, Bourgeois M (2016) Risks of extreme and rare events in asset management. Safety Science 88:129–145

Koseoglu MA (2016) Growth and structure of authorship and co-authorship network in the strategic management realm: evidence from the strategic management journal. BRQ Business Research Quarterly 19(3):153–170

Kouw M, Petersen AC (2018) Diplomacy in action: Latourian politics and the intergovernmental panel on climate change. Sci Technol Stud 31(1):52–68

Leitinger G, Tasser E, Newesely C, Obojes N, Tappeiner U (2010) Seasonal dynamics of surface runoff in mountain grassland ecosystems differing in land use. J Hydrol 385(1-4):95–104

Li J, Wang MH, Ho YS (2011) Trends in research on global climate change: a science citation index expanded-based analysis. Global Planet Chang 77:13e20

Li W, Zhao Y (2015) Bibliometric analysis of global environmental assessment research in a 20-year period. Environ Impact Assess Rev 50:158–166

Mishra AK, Singh VP, Jain SK (2010) Impact of global warming and climate change on social development. J Comp Soc Welf 26(2-3): 239–260

Orimoloye IR, Ololade OO (2020) Potential implications of gold-mining activities on some environmental components: a global assessment (1990 to 2018). Journal of King Saud University-Science 32(4): 2432–2438

Orimoloye IR, Ololade OO (2021) Global trends assessment of environmental health degradation studies from 1990 to 2018. Environ Dev Sustain (3):3251–3264

Pan N, Feng X, Fu B, Wang S, Ji F, Pan S (2018) Increasing global vegetation browning hidden in overall vegetation greening: insights from time-varying trends. Remote Sens Environ. 214:59–72.

Pricope NG, Husak G, Lopez-Carr D, Funk C, Michaelsen J (2013) The climate population nexus in the East African Horn: emerging degradation trends in rangeland and pastoral livelihood zones. Global Environ Chang 23(6):1525–1541

Sarto F, Cuccurullo C, Aria M (2014) Exploring healthcare governance literature: systematic review and paths for future research.:61–80

Seppelt R, Dormann CF, Eppink FV, Lautenbach S, Schmidt S (2011) A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J Appl Ecol 48(3):630–636

Sivakumar MVK (2006) Interactions between climate and desertification. World Meteorological Organization, Geneva. Received 23 March 2005

Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner HO, Roberts DC, Malley J (2019) IPCC, 2019: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 2019 (eds.). In press. 34, p. 874

Tan J, Fu HZ, Ho YS (2014) A bibliometric analysis of research on proteomics in science citation index expanded. Scientometrics. 98: 1473–1490

Turner LR, Alderman K, Connell D, Tong S (2013) Motivators and barriers to incorporating climate change-related health risks in environmental health impact assessment. Int J Environ Res Public Health 10(3):1139–1151

Tucker CJ, Slayback DA, Pinzon JE, Los SO, Myneni RB, Taylor MG (2001) Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999. Int J Biometeorol 45(4):184–190

United Nations (2015) The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC).

Wang MH, Li J, Ho YS (2011) Research articles published in water resources journals:a bibliometric analysis. Desalin Water Treat. 28: 353–365

Wang Z, Huang Z, Li J, Zhong R, Huang W (2016) Assessing impacts of meteorological drought on vegetation at catchment scale in China based on SPEI and NDVI. Transactions of the Chinese Society of Agricultural Engineering 32(14):177–186

Wang J, Wang P, Qin Q, Wang H (2017) The effects of land subsidence and rehabilitation on soil hydraulic properties in a mining area in the Loess Plateau of China. Catena 159:51–59

Wang Z, Zhao Y, Wang B (2018) A bibliometric analysis of climate change adaptation based on massive research literature data. J Clean Prod 199:1072–1082

Walther GR (2010) Community and ecosystem responses to recent climate change. Philos Trans R Soc B Biol Sci 365(1549):2019–2024

Walz Y, Min A, Dall K, Duguru M, de Leon JCV, Graw V, Post J (2020) Monitoring progress of the Sendai Framework using a geospatial model: the example of people affected by agricultural droughts in Eastern Cape, South Africa. Progress in Disaster Science Jan 1; 5, p. 100062

Wei YM, Yuan XC, Wu G, Yang LX (2014) Climate change risk assessment: a bibliometric analysis based on Web of Science. Bulletin of National Natural Science Foundation of China 28(5):347–356

Wheeler SM (2013) Planning for sustainability: creating livable, equitable and ecological communities. Routledge, New York, p 424

Wu D, Zhao X, Liang S, Zhou T, Huang K, Tang B, Zhao W (2015)Time-lag effects of global vegetation responses to climate change. Global change Biol 21(9):3520–3531

Xie H, Zhang Y, Wu Z, Lv T (2020) A bibliometric analysis on land degradation: current status, development, and future directions. Land 9(1):28

Yevide AS, Wu B, Khan AS, Zeng Y, Liu J (2016) Bibliometric analysis of ecosystem monitoring-related research in Africa: implications for ecological stewardship and scientific collaboration. Int J Sustain Dev World Ecol 23(5):412–422

Xiao J, Moody A (2005) Geographical distribution of global greening trends and their climatic correlates: 1982–1998. Int J Remote Sens 26(11):2371–2390

Zhang J, Yu Q, Zheng F, Long C, Lu Z, Duan Z (2016) Comparing keywords plus of WOS and author keywords: a case study of patient adherence research. J Assoc Inf Sci Technol 67(4):967–972

Zhang Y, Zhang Y, Shi K, Yao X (2017) Research development, current hotspots, and future directions of water research based on MODIS images: A critical review with a bibliometric analysis. Environ Sci Pollut Res 24(18):15226–15239

Zhang L, Gong J, Zhang Y (2018) A review of ecosystem services: a bibliometric analysis based on Web of Science. Acta Ecologica Sinica. 36:5967–5977

Zhang X, Estoque RC, Xie H, Murayama Y, Ranagalage M (2019) Bibliometric analysis of highly cited articles on ecosystem services. PLoS ONE 14:e0210707

Zhao Y, Yu Z, Chen F, Zhang J, Yang B (2009) Vegetation response to Holocene climate change in monsoon-influenced region of China. Earth Sci Rev 97(1-4):242–256

Zhuang Y, Liu X, Nguyen T, He Q, Hong S (2013) Global remote sensing research trends during 1991–2010: a bibliometric analysis. Scientometrics 96(1):203–219

Zipper CE, Burger JA, Skousen JG, Angel PN, Barton CD, Davis V, Franklin JA (2011) Restoring forests and associated ecosystem services on appalachian. Coal Surf Mines Environ Manag 47:751–765