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RESEARCH AND EDUCATION HIGHLIGHTS

Mapping of climate change research in the Arab world: a bibliometric analysis

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Abstract

The attendant threats of climate change in the Arab world are accelerating at a high pace. The realization of these risks has promoted scientific research activities in climate change (i.e., modeling of climate change effects and development of mitigation and adaptation measures). A bibliometric analysis was desired to trace the status and trends of these research activities with an origin from the Arab world. The aim was to contribute to a better understanding of the scientific knowledge of climate change and its impacts and survey its evolution. Moreover, it is aimed at enabling recommendations for future research activities in this field. The data of this analysis were retrieved from the Scopus database using the most common terms of climate change to search titles, abstracts, and keywords. The collected data, in the form of documents referring to climate change, enabled to extract and further assess different quantitative and qualitative bibliometric indicators. Productivity of countries, sources, and institutions; collaboration figures; impact of published research; and citation rates were being among the assessed indicators. Subsequently, the data were analyzed using visualization maps and clustering techniques to characterize the hot spots and vital topics of research. A total of 2074 documents (1.2% of the total global research output) were retrieved from the Arab world. Saudi Arabia took the leading positions in terms of the number of publications (473 documents; 22.8%), impact of research (Hirsch index (*h*-index), 48), collected citations (10,573 citations), and number of documents from collaboration (389 documents). The USA was the most collaborated country with the Arab world (344 documents; 17.0%), followed by France (311 documents; 15.0%). The most productive journal was *Plos One* (42 documents; 2.0%), followed by the *Arabian Journal of Geosciences* (38 documents; 1.8%). Three institutions from Saudi Arabia were in the forefront in terms of research productivity (King Abdulaziz University, 124 documents; King Saud University, 117 documents; and King Abdullah University of Science and Technology, 102 documents). The vital climate change-related topics which will continue to be active in the future are climate modeling, physiology, genetics, and animals. The present data indicate a committed scientific research progress. Increasing the fund, capacity building, and development of regional experience with climate change-related disasters are key factors to promote the scientific research in this field.

Keywords Climate change · Energy · Sustainable development · Visualization maps

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Introduction

Climate changes represent alterations in the status of climate which can be identified by variations in the mean and/or the variability of climate's characteristics and their persistence for prolonged periods, commonly decades or longer (IPCC 2007). The climate changes are diagnosed as threats to human societies as they are posing serious risks on natural systems (Lee et al. 2015). In the last years, increased interests in climate change research by scholars have been witnessed. These interests are accompanied by spectacular rise in the amount of scientific output in this topic of research (Aleixandre-Benavent et al. 2017). The substantial research progress has

been rooted since the issue of the fourth assessment report of the Intergovernmental Panel on Climate Changes (IPCC) in 2007 (Gosling et al. 2011). This synthesis report has drawn together and integrated up-to-date policy-relevant scientific knowledge and technical and socioeconomic information on climate changes (Barker et al. 2007).

The IPCC in its fifth assessment report which has been issued in 2014 pointed out that the literature available for assessing climate change impacts, adaption, and vulnerability has increased more than doubled between 2005 and 2010 (Pachauri et al. 2014). Furthermore, the geographic distribution of researchers who are having contributions to the knowledge base of climate changes research has expanded, and the authorship of the literature from developing countries has increased, although their contributions represent a small fraction of the total global output (Field et al. 2014). Despite the rising public concern of research on climate changes in developed and developing worlds (Aleixandre-Benavent et al. 2017), many developing countries invest limited resources for research and development in technological innovations for climate change adaptation and mitigation (Adenle et al. 2015). The constraints were weak infrastructure, limited research capacity, and lack of credit facilities and technology transfer (Adenle et al. 2015). A study by Belter and Seidel (2013), which focused on climate engineering research, pointed out that in the past 5 years, there is increasing calling for more research on climate engineering as a possible supplement to climate change mitigation and adaptation strategies. The results showed that the majority of research in this field is produced by countries located in the Northern Hemisphere and speaking English (Belter and Seidel 2013).

Accordingly, the placing of climate change issues on top of the list of research priorities in the developing world became inevitable to save economic and social development process (Patlitzianas et al. 2006). This should be motivated, as well, with the increase of climatic extremes in terms of frequency and severity in the developing world coupled with limited adaptive and coping capabilities (Abbas et al. 2016; Abbas et al. 2018; IPCC 2007; Monirul Qader Mirza 2002). The Arab world as part of the developing world, located in a zone that is marked by a critical vulnerability to climate changes impacts, has been identified as a close victim of climate changes (Elasha 2010). The climate changes in this region threaten to reverse the gains in human and economic developments which have been acquired during the last few decades (El-Zein et al. 2014; The World Bank 2010). Its harsh and demanding environments (i.e., hyperarid to arid conditions, scarcity of water, very low rates and variable precipitations, and extreme climate events like drought and desertification integrated with high levels of poverty) make the region one of the most vulnerable regions to climate changes (Verner 2012).

A strong body of scientific research relying on global and regional climate change models indicates that the countries of the Arab world are likely to experience significantly higher means of annual temperature and decrease in rainfall with increasing in water stress during the twenty-first century (Giorgi and Lionello 2008; Hoerling et al. 2012; Lange 2019). This will induce serious impacts in different sectors such as the agriculture sector, human health, etc. (Constantinidou et al. 2019). An environmental awakening process from this region is witnessed (Patlitzianas et al. 2006) with the aim of boosting efforts of addressing and mitigating various environmental risks (i.e., air pollution, climate changes, etc.) (Zyoud et al. 2017). Almost all of the Arab world countries have signed and ratified into the United Nations Framework Convention on Climate Change and have accessed the Kyoto Protocol (Patlitzianas et al. 2006). This was in association with large improvements in health services, educational levels, scientific research, and living norms (Benamer and Bakoush 2009).

The present research statement is concerned with the assessment of the Arab world's commitments to the state of science in climate change research. This is crucial to the thorough understanding of the present status of climate change research in this region. Moreover, this study was conducted in order to recognize the trends of research with the aim of assisting in directing future research investments, improving research activities, and helping scholars in identifying and conducting new lines of climate change research. Since the assessment of the quantity and quality of scientific research is a useful tool in evaluating the endeavors of a region toward the global science, a large number of research works were devoted to assess the performance of science among different fields of research at the national, regional, and international dimensions (Zyoud et al. 2016). Bibliometric techniques, which are of high relevance in this regard as they offer valuable quantitative and qualitative indicators of scientific research (Zyoud and Fuchs-Hanusch 2017), will be employed to reach the objectives of this analysis. Mainly, objectives are formed to contribute to a thorough and well-informed understanding of the scientific knowledge of climate change research in the Arab world and, furthermore, to investigate its evolution through published research from the Arab world in the Scopus database. This informative analysis will offer well-grounded insights into a very pivotal research realm in a highly susceptible region to climate fluctuations.

Methods

Search strategy and inclusion criteria

Typically, bibliometric studies are performed utilizing one of the four most common literature databases that comprise the Scopus, Web of Science, PubMed, and Google Scholar (Falagas et al. 2008). In the current analysis, we used the Scopus database to retrieve documents related to climate change research. Scopus and Web of Science databases have selective journal-based inclusion policies, but Scopus has a larger number of indexed journals than Web of Science (Falagas et al. 2008; Martín-Martín et al. 2018). It is awarding an overview over research activities in all branches of science at regional and global levels with high flexibility (Yataganbaba and Kurtbaş 2016). Moreover, it has considerable functions which facilitate further assessment over collected data. For the purpose of sourcing and compiling data required for this analysis, all subject fields encompassed within the Scopus database were considered. These subject fields include physical, life, health, and social sciences. The Scopus database was searched for the following terms in titles, abstracts, and keywords: "climate change," "climate changes," "climatic change," and "climatic changes." These terms were used previously in the work of Li et al. (2011), where the authors have assessed the trends in research on global climate change research by collecting data from the Web of Science for a period extended from 1992 to 2009, and the work of Aleixandre-Benavent et al. (2017), where authors have assessed the trends of climate change research in agriculture and forestry subject areas for a time period between 2005 and 2014. The start of the timeframe to search for the previous terms was preserved as an open interval which continued to the close of the year 2017. The exclusion of scientific research output beyond the year 2017 is justified by the still opening period after December 31, 2017, for new publications.

The types of documents that are considered include reviews, articles, and articles in press, whereas the others such as conference papers, conference reviews, books, book chapter, notes, erratum, etc. were eliminated during the search round. To limit the search to just Arab countries, Arab states within the league of Arab states (Algeria, Egypt, Morocco, Syrian Arab Republic Iraq, Sudan, Saudi Arabia, Jordan, Tunisia, United Arab Emirates, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Bahrain, Comoros, Djibouti, Mauritania, Palestine, Qatar, Somalia, and Yemen) were employed as country keys. At a one-time interval (September 16, 2018), with a specific objective of averting any bias that could come out as a consequence of continually updating the database of Scopus, the searching and gathering of all data and relevant information were accomplished. Figure 1 illustrates the methodology of the search strategy and inclusion criteria used to retrieve publications related to climate change research from the Arab world using the Scopus database.

Statistical analysis and indices of research output

The extracted data from the Scopus database were exported to MS Excel spreadsheets for further analysis. These data include document types, growth rates of publications, name of sources, area of interests, countries of origin, affiliations, authorships, number and evolution of citations, etc. The annual growth of published documents has been used as an indicator of Arab world research productivity in climate change-related topics. This indicator has been utilized to assess the productivity, in total, at country level, institutions and journals. In terms of evaluation of the impact of published works by countries, the collected citations for these works and the average and median of citations were assessed. In this regard, the Statistical Package for Social Sciences (SPSS) has been utilized to evaluate the calculations of descriptive statistics (i.e., frequency, percentage, average, median and interquartile ranges). The standard competition ranking (SCR) has been used to order institutions, sources, and countries according to their productivity and the most cited works according to their collected citations in descending order.

An index, the Hirsch index (*h*-index) (Egghe 2006), which integrates quantitative scales (i.e., the amount of published works) and qualitative scales (i.e., the amount of citations), has been employed to assess the impact and performance of published works in a qualitative view. The *h*-index has potential in assessing the quality of research produced by countries, institutes, sources, scholars, etc. (Hirsch 2005). Furthermore, the sources most used by researchers from the Arab world have been collected and their impact factors (IFs) are extracted from the 2018 version of Journal Citation Report (JCR) issued by Thomson Reuters. The IFs are employed frequently to evaluate the quality of journals. They are reached by dividing the amount of citations attached to published documents in a specific source during the last 2 years by the total amount of documents being published in the source during the same period of time.

Bibliometric mapping and word frequency analysis

The VOSviewer software of van Eck and Waltman (2010) has been utilized in displaying the associated bibliometric maps with various bibliometric indicators (i.e., co-authorships between countries; citation and co-citation analyses of different sources). This software generates maps of visualization relied on the data of networks. It utilizes clustering techniques and similarity mapping which are employed mostly to analyze bibliometric networks (Zeraatkar 2013). In assessing research collaboration between countries, the VOSviewer can generate a two-dimensional distance-based map.

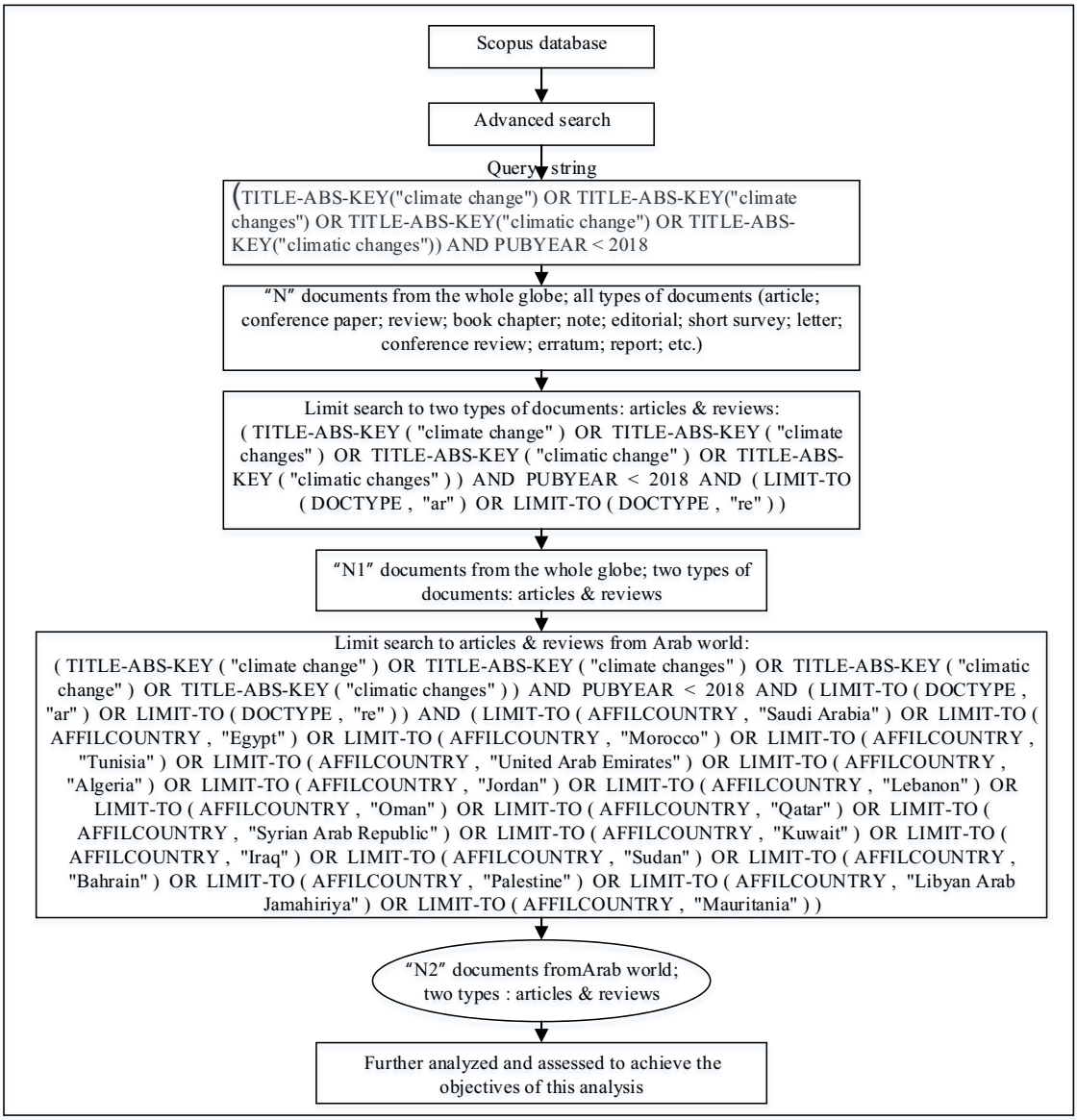


Fig. 1 Methodology of the search strategy and inclusion criteria used to retrieve publications related to climate change research from the Arab world using the Scopus database

The distance that appears between two countries, for example, on the map indicates the strength of collaboration between the two countries (van Eck and Waltman 2010). When two countries on the map are closer to each other, this indicates more frequent joint research works between them (Bornmann 2016).

A word frequency analysis in association with co-occurrence keyword analysis has been performed to identify the topics of high concern. The word frequency analysis is an effective technique in assessing the contents of published works (Wang et al. 2017) as core words indicate the core of literature and the hub of research. The co-occurrence keyword analysis assists in identifying the association between the concepts of different works. These analyses help in recognizing research hot spots and suggesting new novel directions of science (Tan et al. 2014). As threshold pertaining to documents published as an outcome of collaboration between different countries, co-citation of sources or co-occurrence of keywords was applied to the visualization of the networks (Aleixandre-Benavent et al. 2017).

Results

The overall number of documents retrieved from the Scopus database which are related to climate changes at the global level was 221,108 documents (all types of documents). By limiting the search to articles and reviews, the total research

productivity was 173,612 documents. Articles were the most frequently used document type encompassing 92% (159,559 documents) of the total global research productivity in climate changes. The oldest documents at the global level date back to the year 1883. The two documents were published in the *Science* journal, volume 1, issues 5 and 6. The articles' titles were "Whitney's climate changes" with no available information (i.e. author, abstract, etc.). From 2 articles in 1883 to 18,640 documents in 2017, a very rapid development of global climate change research was made. A notable growth in global climate change research was noticed after the 1990s (Fig. 2). The Arab world's contribution was 2074 documents which represents 1.2% out of the global research productivity. Articles were the dominant type of documents such as in the case of the global figure (1900 documents; 92.0%).

The first article from the Arab world was published in 1971 in *Biological Conservation* by Kassas from the Department of Botany, Faculty of Science, University of Cairo, Egypt. The article titled "The River Nile ecological system: a study towards an international programme" (Kassas 1971). Research activities from the Arab world in climate change research were very modest at their beginnings. A breakthrough after the year 2010 was noticed (Fig. 2) as more than 80.0% of documents were published.

The outcomes of the bibliometric evaluation of 2074 documents published by scholars from the Arab world in climate change research during a period of time extended from 1971 to the end of 2017are displayed in Table 1. Eighteen countries out of 22 countries of the Arab world had contributions in climate change research. Among the Arab world countries, Saudi Arabia had the highest share of publications (473 documents; 22.8%), followed by Egypt (372 documents; 17.9%), Morocco (247 documents; 11.9), Tunisia (231 documents; 11.1%), and the United Arab Emirates (174 documents; 8.4%). Saudi Arabia had the highest number of citations (10,573 citations) and the highest *h*-index (48).

Figure 3 illustrates in a space of two dimensions the cooperated countries. Countries with higher rates of collaboration are arranged more closely to each other. Furthermore, countries frequently collaborated are assigned to clusters with distinct colors. The size of the node in the network visualization map indicates the contribution of each country in terms of co-authorship and collaboration (i.e., the larger the node, the higher the contribution of the country). The least number of documents of a country was set as 20 documents, and of 202 countries, 48 countries met the threshold. The number of links between collaborated countries was 986 links with a total strength of 7458. Saudi Arabia was the most active country at the Arab world level in terms of collaboration. Saudi Arabia had 47 links with a total strength of 821. It is followed by Egypt which had 45 links with a total strength of 472. The strongest link strength was between Saudi Arabia and the USA (113). The collaborated countries are categorized into three clusters: red cluster with 19 items, green cluster with 19 items, and blue cluster with 10 items.

The most productive journals where researchers from the Arab world have published their works are displayed in Fig. 4. *PloS One* journal with 42 documents (2.0%) was in the forefront among 158 journals. It is followed by the *Arabian Journal of Geosciences* (38 documents; 1.8%), *International Journal of Climatology* (31 documents; 1.5%), *Environmental Earth Sciences* (25 documents; 1.2%), *Journal of Hydrology* (24 documents; 1.1%), and *Renewable and Sustainable Energy Reviews* (24 documents; 1.1%). Thirty out of 31 journals which have been classified as the most productive journals had impact factors and appeared in JCR 2018.

Figure 5 demonstrates the map of density visualization (item density) of top journals based on co-citation analysis. The least number of citations of each source was set as 100.

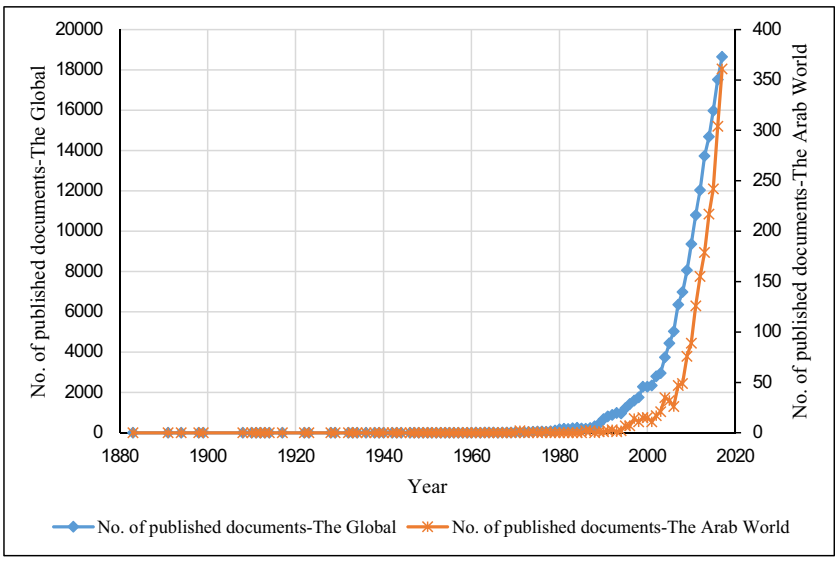


Fig. 2 Number of published documents at the Arab world level in fields of research related to climate change with comparison to research productivity from global in the same fields of research

Table 1 Bibliometric analysis of 2074 documents published by Arab world in climate change research during a period of time extended from 1971 to the end of 2017

SCR[a]	Country	No. of documents (%)	*h*-index	No. of citations	Average citation	Median citation (Q1–Q3)[b]	Collaboration with foreign countries—no. of collaborated countries	No. of documents form collaboration (%)[c]	Most collaborated country	No. of documents with most collaborated country (%)[d]
1st	Saudi Arabia	473 (22.8)	48	10,573	22.4	7 (2–20)	111	389 (82.0)	USA	114 (24.0)
2nd	Egypt	372 (17.9)	36	4687	12.6	5 (1–13)	121	223 (60.0)	USA	57 (15.0)
3rd	Morocco	247 (11.9)	36	5328	21.6	6 (1–22)	109	184 (74.0)	France	89 (36.0)
4th	Tunisia	231 (11.1)	36	5710	24.7	8 (2–25)	97	177 (77.0)	France	99 (43.0)
5th	United Arab Emirates	174 (8.40)	32	5666	32.6	8 (3–24.3)	90	133 (76.0)	USA	49 (28.0)
6th	Algeria	151 (7.30)	25	4778	31.6	5 (1–14)	89	84 (56.0)	France	41 (27.0)
7th	Jordan	138 (6.70)	26	2422	17.6	5 (2–21.25)	69	86 (62.0)	USA	20 (14.0)
8th	Lebanon	91 (4.40)	21	1505	16.5	7 (2–20)	53	69 (76.0)	France	27 (30.0)
9th	Oman	80 (3.90)	19	2538	31.7	7 (3–18)	50	62 (78.0)	UK	16 (20.0)
10th	Qatar	72 (3.50)	13	1122	15.6	5 (2–10)	52	60 (83.0)	USA	17 (24.0)
11th	Syrian Arab Republic	53 (2.60)	20	1385	26.1	10 (3–37)	82	42 (79.0)	UK Australia	− 7 (13.0) − 7 (13.0)
12th	Kuwait	50 (2.40)	20	1818	36.4	11.5 (1–39.8)	55	30 (60.0)	USA	19 (38.0)
13th	Sudan	49 (2.40)	16	1430	29.2	9 (2–24)	53	37 (76.0)	USA	10 (20.0)
14th	Iraq	47 (2.30)	11	690	14.7	3 (1–10)	40	35 (74.0)	UK	9 (19.0)
15th	Bahrain	27 (1.30)	10	742	27.5	4 (1–15)	38	16 (59.0)	UK	9 (33.0)
16th	Palestine	23 (1.10)	9	289	12.6	7 (1–18)	34	15 (65.0)	Germany Jordan	− 5 (22.0) − 5 (22.0)
17th	Libyan Arab Jamahiriya	21 (1.00)	8	292	13.9	2 (0–19)	39	17 (81.0)	UK	6 (29.0)
18th	Mauritania	15 (0.70)	6	358	23.9	5 (1–7)	41	15 (100.0)	France	9 (60.0)

SCR = standard competition ranking; *Q1–Q3* = lower quartile–upper quartile

[a] Equal countries have the same ranking number, and then a gap is left in the ranking numbers

[b] For the small number of articles, the interquartile range was not available

[c] Percentage of documents with international authors (i.e., from other Arab and non-Arab countries) out of the total number of documents for each country

[d] Percentage of documents with most collaborated country out of the total number of documents for each country

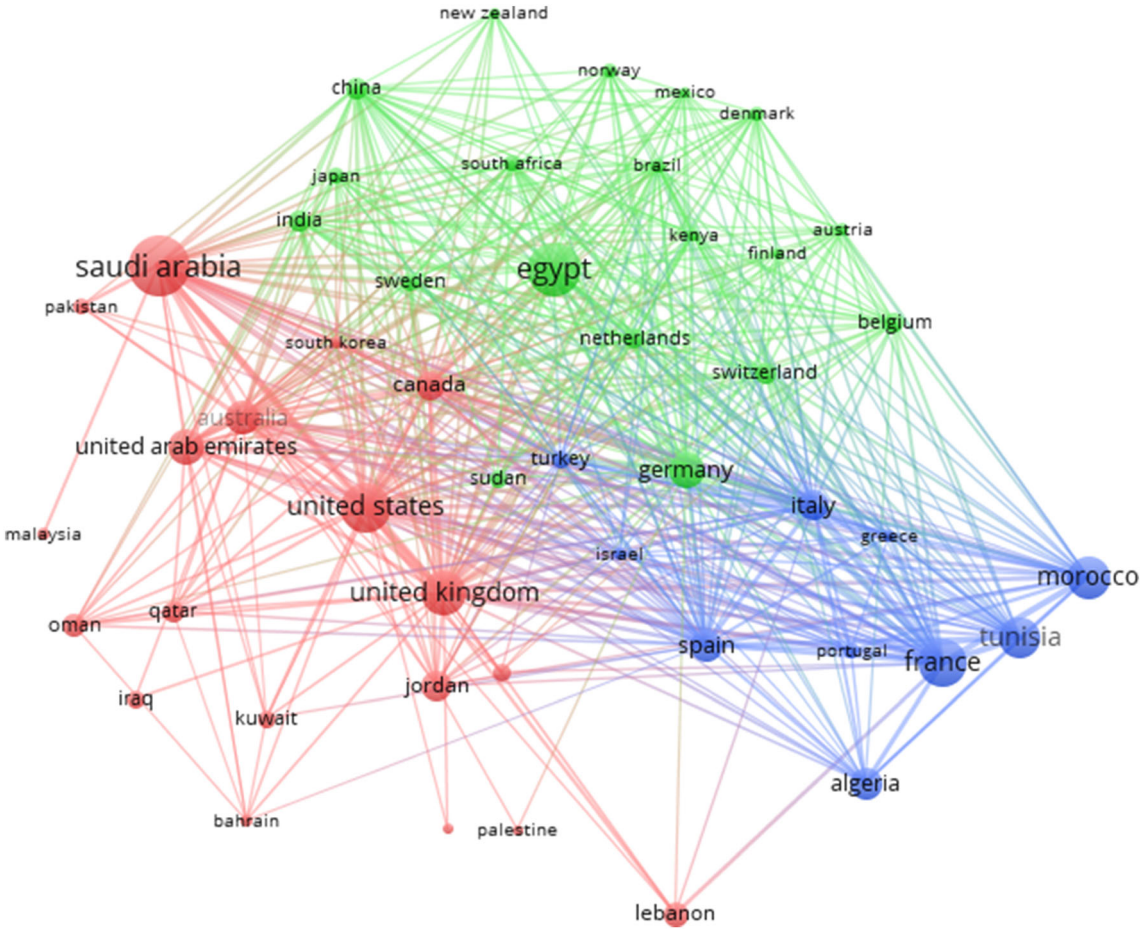


Fig. 3 Network visualization map for country collaboration. A minimum of 20 documents per country was set as a threshold and 48 countries meet the threshold. The thickness of the link between any two countries is an indicator of the strength of collaboration between the two countries. The volume of the circle around the item is an indicator of the contribution of the item (i.e., the larger circle, the higher the contribution of the country in terms of co-authorship). The items with the same color indicate that these items are related to each other (i.e., within the same cluster)

Out of 31,408 sources, 52 met the threshold. The total number of links between sources was 914 with a total strength of 78,542. The hot sources with high rates of co-citations appeared in the zone of red color. *Science* and *Nature* journals were the two journals with the highest number of links (51 links for each), while *Science* journal was the one with the strongest link strength (19,039) followed by *Nature* journal (the total link strength was 16,015.

The top 20 most cited documents (articles and reviews) are displayed in Table 2 (Allen et al. 2010; Armitage et al. 2011; Babiker 2005; Butchart et al. 2010; Coll et al. 2010; Dahl-Jensen et al. 2013; Defeo et al. 2009; Donat et al. 2013; Duarte et al. 2013; Foden et al. 2013; Gairuso et al. 1999; Hannachi et al. 2007; Lejeusne et al. 2010; Maestre et al. 2012; McVicar et al. 2012; Nugent et al. 2013; Orlando et al. 2013; Schlacher et al. 2008; Sheppard et al. 2010; Trenberth et al. 2014). *Science* and *Nature* journals gathered the highest number of documents with high rates of citations in the list (three documents for each). They are followed by *PLoS One* and *Nature Climate Change* with two documents for each. The article entitled "A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests" which was published in the *Forest Ecology and Management* journal by Allen et al. (2010) was the most cited document at the time of analyzing data (2109 citations). Twenty authors from the USA. Algeria, France, Argentina, Switzerland, Canada, Australia, China, Spain, the Russian Federation, Republic of Korea, Italy, and Turkey worked on this research. The authors of this work presented the first assessment which has been conducted at the global level to evaluate the mortality of trees in association with droughts and heat stresses. Furthermore, they identified the gaps in information and uncertainties in scientific works which hinder accurate prediction of mortality of trees attributed to climate changes. In their conclusion, the authors have recommended the necessity to establish an observation system with global coordination (Allen et al. 2010). The second most cited paper, with 1631 citations, has been published in the *Science* journal. Forty-five authors from the UK, Netherlands, USA, Canada, Italy, Switzerland, Australia, South Africa, France, India, and

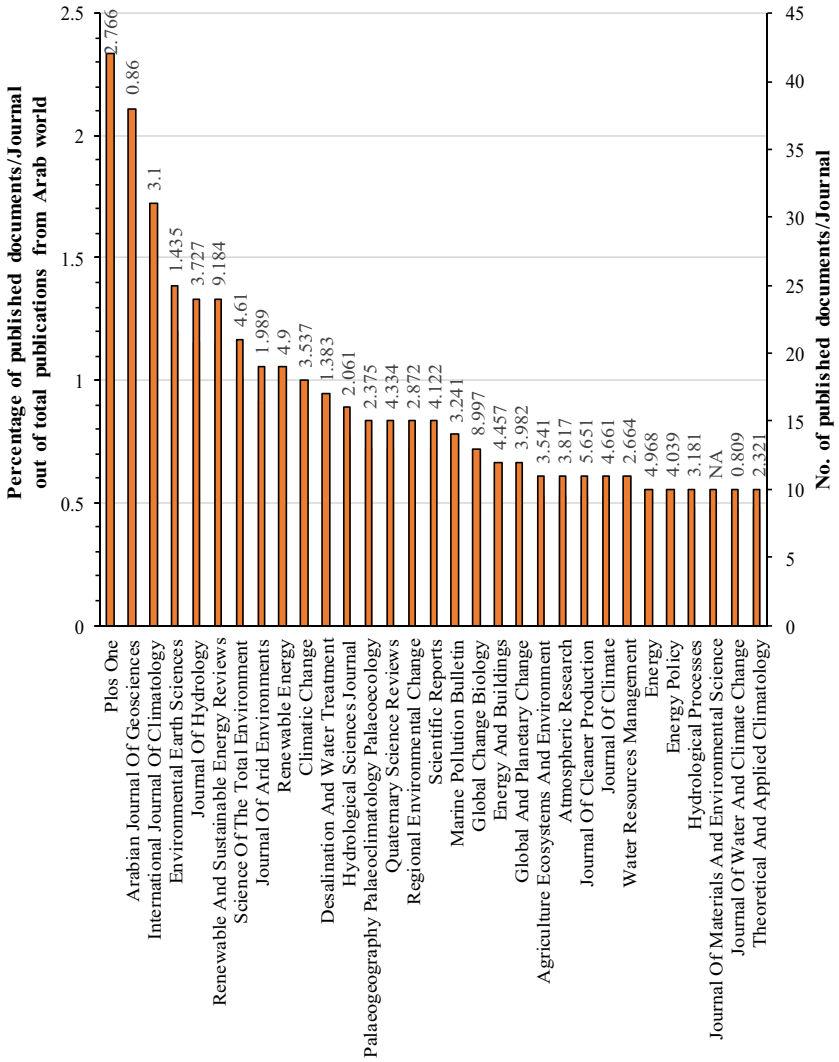


Fig. 4 Top most productive journals (the top 31) where researchers from the Arab world have published their research in climate change research. Impact factors of journals are collected from the Journal Citations Report (JCR): released in 2018 by Thomson Reuters for 2017 citations data and written at the head of the columns which represent the productivity of each journal

United Arab Emirates participated in this work which is entitled "Global biodiversity: indicators of recent declines." They assessed the loss of biodiversity by evaluating 31 indicators. They found that most of the state of biodiversity indicators showed declining trends. On the other hand, the indicators related to pressure on biodiversity showed increasing trends. In their conclusion, and despite some achievements in the reduction of loss of biodiversity at local levels, the rates of loss of biodiversity are not in decreasing tendency (Butchart et al. 2010).

Figure 6 displays the leading institutions which had contributions to climate change research published from the Arab world and in collaboration with other non-Arab institutions. The total number of institutions was 160 institutions across the globe with different contributions ranging from 124 documents for the most prolific institution to 9 documents for the least productive one. The most productive institutions at the Arab world level were King Abdulaziz University (124 documents; 6.0%), King Saud University (117 documents; 5.6%), and King Abdullah University of Science and Technology (102 documents; 5.0%). These three most prolific institutions were all from Saudi Arabia.

Figure 7 illustrates the overlay visualization map of the co-occurrence keywords analysis. The least number of occurrence of a keyword was set to a threshold of 50 occurrences. Of the 15,075 keywords, 65 met the previously specified threshold. The number of links of co-occurrence of keywords was evaluated for each of the 65 keywords. The keywords with the largest number of links have been selected. The analysis divided the keywords into five clusters. The number of links was 1669 with a total link strength of 12,771. The most total link strength was 4071 to the benefit of climate change keyword. The strongest link strength was between climate change and climate effect (link strength = 132), followed by the link between climate change and nonhuman (link strength = 115). The red color shows the trend of climate change research in the last period which is devoted to climate models, physiology, genetics, and animals. Keywords with the

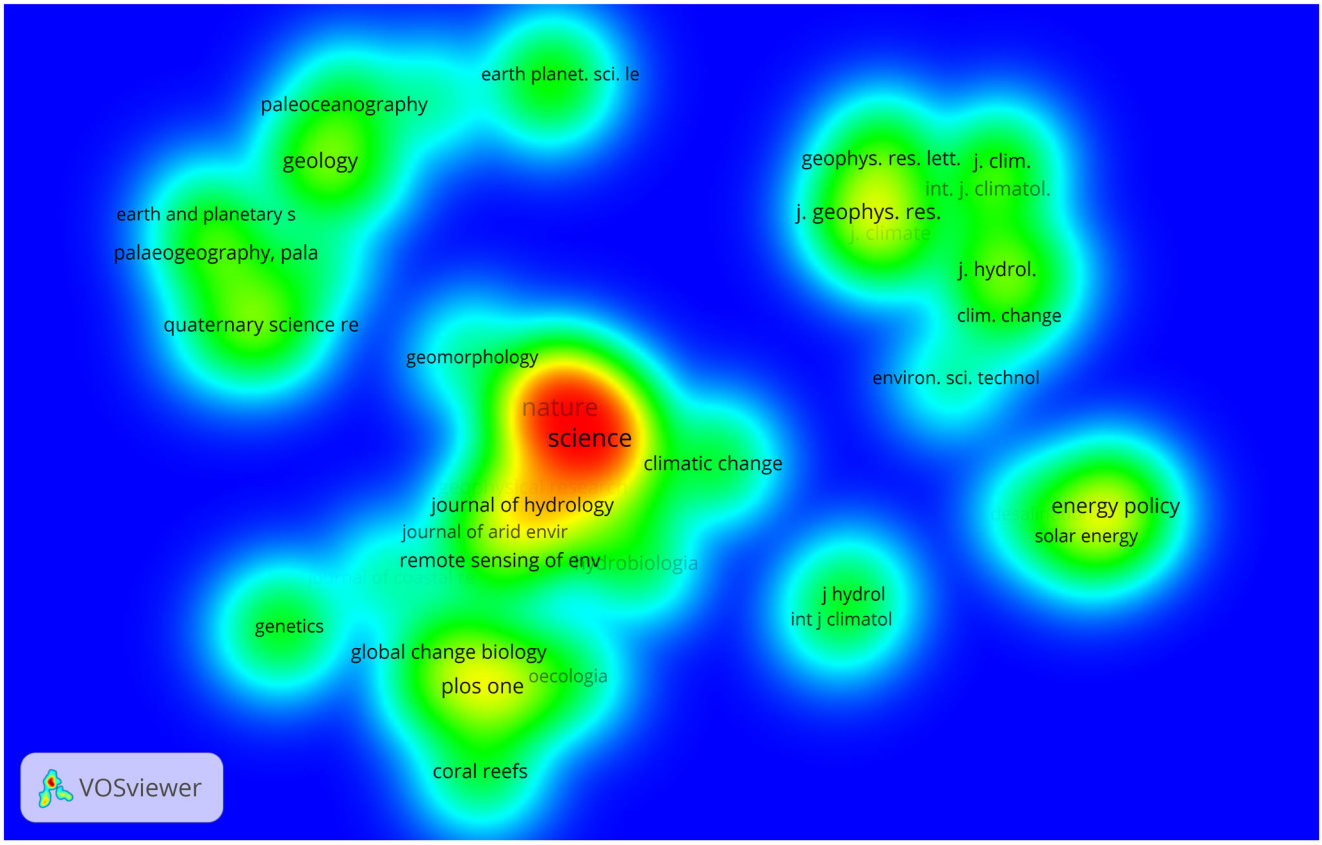


Fig. 5 Density visualization map of top journals based on co-citation analysis (item density). A minimum number of citations of a source = 100. Of the 31,408 sources, 52 met the threshold. For each of the 52 sources, the total strength of co-citation links with other sources was calculated. The sources with the greatest total link strength are selected

most occurrences were climate change (1461 occurrences), climate models and climate modeling (185 occurrences), global warming (150 occurrences), climate effect (146 occurrences), nonhuman (138 occurrences), Egypt (134 occurrences), temperature (131 occurrences), and animals (127 occurrences).

The network visualization maps of the analysis of co-occurrence of keywords for two periods, 1971–2009 and 2010–2017, are displayed in Fig. 8 a and b, respectively. For the period extended from 1971 to 2009, keywords with the most occurrences were Africa (80 occurrences), North Africa (62 occurrences), Eurasia (58 occurrences), Asia (49 occurrences), Middle East (48 occurrences), Egypt (37 occurrences), and global warming (30 occurrences). The strongest link strengths were, respectively, between climate change and global warming (total link strength 129) and between climate change and Africa (total link strength 57). For the period extended from 2010 to end of 2017, keywords with the most occurrences were rain, rainfall, and precipitation (248 occurrences); animal and animals (207 occurrences); climate models and climate modeling (180 occurrences); climate effect (127 occurrences); temperature (121 occurrences); global warming (120 occurrences); nonhuman (118 occurrences); and Egypt (98 occurrences). The strongest link strength was collectively between climate change and both climate models and climate (total link strength 175).

Discussion

The Scopus database has been utilized to source the publications of climate change research with origin from the Arab world. The work addressed the evolution of scientific research on climate changes; the most productive countries, journals, and institutions; research collaboration links; most cited works; and hot topics with the most interests. The work contributes to promote collaboration among research communities with interests in climate changes at the regional and international levels. Furthermore, the assessment of status quo of climate change research activities in the Arab world would be of advantage in evoking valuable discussions and interactions among research policy makers. In turn, this will help in directing the future research developments and investments toward innovative research with significant impact in solving climate change issues.

As climate changes and their impacts become more evident, the scientific efforts to identify the causes, the consequences, and the mitigating measures to combat the potential

Table 2 Top 20 most cited articles on climate change research published from the Arab world and in collaboration with scholars from non-Arab countries

SRC[a]	Authors	Title	Journal name	Times cited[b]	Document type
1st	Allen et al. 2010	A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests	*Forest Ecology and Management*	2109	Article
2nd	Butchart et al. 2010	Global biodiversity: indicators of recent declines	*Science*	1631	Article
3rd	Nugent et al. 2013	Porous materials with optimal adsorption thermodynamics and kinetics for CO2 separation	*Nature*	835	Article
4th	Coll et al. 2010	The biodiversity of the Mediterranean Sea: estimates, patterns, and threats	*PLoS ONE*	581	Review
5th	Trenberth et al. 2014	Global warming and changes in drought	*Nature Climate Change*	416	Review
6th	Defeo et al. 2009	Threats to sandy beach ecosystems: a review	*Estuarine, Coastal and Shelf Science*	404	Review
7th	Gairuso et al. 1999	Photosynthesis and calcification at cellular, organismal and community levels in coral reefs: a review on interactions and control by carbonate chemistry	*American Zoologist*	362	Article
8th	McVicar et al. 2012	Global review and synthesis of trends in observed terrestrial near-surface wind speeds: implications for evaporation	*Journal of Hydrology*	354	Review
9th	Hannachi et al. 2007	Empirical orthogonal functions and related techniques in atmospheric science: a review	*International Journal of Climatology*	304	Review
10th	Donat et al. 2013	Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: the HadEX2 dataset	*Journal of Geophysical Research Atmospheres*	303	Article
11th	Maestre et al. 2012	Plant species richness and ecosystem multifunctionality in global drylands	*Science*	302	Article
12th	Orlando et al. 2013	Recalibrating equus evolution using the genome sequence of an early Middle Pleistocene horse	*Nature*	280	Article
13th	Lejeusne et al. 2010	Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea	*Trends in Ecology and Evolution*	266	Review
14th	Foden et al. 2013	Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals	*PLoS ONE*	261	Article
15th	Dahl-Jensen et al. 2013	Eemian interglacial reconstructed from a Greenland folded ice core	*Nature*	245	Article
16th	Duarte et al. 2013	The role of coastal plant communities for climate change mitigation and adaptation	*Nature Climate Change*	234	Review
17th	Armitage et al. 2011	The southern route "out of Africa": evidence for an early expansion of modern humans into Arabia	*Science*	229	Article
18th	Sheppard et al. 2010	The Gulf: a young sea in decline	*Marine Pollution Bulletin*	207	Article
19th	Schlacher et al., 2008	Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts	*Marine Ecology*	201	Article
20th	Babiker 2005	Climate change policy, market structure, and carbon leakage	*Journal of International Economics*	200	Article

SCR = standard competition ranking

[a] Equal documents in terms of the number of citations have the same number of ranking, then a gap is left in the numbers of ranking

[b] Total citations have been collected from the Scopus database and could differ when using other research database

adverse environmental consequences flowing from climate changes are progressing at a fast pace. It is manifested by the large number of projects concerned with climate changes and sponsored by international organizations such as the World Bank which invested $11.9 billion in 224 projects in 77 countries across the globe (World Bank 2018); initiatives and projects of the Food and Agriculture Organization (FAO) which aimed to support communities in creating suitable environments for the advancement of agricultural activities in the presence of climate changes (FAO 2018); work plans of the World Health Organization (WHO) which are related to climate changes and health and directed toward the enhancement of scientific evidence, boosting of awareness, and reinforcement of health systems (WHO 2018); and the projects and initiatives managed by the United Nations Environment Programme (UNEP) focusing on helping countries tackle climate changes (UNEP 2018). A large number of programs and projects have been planned, underway, or completed around

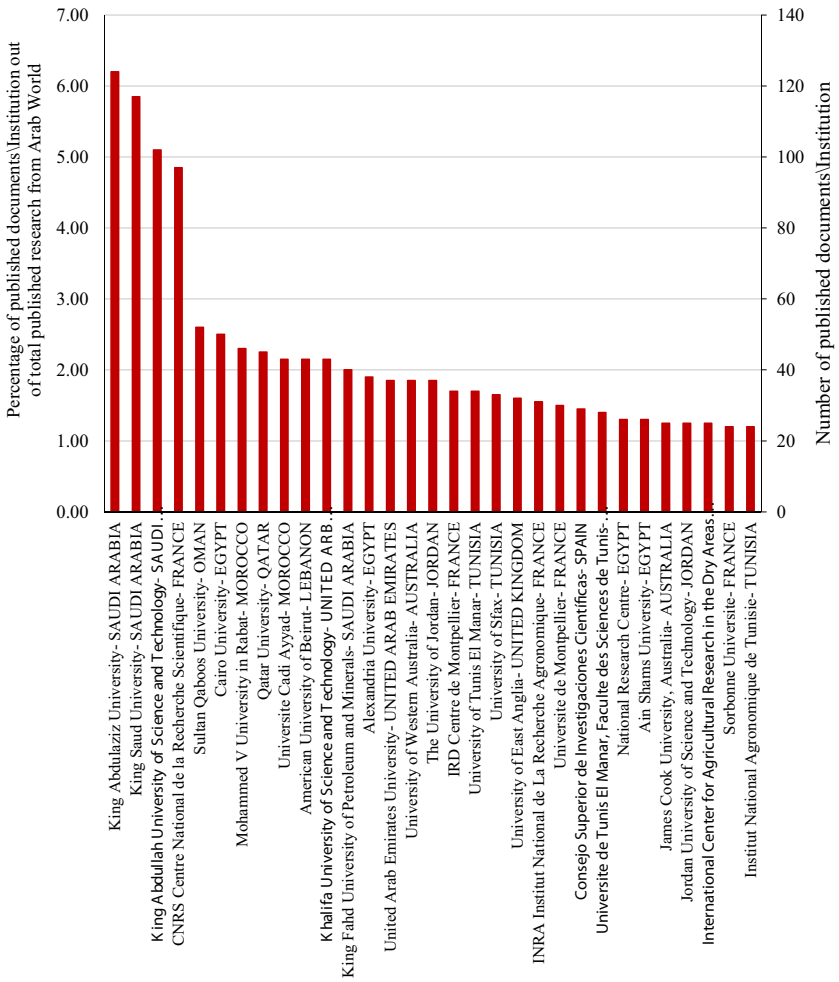


Fig. 6 Top productive institutions (the top 31) in climate change research published from the Arab world and in collaboration with other foreign institutions. The horizontal axis shows the names of the institutions and their countries. The primary vertical axis shows the percentage of published documents out of the total published research, while the secondary vertical axis shows the number of documents for each institution

the globe and at the national levels as a response to climate changes with aims of coordinating the efforts of combating climate changes (i.e., Climate Change Program Office (CCPO) in the USA, Institut National de la Recherche Agronomique (INRA) in France, and Climate Reality Project) (Aleixandre-Benavent et al. 2017).

Furthermore, numerous scientific journals with topics related to study, analyze, and combat the effects of climate changes on social developments, water resources, ecology, environment, agriculture, etc. have been emerging with active addressing of this important topic. Different bibliometric studies which have been conducted earlier and tackled the evolution of climate change research at the global level affirmed the fact of the growing interests in climate change research (Aleixandre-Benavent et al. 2017; Li et al. 2011; Stanhill 2001; Wang et al. 2014). The scope of the present work focused on climate change research productivity at the regional level (the Arab world level). The beginnings of climate change research activities in the Arab world were concurrent with the actual growth of global climate change research since the seventeenth to the twentieth century, despite the fact that these activities began very modestly. The low contribution of the Arab world in global climate change research (1.2%) is in harmony with the contribution of the Arab world in most fields of research. In medical research, for example, the Arab world countries, in total, are currently producing less than 1% of citations in the global and contributing less than 0.5% of documents which are appearing in the top 200 leading medical sources (Maziak 2005). In spite of that, different lines of evidence from the literature showed a quantum leap in scientific research from the Arab world in specific fields of research such as desalination. Zyoud and Fuchs-Hanusch (2015) in a study to assess the scientific research productivity of Arab scholars in desalination field of research concluded a figure of 16% which represents the Arab world's contribution in global desalination research.

At the country level, the Arab world countries showed different performance indicators. Saudi Arabia and Egypt were the most productive countries. It is visible that Saudi Arabia is progressing in regard to research and development and having agendas pertaining to long-term funding of scientific research to an amount of 2.0% of its total gross domestic product (Alshayea 2013). The localizing of the best foreign capacities and innovative scientific research and development

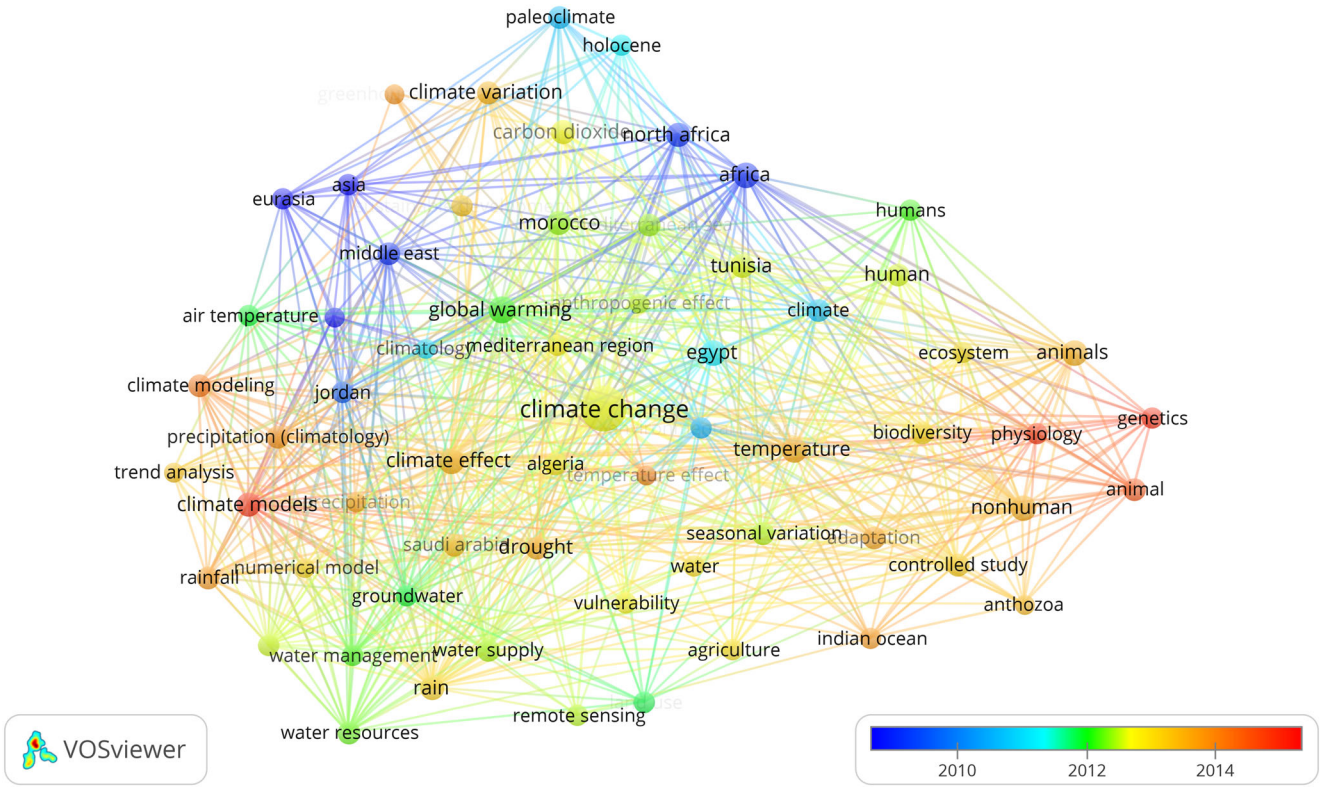


Fig. 7 Overlay visualization map; analysis of co-occurrence of all keywords (author and index keywords); minimum number of occurrences of a keyword was set to 50; of the 15,075 keywords, 65 meet the threshold. For each of the 65 keywords, the number of co-occurrence links was calculated. The keywords with the largest number of links are selected

foundations in villages of knowledge managing by local institutions such as the King Abdul-Aziz City for Science and Technology was the strategy of Saudi Arabia in setting up a well-established base of science (Waast and Rossi 2010). Saudi Arabia also attracted the highest *h*-index, the highest rate of collaboration with non-Arab countries after Egypt, and produced the highest number of documents as an outcome of collaboration. The findings indicate the endeavors of Saudi Arabia in advancing scientific research activities with aims of promoting scientific innovations as well as the development of universities and research centers (Alshayea 2013).

The climate changes, which are manifested by the consistent increase in temperatures in Saudi Arabia, have effects on the productivity of vegetables and fresh fruits, promotion of healthy lifestyle habits, and deficiencies in micronutrients (Pal and Eltahir 2016). It is anticipated that the future temperature as a consequence of climate changes will exceed a threshold considered inadequate for human adaptability in this region (Pal and Eltahir 2016). Therefore, Saudi Arabia is working hard toward the mitigation of climate change effects (i.e., by adopting agricultural techniques of vertical farming and hydroponics) to increase the food production (Elachola and Memish 2016). Another mitigation measure is concerned with the management of aquifer recharge to combat the stresses of climate change on the water sector and water resources in Saudi Arabia (Taylor et al. 2013). This approach focuses on the utilizing of depleted aquifers as a storage of excess surface waters, water from desalination plants, and treated wastewaters to be employed as a water resource during extreme droughts (DeNicola et al. 2015). The promotion of rainfall harvesting activities is also considered as an effective measure to manage water resources efficiently in Saudi Arabia under climate change effects (Almazroui et al. 2017). The performance of Saudi Arabia institutions was well noted. King Abdulaziz University in the forefront, among the Arab world's institutions, is the home of the Centre of Excellence for Climate Change Research. This university has been selected by the World Bank to lead an Arab research team to write a scientific report about climate change in the Arab world.

Egypt was among the first countries in the region that had concerns regarding climate changes, and the first prime climate change conference in the Middle East region was hosted by Egypt. The conference has been convened by the Climate Institute as well as the government of Egypt and the United Nations Environment Programme in 1989 (Climate Institute 2009). There are pieces of evidence that Egypt is facing early warnings linked to climate change such as the declines in the flow of the Nile River, the loss of arable lands, and the variations in Egypt's trade balance for critical and major crops (Climate Institute 2009). Egypt joined the cooperative

endeavors at global levels in combating climate changes as one of first Arab countries. Egypt has signed the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and the Kyoto Protocol in 1999 since the Rio de Janeiro Earth Summit in 1992. The first national communication of Egypt to the United Nations Framework Convention on Climate Change was published in 1999. The work has paid an inclusive attention to the threats which are facing Egypt as consequences to climate changes and rising of sea levels, at most in relations to water resources, agriculture, human health, and coastal zones (in particular, the delta of the Nile River) (El Raey et al. 2004).

Since the international research collaboration is powerful in yielding high-impact research based on complementary expertise (Havemann et al. 2006), the classical research collaboration which is mostly performed based on conducting joint research activities in developing countries (Hammoud et al. 2012) seems to be of less impact. This is because no research infrastructure will continue to be available in developing countries after the accomplishment of research works (Glickman et al. 2009). The novel alternative was to set up research partnerships, as in the case of Arab countries with sufficient wealth resources. This allowed to find rigid and robust research infrastructures (Hammoud et al. 2012). The collaboration figures with foreign countries displayed a high rate of collaboration with Western Europe countries especially France, UK, Germany, and Spain followed by countries from Northern America, at most the USA which took first place in collaboration with Arab countries. The majority of Arab scholars acquired their scientific knowledge from the USA and Western Europe institutions where environmental sustainability measures and indicators are well proven in science and research. Accordingly, high rates of research collaboration between the Arab world and these two regions are expected (Zyoud et al. 2015). As the USA has the largest productivity in scientific research at the global level, in general, it has a leading role in networking of international research collaboration and activities despite its low share in multinational publications compared to its productivity.

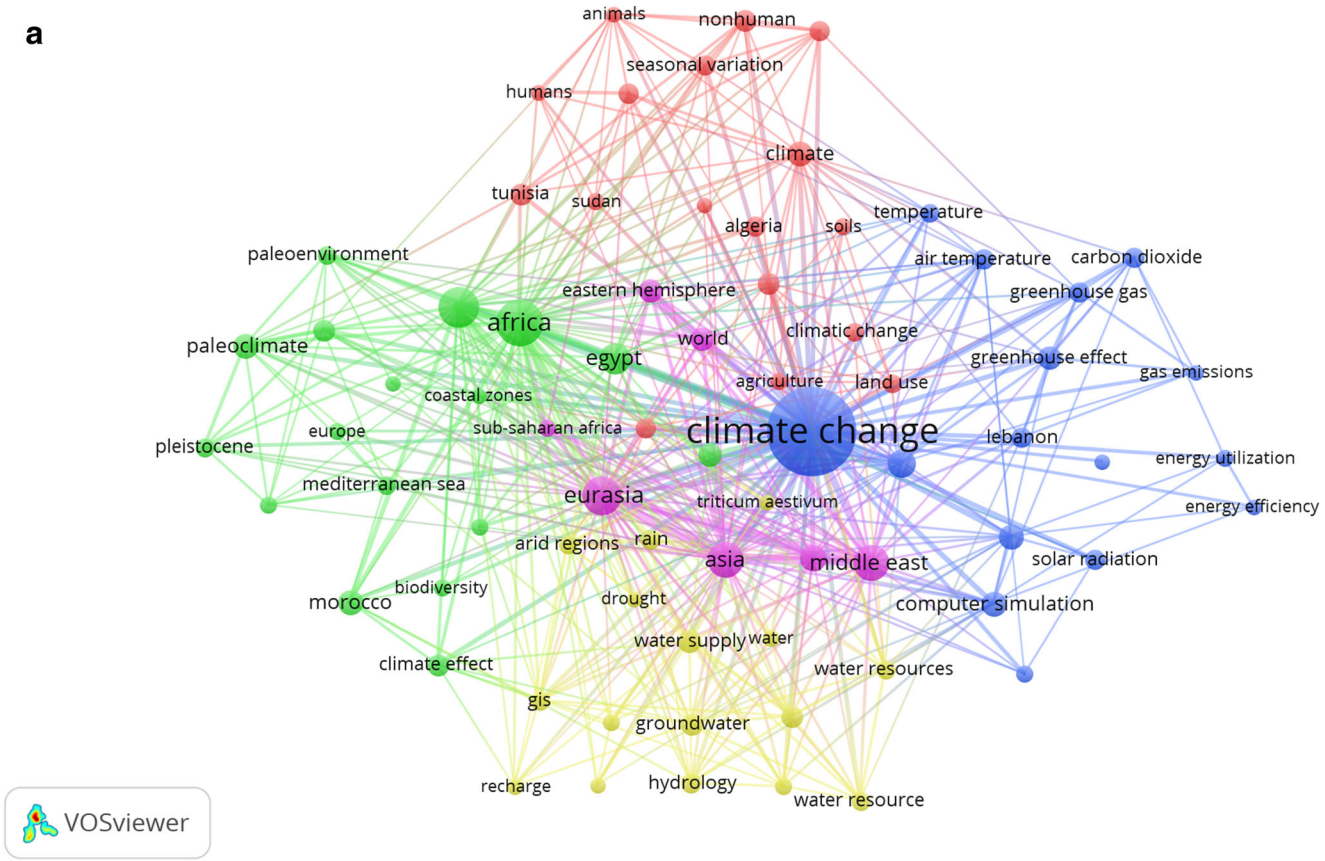
The fact that most productive journals in climate change research are having impact factors reveals the importance of this theme of research for the scientific community. Most of these journals are published by renowned publishers such as Elsevier, Springer, Sage, Taylor and Francis, etc. Their identification is of great advantage in the recognition of journals with high reliability (Herrera-Viedma et al. 2016). Moreover, this will help researchers and practitioners in considering the most reliable sources of research publications in conducting literature reviews (Rey-Martí et al. 2016). The co-citation analysis which is of advantage in clustering sources with interconnections among their contributions showed also that most of the co-cited sources are prestigious journals with high impact in the field of investigation. In the core of interest, there were *Science* and *Nature* journals. The two journals are categorized as multidisciplinary journals and ranked first and second among 87 journals within the multidisciplinary category in the Scopus database.

The analysis of co-occurrence of keywords has revealed that the main issues are related to climate models and climate modeling. Their importance is stemmed from their potential in understanding the different climate change scenarios and their effects on human-related parameters (Mejia et al. 2018). The wide use of climate models is attributed to the fact that most studies, which are devoted to address issues related to climate change, utilize these models in determining the anticipated fingerprint of climate changes and the associated uncertainties in the calculated magnitude of the observations (Hegerl and Zwiers 2011). Furthermore, the application of these models is possible both globally and regionally. One of the most used models to predict future climate changes is the Coupled Model Intercomparison Project (CMMIP) (Ramirez-Villegas et al. 2013). At larger scales, the Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible estimates of future climate changes and have great potential in simulating the most realistic present-day climate (Siew et al. 2014).

The comparison between the core topics in the two main periods of evolution of climate change research in the Arab world before and after 2010 based on co-occurrence keyword analysis and high-frequency keywords to show the emerging topics shows that the focus of research activities in the earlier period (1971–2009) was on studying climate changes in different regions within the Arab world. In association with the breakthrough of research on climate change in the Arab world after the year 2010, the trend of research has been mutated clearly toward the employing of climate models as important sources of information for structuring of mitigation and adaptation measures. This approach of climate change modeling, mitigation, and adaptation represents the most current thinking on the environmental techniques which contribute in reducing the climate change effects.

Conclusions

The central point of interest in this analysis was to perform a regional bibliometric evaluation on climate change research with origin from the Arab world along the following lines: productivity of countries, journals, and institutions; collaboration figures; citation rates; and topics of hot discussions among the climate change research community in the Arab world. Clearly, research productivity of the Arab world in climate change is growing at an increasing rate during the last period. This indicates a sustained growth trajectory that is expected to continue for the foreseeable future. The contribution of the Arab world in the global climate change research was almost compatible with the average of the Arab world's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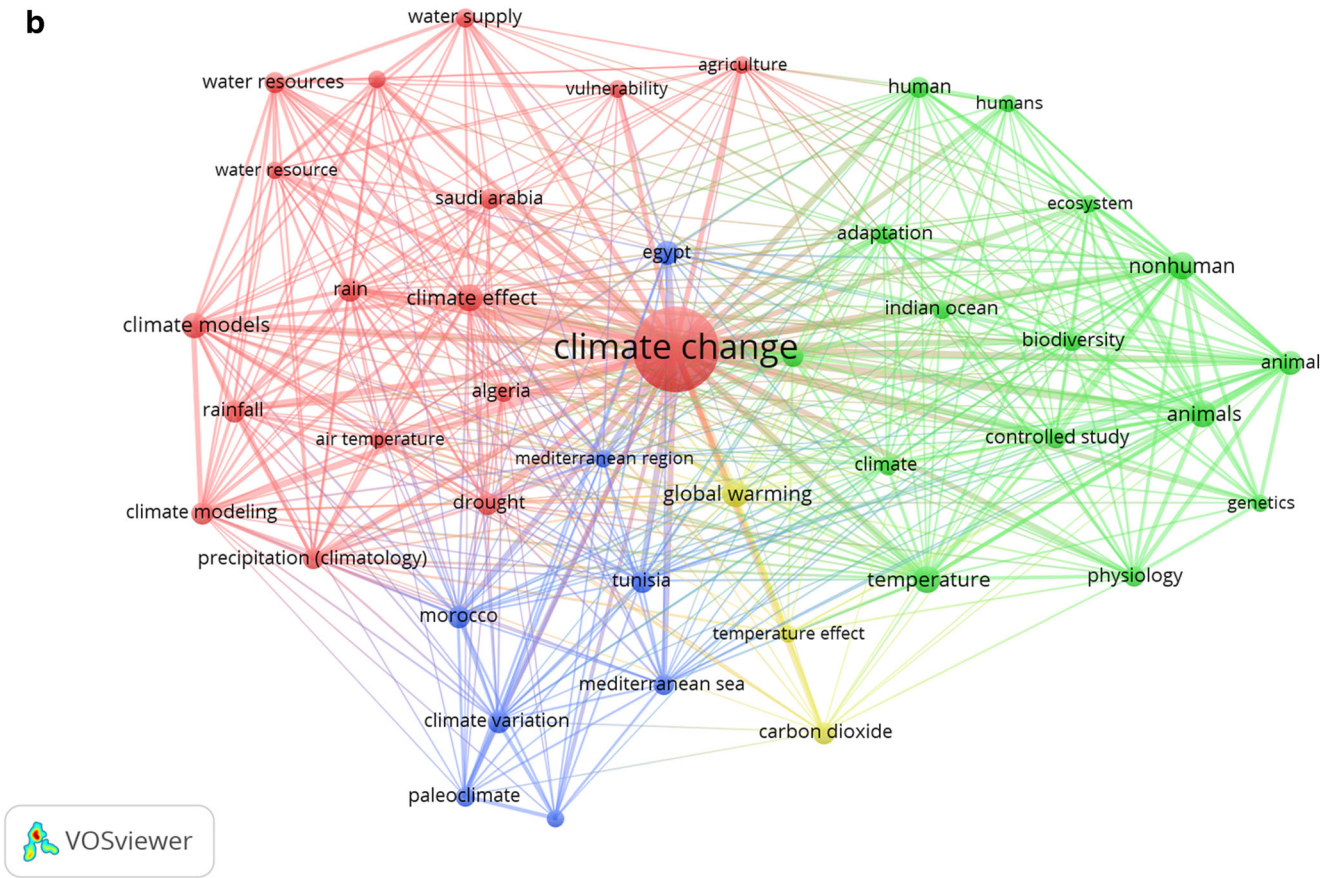
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climate variation
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paleoclimate
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◀ **Fig. 8** **a** Network visualization map, analysis of co-occurrence of all keywords (author and index keywords) for the period extends from 1971 to the end of 2009, minimum number of occurrences of a keyword was set to 10; of the 3939 keywords, 75 meet the threshold. For each of the 75 keywords, the number of co-occurrence links was calculated. The keywords with the largest number of links are selected. **b** Network visualization map; analysis of co-occurrence of all keywords (author and index keywords) for the period extends from 2010 to the end of 2017; minimum number of occurrences of a keyword was set to 50: of the 13,109 keywords, 45 meet the threshold. For each of the 45 keywords, the number of co-occurrence links was calculated. The keywords with the largest number of links are selected

contribution to global literature in all branches of science and research. The analysis reported an obvious differentiation in terms of the performance of Arab world countries toward climate change research. This is attributed to different factors such as population size, scientific abilities, level of development, availability of well-educated people, wealth of a country, etc. This analysis has confirmed the prime role that Saudi Arabia and Egypt play in climate change research at the Arab world level. The two countries showed prominent performance as they were the two larger producers of climate change research in the Arab world and are having the high figures of collaboration with other countries.

The most treated topics were those related to climate models, climate modeling, genetics, animals, physiology, and temperature effect. This indicates the climate change-related themes which will continue to be the focus of climate change research in the future. Furthermore, this reveals the concerns about the associated risks with climate change on ecosystems. In conclusion, climate change research activities have witnessed an increased attention by scholars in the Arab world. The promising start should have the required support by governmental bodies relying on well-based initiatives and related legislations. The reinforcement of research collaboration and partnerships at regional and international levels is a prerequisite in achieving both success and progress in this regard. As an informative evaluation, this work is of benefit in assisting researchers and policy makers with concerns toward both climate change and its effects to guide future research in this regard with high priority.

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