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Bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019

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Abstract

Background: Climate change poses a threat to global food security. Assessing research activity on food security in the presence of climate change is important for policymakers and funding sponsors to make future decisions. The current study aimed to give an overview of research activity on food security in the context of food security.

Methodology: A bibliometric methodology was implemented using the Scopus database for the period from 1980 to 2019. The search strategy utilized the title/abstract search of keywords related to food security and climate change with certain constraints. Bibliometric indicators, frequent author keywords, research themes, and international research collaboration were presented.

Results: The search query retrieved 5960 documents. The last decade of the study period witnessed an increasing trend in both the number of publications and the number of cumulative citations. The top five author keywords were climate change, food security, drought, adaptation, agriculture, and water scarcity. Mapping the retrieved documents showed four general research themes: water security, crop yield, food availability, and health. The *Sustainability* journal ranked first in terms of productivity while documents published in the *Global Change Biology* journal received the highest number of citations per document. At the country level, the USA ranked first in terms of numbers, India ranked first in terms of research productivity per GDP/capita, and the UK ranked first in terms of the number of citations per document. France and the Netherlands had the highest percentage of documents with international authors while India and China had the least. At the regional level, the European region had the highest contribution and the Eastern Mediterranean region had the least contribution. Half of the top-cited documents in the field were review articles and appeared in prestigious journals. At the institutional level, the active list included three Chinese and two American institutions.

Conclusion: Food security under the umbrella of climate change is an emerging global challenge. Research on new technologies to mitigate the impact of climate change on food security is a top priority. Research contribution and collaboration from world regions with limited resources should be encouraged.

Keywords: Food security, Climate change, Bibliometric analysis, Scopus

Background

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer” [1]. Climate change

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is associated with greenhouse gases such as carbon dioxide, methane, chlorofluorocarbons and nitrous oxide [2]. Greenhouse gases are released into the atmosphere by natural and anthropogenic mechanisms and pose serious risks to human health and survival on planet earth [3]. One of the most dangerous consequences of climate change is food shortage due to the damaging effects of climate change on food security.

The IPCC report published on 2014 demonstrated that, on average, global mean crop yields of rice, maize and wheat are projected to decrease between 3 and 10% per degree of warming above historical levels. Climate change will contribute to global food insecurity by reducing crop yield, increasing expenses due to drought, and therefore increasing food prices and the number of people with poor nutrition [4, 5].

The increasing number of the world population worsens the food security challenge. It is estimated that the world population is projected to reach eight billion by 2024–2030 [6]. Meeting the needs of the world population under climate change effects is a serious challenge [7]. Climate and food challenges are well presented in the Sustainable Development Goals (SDGs). For example, the second goal in the SDGs is "Zero Hunger". The SDGs aim to end all forms of hunger and malnutrition by 2030, making sure all people—especially children and the more vulnerable—have access to sufficient and nutritious food all year round [8]. The Food and Agricultural Organization of the United Nations (FAO) estimated that the food production will have to increase by at least 60% in the next decades to meet the growing global food demand [9].

The term food security originated in the mid-1970s, almost 50 years ago [10, 11]. The widely accepted definition of "food security" is the one negotiated in the World Food Summit in 1996. "Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [12]. In 2009, the World Summit on Food Security stated that the "four pillars of food security are availability, access, utilization, and stability" [13]. Availability is the amount of food that is physically present regardless of the source. Access refers to economic and sociocultural reasons that might limit access of people to available food. Utilization refers to the idea that available and accessible food is nutritious, safe, and of good quality. The fourth dimension which is stability refers to the idea that availability, access, and utilization do not to occur only at a single moment in time, but need to be present all the time and with sustainability [14].

The evolution of the food security concept was discussed in an article published in the *Global Food Security* journal in 2013 by Jennifer Coates [10]. The concept of food security has witnessed several shifts with time [10, 15]. Examples on the changes in food security concept was a shift in the definition from food availability to food access and utilization. With time, the concept of food security has witnessed a stronger link with economic and social development. Furthermore, a shift from 'food first' to a more inclusive 'livelihood' perspective and a shift from the world and the nation towards households and individuals have been witnessed in the last few decades. Other changes included the tendency to consider the subjective perceptions of food security or insecurity, market mechanisms and incentives, nutrition and food safety, and a growing consideration of local food habits, the right to food, 'food sovereignty' and smallholder production.

Climate change will have serious negative effects on the four pillars of food security: food availability, food accessibility, food utilization and food system stability. The negative effects of climate change are particularly significant for millions of people living in specific rural locations where agriculture is the backbone of their living. Research on climate change and food security is of national and global importance because it gives policymakers baseline information on the current situation and what needs to be done in the future to adapt and mitigate the situation. Climate change and food security are topics of hot debate due to their direct effects on human health. The contribution of scientists in both developing and developed countries to the discussion about climate change and food security is needed because climate change is expected to have different effects on different world regions. For example, in Africa, the main risks of climate change will be water and food scarcity in addition to increased spread of infectious diseases such as malaria [16]. In Europe, climate change will cause more coastal floods and higher frequency of wildfires [17, 18]. Therefore, it is important to investigate and assess research themes and research pattern on climate change and food security at the global and regional levels.

Assessment of scientific productivity has been carried out for food security as a single topic and also has been carried out for climate change as a single topic [19, 20]. However, no published studies analyzed scientific literature on food security in the context of climate change. Therefore, the current study was undertaken to assess and analyze scientific literature on climate change and food security. The approach commonly utilized to assess and analyze science is called bibliometrics, which is different from systematic or scoping reviews. The main goal in the bibliometric analysis is to analyze growth of

research, main research themes, top-cited documents in the field, national and regional contribution, scientific impact, and key players in the field. Bibliometric analysis has been used to assess the research activity in different medical subjects and topics [21, 22]. However, bibliometric studies should always abide by certain principles to ensure best practice in metrics-based research assessment. Such principles were named the Leiden Manifesto after the name of the conference in which they were formulated [23]. The Leiden Manifesto came as an endorsement to the Declaration on Research Assessment (DORA), which aimed to improve how the outputs of scholarly research are evaluated. The author of the current manuscript did his utmost to ensure that current study was comprehensive, accurate, relevant, valid, and supported by evidence.

Literature review on bibliometric studies on climate change and food security

Bibliometric analysis of publications on climate change has been published [20, 24–31]. Similarly, bibliometric analysis of publications on food security has been published [32–37]. None of the published bibliometric studies analyzed literature discussing the impact of climate change or the presence of climate change on food security. However, for comparative purposes, few bibliometric studies on food security were discussed. A recently published bibliometric study on food security was carried using Web of Science and analyzed documents on food security in general [38] without specifying the keywords used to retrieve the relevant documents. Results of the study showed that 19,449 publications on food security were published from 193 countries in 3792 journals with Mario Herrero being the most productive author, while the USA ranked first in productivity. Among the journals, *Food Security* ranked first by total link strength, links, and the number of documents. The co-occurrence network map of keywords showed that, over the last decades, the focus of food security research has shifted from socio-economic to environmental aspects. A second recently published study on the impact of climate change and infectious diseases was published and analyzed the research themes of the impact of climate change on human health with an emphasis on infectious diseases [30]. A third recently published scientometric study discussed the impacts of climate change on water quality by reviewing 2998 related articles extracted from the Science Citation Index-Expanded (SCI-E) database from 1998 to 2018. The results of the study revealed that the impacts of climate change on water quality mainly included the aggravation of eutrophication, changes in the flow, hydrological and thermal conditions, and the destruction of ecosystems and biodiversity [29].

Methodology

Database used

For an ideal bibliometric study, different databases need to be used to retrieve the relevant documents to ensure the comprehensiveness of the analysis. However, the use of multiple databases is applicable only when the volume of literature on the investigated topic is limited. In the current study, a single database was used because of the large volume of literature on the investigated topic. Literature review showed that Scopus database is superior to both PubMed and Web of Science in terms of size and functions available for analysis and sorting of data [39–43]. Therefore, in the current study, Scopus was used to achieve the required objective. The advanced search function in Scopus was used because it allows for building long and complex search queries. In bibliometric studies, usually one database is used because bibliometric indicators and literature mapping are difficult to perform on documents retrieved from different databases. Scopus is 100% inclusive of PubMed and has double the number of indexed journals than Web of Science. Therefore, Scopus is considered almost comprehensive of publications in PubMed and Web of Science.

Search strategy

To be able to build a search query that can retrieve the maximum related number of documents with minimum false-positive results, the author did an extensive literature review on the topic, especially review articles and systematic reviews to find out all potential keywords that could be used [44–50]. The simplest approach was to use the title/abstract search methodology for keywords related to "climate change" and "food security". However, applying such an approach will retrieve a high proportion of irrelevant documents. Therefore, to sharpen the title/abstract approach, a certain constraint was implemented that included the presence of certain "terms" related to food security or climate change in addition to the title/abstract strategy.

Search query

The overall search query consisted of specific phrases related to climate change and specific phrases related to food security entered in the title/abstract search followed by certain terms as a constraint to minimize irrelevant documents.

1. Phrases or expressions related to "food security" were: title-abs ("inadequate food" or "household dietary diversity" or "household food expenditure" or "food consumption" or "food use" or "water *security" or "clean water" or "safe water" or "crop failure" or

- "crop vulnerability" or "food *security" or "food insecurity" or "food utili*ation" or "food access*" or "food abundance" or "food scarcity" or "food limitation" or "food poverty" or "food insufficiency" or "food system stability" or "nutrition security" or "food availability" or "stability of food system" or "food crisis" or "food challenge" or "food shortage" or "stable food supply" or "water scarcity" or "water *security").
2. Phrases or expressions related to "climate change" were: title-abs ("climat* change" or "global warming" or "greenhouse effect" or "changing climate" or "greenhouse effect" or "climatic change" or "extreme weather" or "climat* variability" or "warm clima*" or "climat* extreme*" or "extreme climate" or "greenhouse warming" or "weather variability" or "climate disaster*" or "climat* effect" or drought or "heat wave*").
 3. Terms used as constraints were: title (rice or wheat or corn or coffee or chocolate or honey or banana or beans or poultry or maize or barely or "sea food" or fisheries or sugarcane or vegetable or livestock or cereals or grains or grape* or wine or "triticum aestivum" or "oryza sativa" or "zea mays" or potato or farm* or famine or hunger or *nutrition or land or food or crop or price* or household or conflict or disaster or policy or storage or scarcity or access or utilization or poverty or dietary or diversity or feed* or nutrient or harvest or livelihood or "well-being" or income or supply or resilience or resilient or mitigation or adaptation or smart or agricultur* or production or consumption or availability or quality or safety or water or flood* or "changing weather" or "temperature" or climat*)

Inclusion and exclusion criteria

Documents published between 1980 and 2019 were included regardless of the language of publications. This was the first inclusion criteria. Documents before the year 1980 were not considered for two reasons. First, the modern concept of food security started to evolve in the late 1970s. Second, the number of documents published before 1980 was limited. Therefore, the inclusion of documents published before 1980 might not be of significant value. The second inclusion criterion was documents published in peer-reviewed scientific journals while books and book chapters were excluded. The focus of the current study was on human food security, therefore, documents discussing the effects of climate change on the behavior of certain animals (bear or pig or animal or avian or bird or cats or dogs or trout) were excluded. Furthermore, documents published in certain journals that were irrelevant to human food security were excluded.

Validation of the search strategy

The overall search query was finalized after several trials and fine-tuning process. The following criteria were considered in the development of the search query. First, the retrieved top 100 cited documents should be free of false-positive results and within the scope of the study. Second, the top ten active authors in the search strategy should have a similar number of results as present in their Scopus profile. Third, the top 20 active journals are related to the field of the study. This approach was adopted from the previously published bibliometric study [51]. For the first criterion, the top 100 cited articles were sent as an endnote file to two independent researchers in the field of life sciences and were asked to confirm that the articles were within the scope of the study. Whenever a false-positive result was found, the search query was fine-tuned to sharpen the query. In the second criterion, the number of articles retrieved for active authors and the number of articles for the same authors found in their Scopus profile were compared using *Pearson* correlation test. For example, the overall search query showed that the following researchers were among the top active authors: Herrero, M.; Thornton, P.K; Tao, F. and their research output based on the search query was 29, 25, and 19 documents, respectively. The same authors have produced 30, 25, and 20 documents based on their Scopus personal profile. This approach was carried out for 10 different authors and the correlation between the retrieved and the actual number of publications was significant ($p < 0.01$) and the correlation coefficient was above 95% suggestive of high validity of the search query. The top active author mentioned by Skaf et al. was the same in our study. In Skaf et al., Herrero, M. ranked first and produced 50 documents on food security in general. In the current study, Herrero, M. also ranked first with 29 documents on food security in the context of climate change. For the third criterion, a quick scanning of the top active journals indicated that all were related to food security or climate change or both as indicated in their subject scope in *Scimago Journal Ranking*. The retrieved documents using the developed search query might not be 100% inclusive of literature on food security in the context of climate change, but the retrieved documents are considered an accurate representation of the study question being addressed.

Data export and bibliometric indicators

The validated search query was run using the advance search function in Scopus. The retrieved data from Scopus were exported to Microsoft Excel. The exported data included: annual number of publications, types of documents, languages, subject areas, names of countries

involved in publishing the retrieved documents, authors, journals, author keywords, funding sponsors, institutions, and citations. The exported data were analyzed to produce the bibliometric indicators, which included the followings: (1) annual growth of publications; (2) most frequent author keywords in the retrieved documents; (3) top ten active countries, institutions, and journals; (4) citation analysis and top-cited documents, and (5) international research collaboration. In the citation analysis, we used the mean number of citations per document and Hirsh-index (h-index) which are used as a measure of scientific impact [52].

Network visualization maps

The retrieved literature was mapped to visualize research themes. For research themes, the terms in titles/abstracts of the retrieved documents with a minimum occurrence of 10 were mapped using the free on-line program, VOSviewer [53]. In the map, related terms exist in close proximity and have the same color. Terms having the largest node size are the ones with the highest frequency. Each cluster of terms with the same color represents a research topic or a research theme. Therefore, the number of clusters represents the number of research themes in the retrieved documents. These research themes are overlapping.

International research collaboration

For each active country, the number and percentage of documents that included international authors were investigated. These multiple country publications (MCP) represent the extent of inter-country (international) research collaboration. Documents with no international authors were termed single country publications (SCP). The SCP represent the extent of intra-country collaboration.

Geographic distribution of the retrieved articles

In the current study, the World Health Organization classification of world regions included the region of Americas, the African region, the European region, the Western Pacific region, the South-East Asian region, and the Eastern Mediterranean region.

Citation analysis

The scientific impact of active journals and countries was evaluated using the number of citations per document.

Data presentation

All results were presented as tables except for annual growth, research collaboration, and research themes. The annual growth was presented as a linear graph using Statistical Package for Social Sciences (SPSS, version

25, USA). Research collaboration and research themes were presented as network visualization maps using VOSviewer program [53].

Results

Volume and annual growth

The research query retrieved 5960 documents. The retrieved documents were mainly research articles ($n=5017$; 84.2%) and review articles ($n=752$; 12.6%). The remaining documents were editorials, conference papers, notes, and letters. Eighteen different languages were encountered in the retrieved documents. The main language was English ($n=5750$; 96.5%) followed by Chinese, French, and Spanish. In total, 26,386 authors participated in publishing the retrieved documents, an average of 4.4 authors per document. The annual number of publications showed a steep increase after 2007 and more than half ($n=3455$; 58.0%) of the retrieved publications were published in the last 5 years of the study period (2015–2019) (Fig. 1). During the study period from 2009 to 2019, the last decade, both the cumulative number of citations and the number of publications showed a parallel increasing trend (Fig. 2). The number of publications increased by fivefolds while the cumulative number of citations increased by more than tenfolds.

Subject areas

The retrieved documents belonged to different subject areas emphasizing the multidisciplinary nature of food security and climate change. The subject area of environmental sciences ($n=3036$; 50.9%) ranked first followed by the subject areas of agricultural and biological sciences ($n=2333$; 39.1%), social sciences ($n=1597$; 26.8%), "Earth and Planetary Sciences" ($n=884$; 16.5%), and biochemistry/"genetics/molecular biology" ($n=533$; 8.9%), (Table 1).

Top frequent author keywords

Figure 3 is a network visualization map of the top 50 author keywords. In the map, the keyword "climate change" has the largest node size ($n=1408$ occurrences). The second largest node size was "food security" ($n=747$) followed by drought ($n=316$), adaptation ($n=311$), agriculture ($n=264$), and water scarcity ($n=194$). The map of the most frequent author keywords included the names of the following countries/regions: Africa, sub-Saharan Africa, Ethiopia, Bangladesh, China, and India. The map also included keywords such as health, nutrition, livelihood, and poverty. Of the types of food that appeared on the map were rice, maize and wheat.

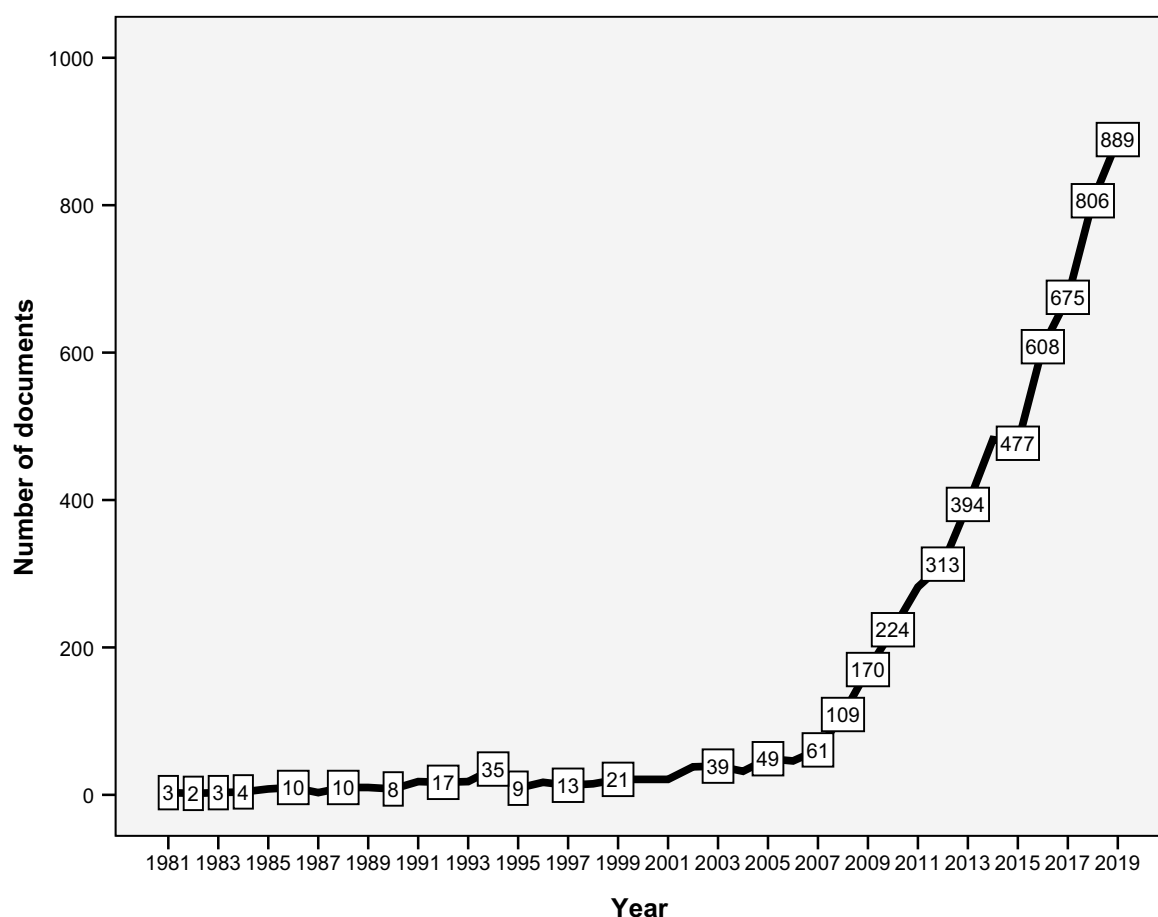


Fig. 1 Annual growth of publications (1980–2019)

Research themes

Figure 4 is a network visualization map of terms in titles/abstracts of the retrieved documents with minimum occurrences of 10 times. The map included 2020 terms distributed into four different clusters (colors). Closely related terms have the same color and represent a separate research topic/theme. The map shows four different clusters representing four general research themes. The largest theme (blue cluster = 826 terms) focused on crop yield of various types of food such as rice, wheat, and grains. The second research theme (green cluster = 587 terms) and discussed water security/scarcity/supply and precipitation. The third research theme (red cluster = 461 terms) focused on health/poverty/household dimension of food security. The fourth research theme (yellow cluster = 146 terms) focused on food availability.

Top ten prolific journals

The retrieved documents appeared in 1831 different journals. Table 2 shows the top ten prolific journals. The

Sustainability journal ranked first with 98 (1.6%) documents followed by the *Climatic Change* journal ($n=94$; 1.6%) and the *Science of the Total Environment* journal ($n=91$; 1.5%). Documents published in the *Global Change Biology* journal received the highest number of citations per document (62.2).

Top ten prolific countries

Authors from 170 different countries participated in publishing the retrieved documents. The top ten prolific countries published 5566 (93.4%) documents. The USA ranked first ($n=1562$; 26.2%) followed by the UK ($n=724$; 12.1%) and China ($n=623$; 10.5%). The top ten prolific countries did not include countries from Latin America or Africa or the Eastern Mediterranean region or Eastern Europe (Table 3). Documents published from the UK received the highest number of citations per document followed by those from the Netherlands and Italy. When the research productivity was standardized by GDP (nominal) per capita, India ranked first followed by China and the USA.

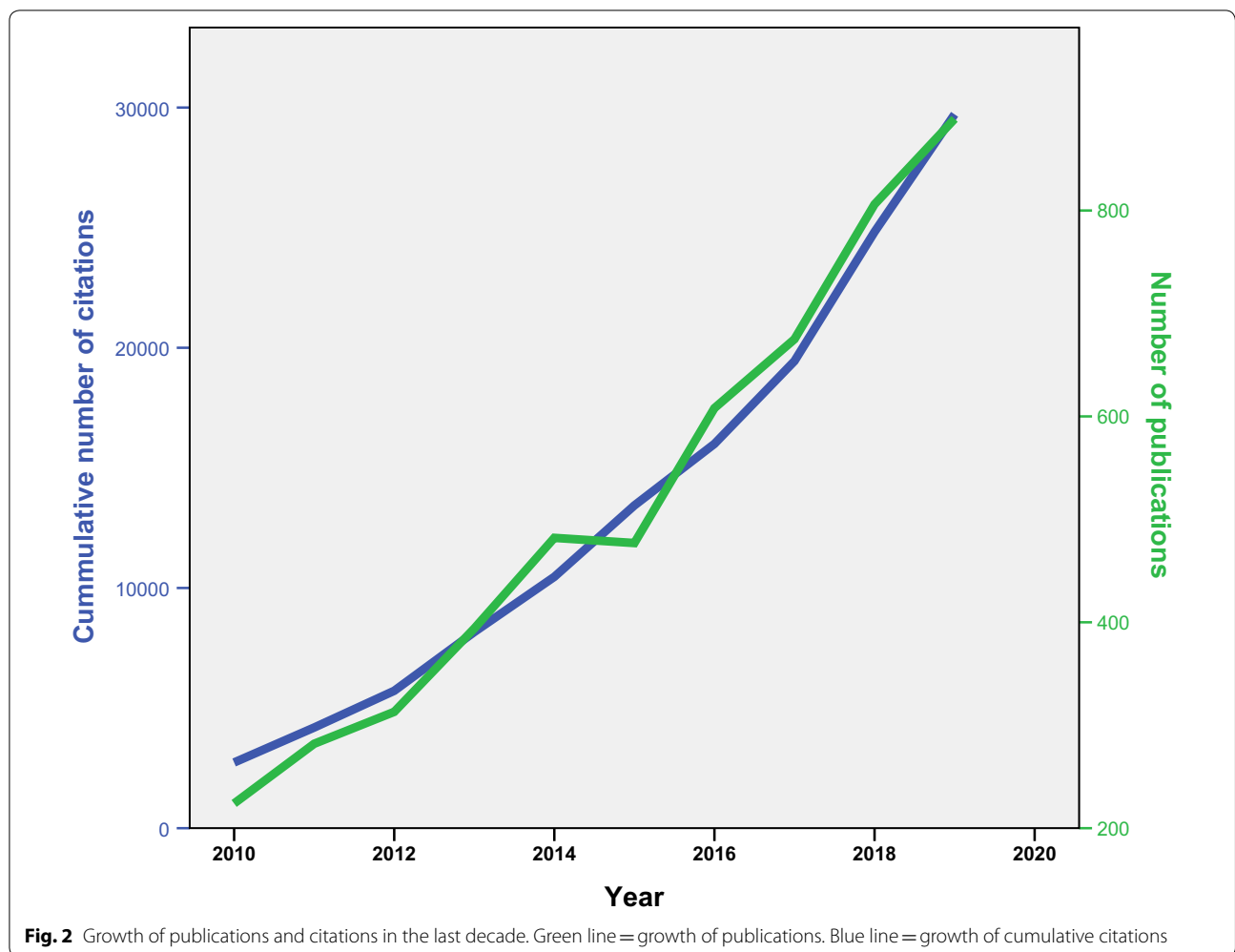


Table 1 Subject areas of the retrieved documents

Rank	Subject area	Frequency <i>N</i> = 5960	% ^a
1	Environmental Science	3036	50.9
2	Agricultural and Biological Sciences	2333	39.1
3	Social Sciences	1597	26.8
4	Earth and Planetary Sciences	982	16.5
5	Biochemistry, Genetics and Molecular Biology	533	8.9
6	Energy	403	6.8
7	Medicine	397	6.7
8	Engineering	382	6.4
9	Economics, Econometrics and Finance	331	5.6
10	Multidisciplinary	218	3.7

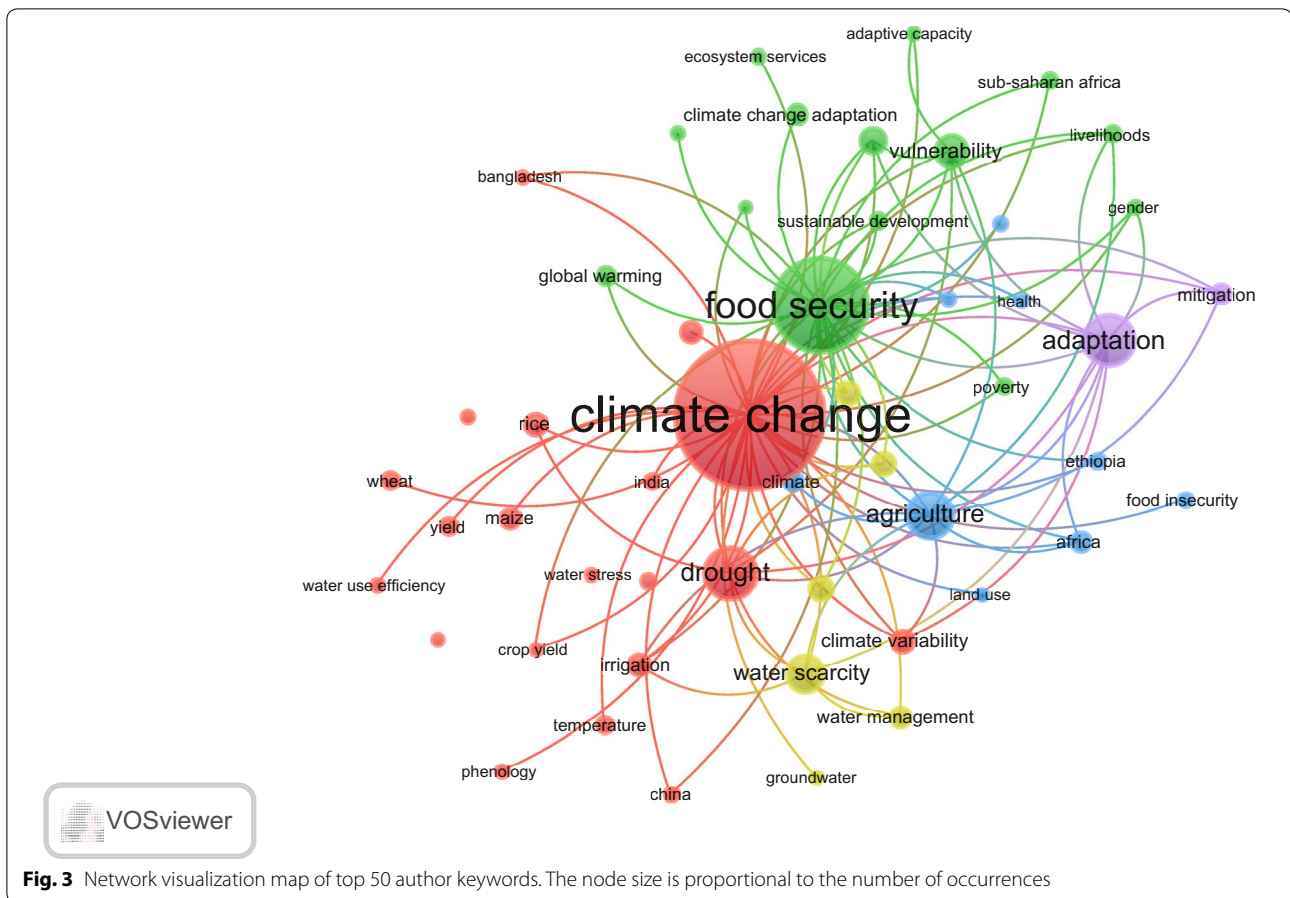
^a The total percentage is greater than 100% due to overlap among different subject areas

International research collaboration

Figure 5 is a stacked bar chart presentation of the extent of international research collaboration for each of the top ten active countries. France had the highest percentage of MCP followed by the Netherlands and Germany while India and China had the least percentage of MCP.

Geographical distribution of the retrieved documents

Table 4 shows the geographical distribution of the retrieved documents. The European region (*n* = 2377; 39.9%) had the highest contribution followed by the region of the Americas (*n* = 2103; 35.1%). The Eastern Mediterranean region had the least contribution (*n* = 348; 5.8%). Figure 6 shows the annual growth of publications from each WHO world region. The growth pattern was similar in all regions. However, for the region of the Americas and the European region, the growth pattern was the steepest. The growth pattern in the Eastern Mediterranean region showed the slowest growth pattern.



Top ten cited documents

The retrieved documents received 164,062, an average of 27.5 citations per document and an h -index of 163. The document that received the highest citations ($n = 4655$) was a review article published in 2010 in the *Science* journal and discussed food security in the face of increasing number of world population and the factors that worsen the threat including climate change [54]. The top-cited documents appeared in leading scientific journals [54–63]. Half of the top ten cited documents were review articles (Table 5) and half appeared in the *Science* journal.

Top ten active institutions

Table 6 shows the top ten active institutions. The Chinese Academy of Sciences ranked first ($n = 190$; 3.2%) followed by Wageningen University & Research ($n = 161$; 2.7%). The list of top ten active institutions included three Chinese and two American institutions.

Discussion

The current study aimed to give an overview of research activity on food security in the context of climate change, which is one of the top important subjects for governments, international non-governmental agencies, policymakers, food and agricultural experts, food technologists, and climate experts. The current study showed a noticeable growth in the number of publications in the last decade with considerable international research collaboration. The increase in the number of publications is due to several reasons. The IPCC fourth report issued in 2007 called for all countries to take adaptive measures to face climate changes [64]. This coincides with the steep rise in the number of publications. Several warning signals appeared in the 1980s and 1990s on the hazardous impact of climate change on livelihood. The first major international conference on the greenhouse effect at Villach, Austria, warned that greenhouse gases will cause a rise of global mean temperature which is greater than any in man's history [65]. In 1992, Climate Change Convention, agrees to reduce emissions from industrialized countries

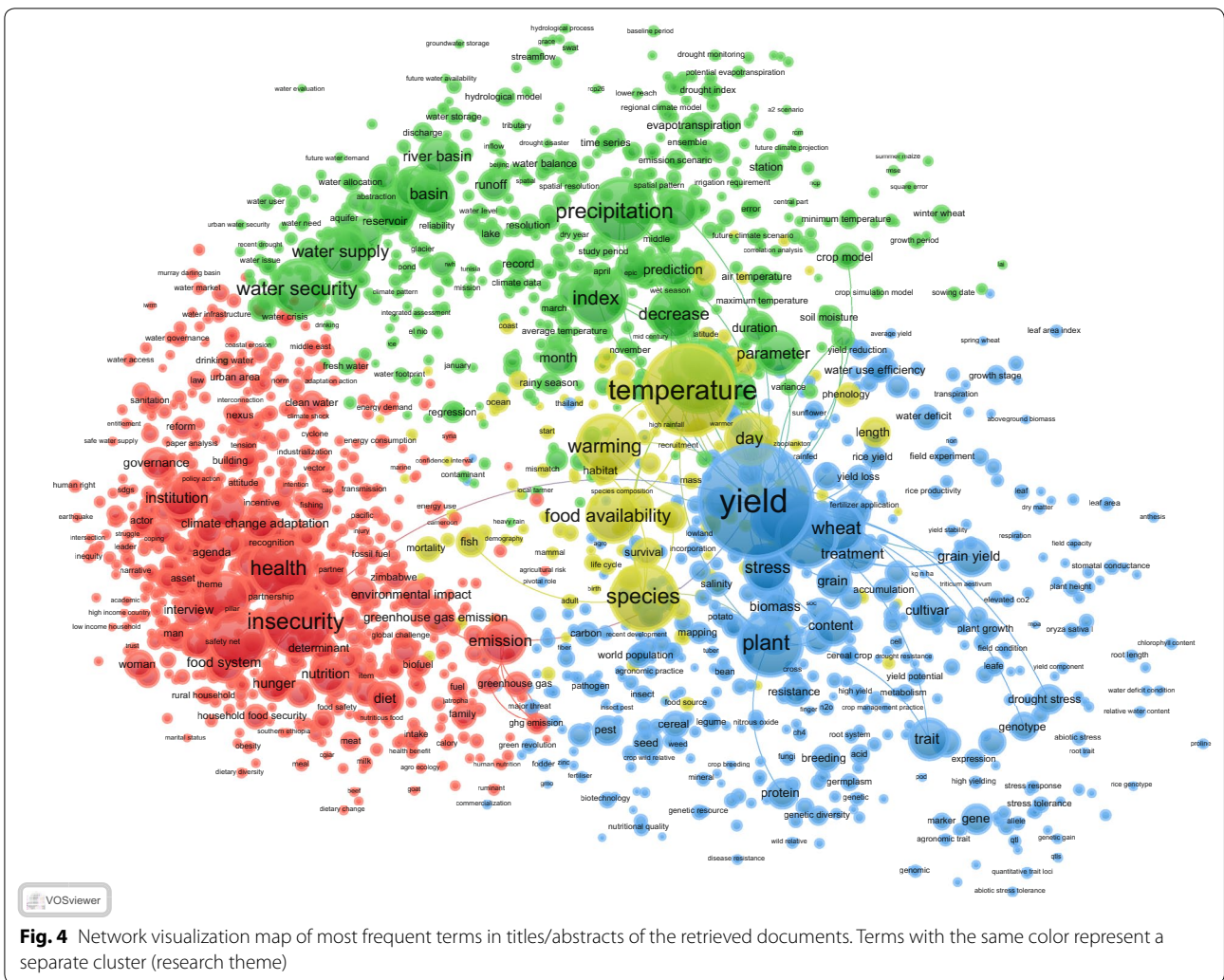


Fig. 4 Network visualization map of most frequent terms in titles/abstracts of the retrieved documents. Terms with the same color represent a separate cluster (research theme)

Table 2 Top 10 active journals

Rank ^a	Journal	Frequency N=5960	%	Total citations	Citations per document
1	<i>Sustainability Switzerland</i>	98	1.6	763	7.8
2	<i>Climatic Change</i>	94	1.6	4648	49.4
3	<i>Science of the Total Environment</i>	91	1.5	1598	17.6
4	<i>Plos One</i>	77	1.3	1349	17.5
4	<i>Water Switzerland</i>	77	1.3	546	7.1
6	<i>Regional Environmental Change</i>	73	1.2	2105	28.8
7	<i>Agricultural Water Management</i>	71	1.2	2253	31.7
8	<i>Environmental Research Letters</i>	68	1.1	2314	34.0
9	<i>Food Security</i>	66	1.1	1816	27.5
10	<i>Global Change Biology</i>	61	1.0	3797	62.2

^a In ranking system, journals with equal productivity were given the same rank

to stop global warming [66]. In 1997, the Kyoto Protocol calls for cutting emissions from industrialized nations [67]. However, due to political and economic

reasons in industrialized nations, the Kyoto protocol did not come into force until 2005. All these warning messages were translated into policies set by the

Table 3 Top 10 active countries

Rank	Journal	Frequency N = 5960	%	Number of citations per document	Number of publications per GDP/capita (10 ⁻³)
1	United States	1562	26.2	38.2	24.0
2	United Kingdom	724	12.1	54.2	17.7
3	China	623	10.5	23.8	61.7
4	Australia	566	9.5	39.7	10.5
5	India	452	7.6	20.7	205.5
6	Germany	445	7.5	41.3	9.5
7	Canada	331	5.6	34.8	7.2
8	Netherlands	329	5.5	51.0	6.3
9	Italy	272	4.6	41.5	8.3
10	France	262	4.4	35.6	6.3

GDP Gross Domestic Product; GDP (nominal) per capita obtained from World Bank data 2019

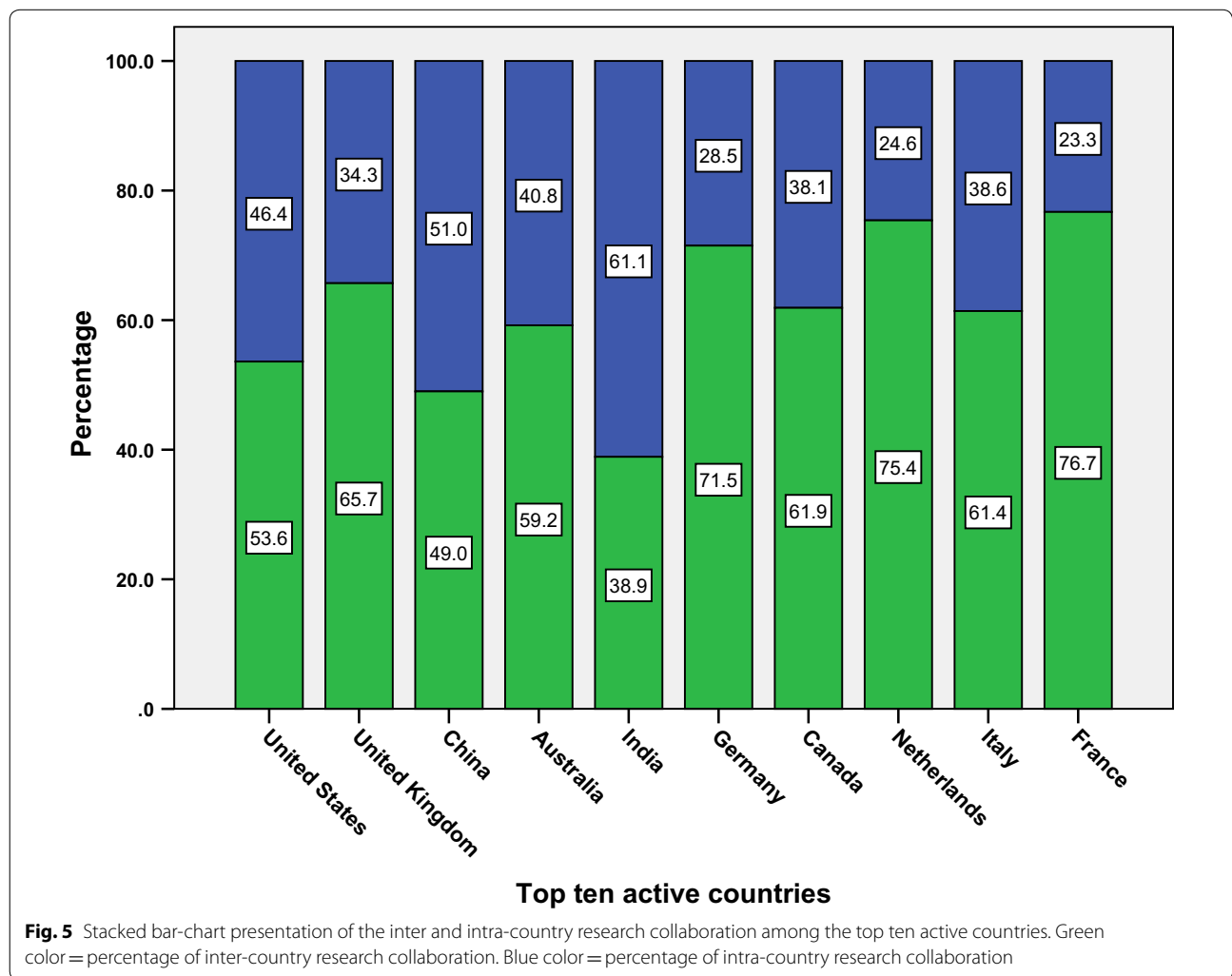


Fig. 5 Stacked bar-chart presentation of the inter and intra-country research collaboration among the top ten active countries. Green color = percentage of inter-country research collaboration. Blue color = percentage of intra-country research collaboration

Millennium Development Goals (MDGs) and SDGs. The steep growth in the number of publications emphasizes the fact that policymakers at the national and

international levels are fully aware and are implementing measures in the area of climate change and food security by supporting research from both academic

Table 4 Distribution of the retrieved documents by the WHO regions

Region ^a	Frequency N=5960	%
Africa	924	15.5
Americas	2103	35.3
Europe	2377	39.9
South-East Asia	657	11.0
Eastern Mediterranean	348	5.8
Western Pacific	1492	25.0

^a These regions represent the World Health Organization’s world regions

and non-academic centers to face the challenges of the twenty-first century.

The current study showed that the retrieved documents belonged to diverse subject areas, but mainly environmental and agricultural sciences. The contribution of

various subject areas to the retrieved literature emphasizes the complex nature of the topic and the role of various sectors in discussing the impact of climate change on food security. Climate change directly affects agriculture through changes in temperature, drought, heat waves, floods and concentration of ozone and atmospheric carbon dioxide [68, 69]. Both agriculture and climate change are inter-related. Agriculture can worsen climate change by producing greenhouse gases such as methane and CO₂ [70]. The global impact of climate change on agriculture is manifested in the reduction of quantity and quality of crops, changes in agricultural practices, changes in soil properties, and changes in plant properties such as the development of drought- or flood- or heat- or salt-resistant rice [71]. A study assessed the projected impacts of climate change on the yield of eight major crops in Africa and South Asia showed that the projected mean change in yield of all crops is 8% by the 2050s in both regions. Across Africa, mean yield changes of 17%

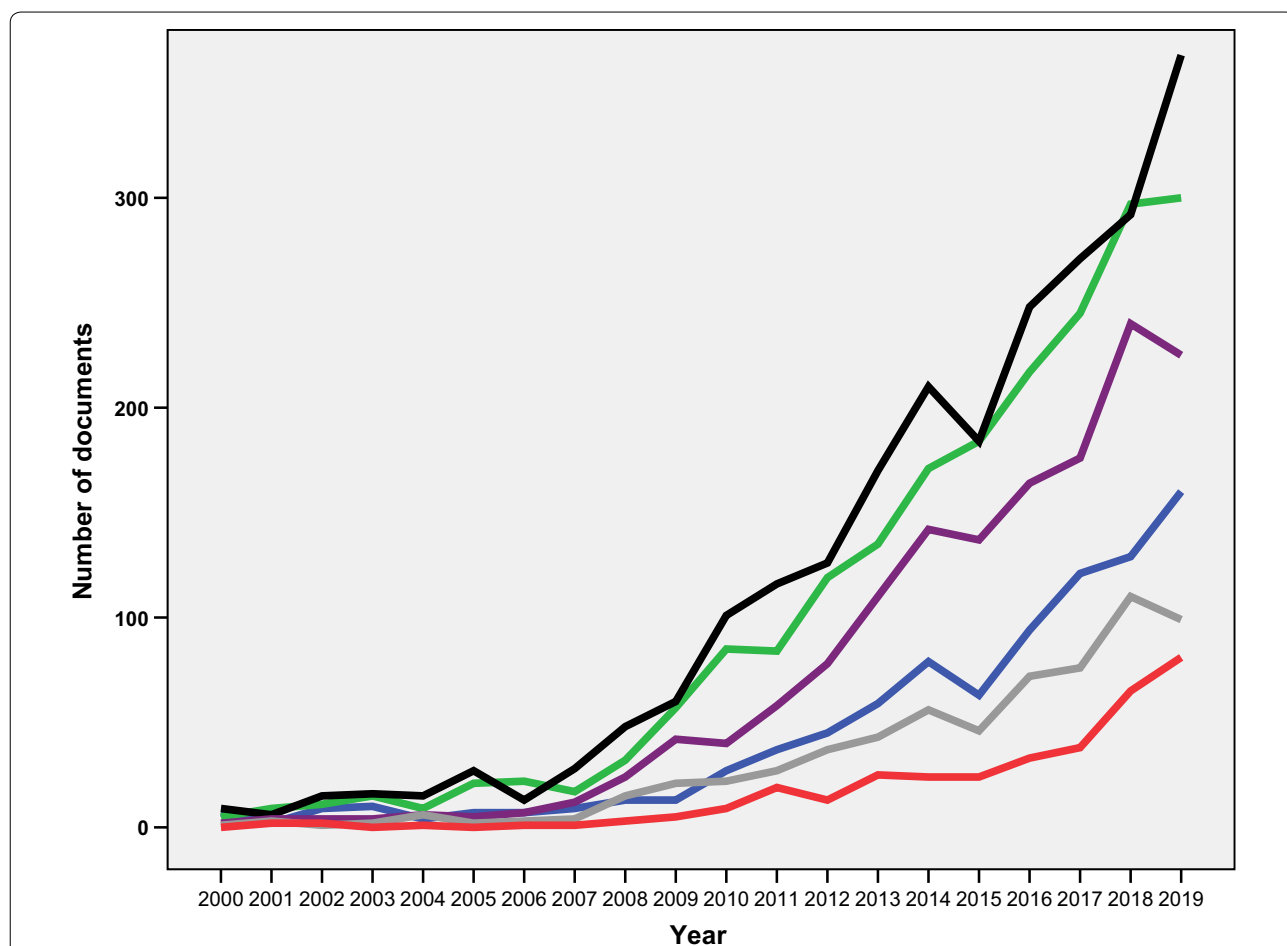


Fig. 6 Annual growth of publications in the WHO world regions. Black line = the European region; green line = the region of the Americas; purple line = the Western Pacific region; blue line = the African region. The grey line = the South-East Asian region; and the red line = the Eastern Mediterranean region

Table 5 Top 10 cited documents

Rank	Title	Document type	Source title	Cited by	Year
1	Food security: The challenge of feeding 9 billion people	Review	<i>Science</i>	4655	2010
2	Climate trends and global crop production since 1980	Article	<i>Science</i>	1617	2011
3	Impact of regional climate change on human health	Review	<i>Nature</i>	1533	2005
4	Prioritizing climate change adaptation needs for food security in 2030	Article	<i>Science</i>	1506	2008
5	Climate change will affect the Asian water towers	Article	<i>Science</i>	1486	2010
6	How plants cope with water stress in the field. Photosynthesis and growth	Article	<i>Annals of Botany</i>	1146	2002
7	Managing the health effects of climate change. Lancet and University College London Institute for Global Health Commission	Review	<i>The Lancet</i>	1130	2009
8	Sustainable biochar to mitigate global climate change	Article	<i>Nature Communications</i>	1006	2010
9	Climate change impacts on global food security	Review	<i>Science</i>	905	2013
10	Global food security under climate change	Review	<i>PNAS</i>	883	2007

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Table 6 Top ten active institutions

Rank	Institution	Frequency N = 5960	%	Country
1	Chinese Academy of Sciences	190	3.2	China
2	Wageningen University & Research	161	2.7	Netherlands
3	International Food Policy Research Institute	84	1.4	USA
4	Beijing Normal University	71	1.2	China
5	University of Oxford	70	1.2	UK
6	Commonwealth Scientific and Industrial Research Organization	67	1.1	Australia
7	International Livestock Research Institute Nairobi	66	1.1	Kenya
8	China Agricultural University	64	1.1	China
9	International Institute for Applied Systems Analysis, Laxenburg	62	1.0	Austria
10	University of California, Davis	61	1.0	USA

(wheat), 5% (maize), 15% (sorghum) and 10% (millet) and across South Asia of 16% (maize) and 11% (sorghum) were estimated [72]. The IPCC report published in 2014 stated that the world might reach "a threshold of global warming beyond which current agricultural practices can no longer support large human civilizations." by the middle of the twenty-first century.

The current study showed that adaptation, mitigation, and crop model prediction were among the top 50 frequent author keywords in the retrieved literature. Several methods of adaptation and mitigation to climate change have been developed and included the development of genetically resistant crop varieties and the development of efficient irrigation systems [73, 74]. In developed countries, innovative agriculture and development of new technologies and the use of cleaner energy have been suggested and implemented to adapt to climate change and to decrease the contribution of agriculture to greenhouse gases [75].

The current study showed that China and Chinese institutions were major key players in this area.

Approximately 20% of the world population lives in China, which has less than 7% of the world's arable land. China observed a ground average temperature increase of 0.24 °C/decade from 1951 to 2017, exceeding the global rate and the annual mean concentration of atmospheric carbon dioxide, methane and nitrous oxide were slightly higher than the global mean concentration in 2016 [76]. Climate change poses a huge challenge to food production in China. Climate change will not only threaten China's food production, but also the global food market of rice, wheat and corn which are produced in large quantities in China [77]. The current study showed that India had higher research output than China when research productivity was normalized by income and population size. India is highly populated and despite its economic growth it failed to achieve the target set in MDG regarding the reduction of hunger [78]. The problem of food security in India will be worsened by climate change because of water scarcity and droughts [79, 80]. The current study also showed that publications from the UK had the highest

number of citations per document. One possible explanation for this is the finding that the *Global Change Biology* journal, which received the highest number of citations in this field, is based in the UK. Interestingly, both China and India had the least international research collaboration, which explains the findings that documents from these countries had the least number of citations per document. In contrast, countries such as the UK, Italy, France, and the USA had a relatively high percentage of international research collaboration and therefore had a higher number of citations per document. Although the top list of active countries did not include countries from the African or the Eastern Mediterranean regions, the contribution of these two regions was reasonable given the limited funding, limited scientific expertise in climate change and food security, as well as the unstable political situation in many countries in these two regions.

The current study showed that documents received a relatively high number of citations per document and high *h*-index. This is indicative of the importance of the topic and the high level of interest of researchers in this field. This is not surprising given that the topic is not limited to a geographical area. Both food security and climate change are global problems and have direct effects on human health, wellbeing, and livelihood. The number of citations is also a function of the number of authors per document and the extent of international research collaboration and both were high for the investigated topic [81]. The contribution of all world regions to the topic was also a motivating factor for collaboration and an increased number of citations. The finding that half of the top-cited documents were review articles and published in highly prestigious journals with high impact factors also played a positive role in the number of citations received by the retrieved documents. However, the fact that these prestigious journals were based in Europe might have created publication bias toward these countries [47].

The current study was the first bibliometric analysis of climate change and food security. Searching Scopus database showed at least 30 bibliometric studies on climate change and a few on food security [28, 31, 82, 83]. However, none was on food security under the umbrella of climate change. Therefore, the current study is the first to discuss this topic from a bibliometric point of view. The current study had a few limitations. The author used all potential and possible keywords to maximize validity. However, missing some data remains a possibility. The use of Scopus as a source for relevant documents is another potential limitation. Scopus is indeed the largest database but there are many peer-reviewed journals in Asia, Africa, Latin America, and Eastern Europe that

are not indexed in Scopus. Therefore, documents published in unindexed journals were missed. This might under-estimate the productivity of certain countries, world regions, authors, and institutions. The third limitation is the type of keywords used in the search query. The author did his best to be comprehensive and to use all keywords mentioned in the literature that are relevant to climate change and food security. However, missing some terms remains a possibility. The final limitation is the use of single database to retrieve all relevant documents [84]. This is common to almost all bibliometric studies.

Conclusion

In the current study, an overview of research activity on food security in the context of climate change was presented hoping to create a beneficial contribution to the field. The retrieved literature was characterized by rapid growth, high citations, and involvement of leading journals. China and India were actively involved in research in this area while the UK, the Netherlands produced publications with the highest impact in the field. International research collaboration in this field was relatively high indicative of the importance of the topic. All world regions were involved in publishing documents in this area with the African region ranking fourth exceeding both the Eastern Mediterranean and the South-East Asian regions. The current study showed that water security, health, crop production, and food availability were the main research themes on food security under the umbrella of climate change. New technologies and innovative solutions to adapt and mitigate climate change need to be investigated to avoid food insecurity, especially in world regions with limited resources.

Abbreviations

WHO: World Health Organization; Q1: First quartile; IPCC: Intergovernmental Panel on Climate Change; UNFCCC: United Nations Framework Convention on Climate Change.

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Author contributions

WS started the idea, designed the methodology; did the data analysis, graphics, and data interpretation; wrote and submitted the manuscript. The author read and approved the final manuscript.

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Availability of data and materials

All data presented in this manuscript are available on Scopus database using the search query listed in the "Methodology" section.

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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