An Overview of Climate Change Adaptation and Mitigation Research in Africa

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An overview of climate change adaptation and mitigation research in Africa

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Research on climate change has increased significantly since the 1970s. There has also been a particular focus on Africa, given its vulnerability to climate change impacts and its urbanization trends that may have massive implications for climate change adaptation and mitigation. Despite the wealth of publications on climate change in Africa, there is a lack of review studies that highlight the overall research landscape. If this status of climate research is clarified, African countries can better deal with climate change. Hence, this paper aims to improve our understanding of the status and trends of research on climate change adaptation and mitigation in Africa. Our review, straddling from 1990 to late 2021, recognizes the foundations that underpin climate change adaptation and mitigation literature. Based on keywords associated with Africa's climate change adaptation and mitigation, we undertook bibliometric research by collecting 3,316 related SCI/SSCI articles. In addition, we provided a thematic evolution over three decades, compartmentalized into four sub-periods (1990–2007; 2008–2014; 2015–2019; 2020–2021). Priority research topics and themes have been dynamic over time, with some core concepts receiving more attention (vulnerability, food, water, and energy security). Although the number of published articles exhibited a rapidly growing trend, their distribution is extremely uneven. Articles were mainly published by institutions from certain parts of the continent, with the University of Cape Town, making the highest contribution. About 72% of the existing studies focused on climate change adaptation, while climate change mitigation was less represented with 22%. The results also showed that researchers have examined not all African countries. South Africa, Ethiopia, and Ghana are hot spots, while most countries are largely neglected. Africa and African countries need to improve their future research ability on climate change mitigation. Assessing climate change risks and measures in African countries should be prioritized.

KEYWORDS

climate change, adaptation, mitigation, Africa, bibliometric analysis, urbanization, vulnerability, risk

Introduction

Climate change is a threat to humanity. Global CO_2 emissions have increased considerably from 14.9 billion metric tons in 1970 to 36.4 billion metric tons in 2021[1]. Consequently, atmospheric concentration of CO_2 emissions has increased from 325 ppm to 414 ppm over the same period. Africa, like other continents, is vulnerable, and exposed to extreme climate events (Busby et al., 2014; Russo et al., 2016). Vulnerability is exacerbated by the continent's low adaptive capacity and its dependence on rain-fed agriculture (Dzoga et al., 2018; Apraku et al., 2021; Azadi et al., 2021).

Temperatures have been reported to be increasing in Africa. North Africa's temperature has been increasing between 0.2°C per decade and 0.4°C since the 1970s (Donat et al., 2014; Lelieveld et al., 2016). Meanwhile, in West Africa, temperatures have undergone positive trends of 0.28°C (Russo et al., 2016; Nikiema et al., 2017). Temperature intensity has increased from 0.25 to 1.8°C in the Sahel and West Africa (Vizy and Cook, 2012; Fotso-Nguemo et al., 2017; Iyakaremye et al., 2021). According to literature, South Africa has the highest projected increase (Engelbrecht et al., 2015; Moron et al., 2016; Hoegh-Guldberg et al., 2018). Frequent temperature increases affect arable land and reduce the production of many African crops (Berck et al., 2018; Mumo et al., 2018).

Annual rainfall in Africa has also varied between regions. North Africa has witnessed negative trends in precipitation (Tramblay et al., 2013; Hertig et al., 2014). Declining trends have also been observed in West Africa (Nicholson et al., 2018), but East and Southern Africa are experiencing high precipitation (Liebmann et al., 2014; Nicholson, 2017; Nikulin et al., 2018). The overall outcome is a negative trend in Africa's rainfall, which negatively impacts the environment, livelihoods, food, water, and energy security (Akinsanola et al., 2021). Approximately, US$ 1.4 billion annually on food crops across Africa has been lost (Sileshi and Gebeyehu, 2021). Aggregate annual production losses of 8.9% have been reported, translating to 2.3 million MT of wheat lost, affecting 48.2 million consumers across Africa (Sileshi and Gebeyehu, 2021). About 57% of arable land in Africa produces fewer crops, resulting in poverty, affecting about 40% of the population (Berck et al., 2018). About 25% reduction has been reported in East Africa's annual crop yields (Mumo et al., 2018). By 2023, $1.4trillion of Africa's GDP will be vulnerable to climate change, a significant 48% of the entire continent's GDP (Sileshi et al., 2019).

Economic growth and rapid urbanization have been evident in Africa. Some countries have recorded increasing economic growth, like Rwanda (8.7%), Ethiopia and Côte d'Ivoire (7.4%), Ghana (7.1%), Tanzania (6.8%), and Benin (6.7%) (Tenaw and Hawitibo, 2021). Africa's urbanization rate increased from 30.8 to 38.8% between 2000 and 2018, with a 2.2% economic growth (Nathaniel and Adeleye, 2021). Seventy-nine African cities are amongst the world's top 100 fast-growing cities and face extreme risks due to climate change (Weforum, 2021). An increase in economic growth and urbanization translates to high energy demand and GHG emissions. Africa is also characterized by its rapid demographic change. Countries like Tanzania, Nigeria, Ethiopia, and Angola have registered annual population growth rates of 4.8, 4.5, 4.3, and 3.7%, respectively (Weforum, 2021). Population explosion has increased CO_2 emission from 399,239Kw in 1990 to 823,424Kt in 2018 (Worldbank, 2022). In 2019, South Africa was the most polluting country, having emitted 479 billion metric tons of CO_2 emissions, followed by Egypt with 247 billion metric tons of CO_2 emissions (Saleh, 2021). Countries like Nigeria, Algeria, Libya, and Morocco are other large producers of CO_2 ($\geq$10 Mt/year) (Boden et al., 2017; Habimana Simbi et al., 2021). Rapid economic growth and population lead to the fast growth of CO_2 emissions and environmental degradation in many African countries. This showcases the role of Africa in global climate change during its socioeconomic transformation. Therefore, policymakers must focus more on adaptation and mitigation strategies to curtail the impacts of climate change on the continent.

There has been a rapidly increasing number of reviews on climate change in Africa. Akinyi et al., look at the trade-offs and synergies related to implementing climate adaptation strategies among farmers (Akinyi et al., 2021). There have been studies on the impacts of climate change on water resources (Nkhonjera, 2017; Leal Filho et al., 2022a), with a consensus that adaptation and mitigation measures are necessary to cut the impacts on water resources. A study by (Zinyengere et al., 2013) projects an 18% decline in maize yields and suggests adaptation could potentially moderate the negative impacts of climate change. Nyiwul (2021), examined if the needs of the poor somehow influence adaptation and mitigation policies and states. In addition to review studies, many research papers on climate change in Africa have been published (Steynor et al., 2020; North et al., 2022). This significant increase in publications makes it challenging for climate change researchers to maintain an up-to-date overview of the literature. Therefore, it is imperative to obtain a full overview of climate change mitigation and adaptation research in Africa for intellectual and political reasons.

Bibliometrics stands as one of the powerful quantitative methods that can be used to analyze the development of scientific literature in a research field like climate change (De Bakker et al., 2005; Hirsch, 2005; Sharifi et al., 2021). Bibliometric methods and tools can be used to trace the intellectual landscape of climate change across the globe (Li et al., 2011). Several bibliometric analyses of climate change studies have been conducted. For instance, a bibliometric analysis of climate change adaption has been done, and

1 Statistica.com

results show that the US ranks first in terms of publication output (Wang et al., 2018). Climate change vulnerability has been explored using quantitative analysis showing that food insecurity is one of the most frequently discussed areas in climate vulnerability research (Wang et al., 2014). In 2015, research hotspots and models in climate policy were reviewed using a bibliometric method (Wei et al., 2015). The interrelationship between resilience, adaptation, and vulnerability in the face of changing climate has been researched by Janssen et al. (2006). There have also been studies on the impacts of global warming on tea production using a bibliometric analysis (Marx et al., 2017). A study that has come so close to the present is the study of climate change in the belt and road initiative regions (Tan et al., 2021) where the authors elaborated on the status and trends of climate change research in the Belt and Road Initiative regions of Central Asia, Russia and Europe Other studies have focused on climate change mitigation, adaptation, and resilience (Einecker and Kirby, 2020), and mapped urban sustainability and its links to climate change mitigation and adaptation (Sharifi, 2021; Sharifi et al., 2021).

Thus, there are more than a few previous bibliometric studies with comprehensive analyses of climate change. However, to the best of our knowledge, there are rare, if not none, on climate change adaptation and mitigation in Africa. As Africa is highly vulnerable to climate change, a clearer picture of climate change adaptation and mitigation research is of practical significance to the intellectual community. Therefore, this study aims to review Africa's research status and trends on climate change adaptation and mitigation. This review addresses the following questions: What are the growth trends in research on climate change adaptation and mitigation in Africa? Which authors and documents in the literature on climate change adaptation and mitigation have had the greatest impact on citation in the past 30 years? What is the intellectual structure of the knowledge base on climate change adaptation and mitigation in Africa, and how has the research on this topic evolved? This overview is one of the first attempts to quantify the growth of climate change adaptation and mitigation science literature in the African continent. It should be noted that, unlike systematic reviews, this bibliometric review does not intend to provide details on different issues related to the study topic. Instead, it provides an overview of the state of the knowledge and highlights the related structures and trends.

The paper is organized as follows: Section Methodology describes the methodology, clearly explaining the parameters used in searching articles. Section Results and discussions outlines the results and discussions. Lastly, potential new areas that are likely to influence the field of climate change in Africa are investigated in the final section.

Methodology

Literature search and selection were conducted following the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA) (Moher et al., 2010). To retrieve documents related to two major themes, "Climate Change Adaptation" and "Climate Change Mitigation" a combination of keywords was used to build the search string (see the Supplementary material). The theme of climate change adaptation referred to keywords such as adaptation, resilience, risk, management, and reduction. In contrast, the theme of climate mitigation involved keywords such as decarbonization, mitigation, carbon, CO_2, and GHGs. Synonyms were taken into consideration. All countries in Africa were included in the search string. The search was further performed in the three fields of titles, abstracts, and keywords for a more comprehensive data retrieval. The start time of the search was 1990, and the end time was 2021. The search returned 3,958 documents in formats compatible with the VOSviewer software. The eligibility criteria included the following: (1) articles on adaptation and mitigation studies in Africa and or any African country; (2) Peer-reviewed empirical, primary research papers in academic journals, books or book chapters, or conference proceedings (3), papers pubished in English. The next step was the manual screening of the documents to exclude irrelevant ones. After exclusion, we retained 3,235 articles.

The following bibliometric databases were searched on November 15, 2021: Science Citation Index (SCI), Social Sciences Citation Index (SSCI), SCI-EXPANDED, Arts and Humanities Citation Index (A&HCI), and (Emerging Sources Science Citation Index (ESCI) in the Web of Science Core Collection of Clarivate Analytics, Canada. Vosviewer, which is a freely available Javan application, was used for data analysis (van Eck and Waltman, 2010) (VOSviewer at: https://www.vosviewer.com).

Text mining and bibliometric analysis

Bibliometric analysis was then conducted on related articles, and Vosviewer was used for data analysis. Among the different analyses used were the term co-occurrence analysis, bibliographic coupling, and co-citation analysis. For the term co-occurrence analysis, documents were set as the unit of analysis, while cited references, cited sources, and cited authors as units of analysis for co-citation analysis. Bibliometric coupling was also analyzed. This was done by using the full counting method, and organizations and countries were used as units of analysis.

To highlight major thematic areas, term co-occurrence analysis was used. This kind of analysis presents terms that have

co-occurred frequently and are strongly connected to each other. A thesaurus file was developed and added to the VOSviewer database prior to analysis. The reason is because some terms have different variants and can easily result in separate counting of synonyms; for example, Green House Gases and GHGs. The outputs of bibliometric analysis using VOSviewer are graphs (combination of nodes and links). The size of the nodes in the outputs is proportional to the occurrence frequency, and the width of the links connecting nodes is proportional to the strength of connections. Terms that co-occur more frequently form clusters that show different thematic areas. In addition to bibliometric analysis, content analysis of the abstracts was done to determine the studies' geographic focus (country level).

To map the thematic transition over time, we divided the study period into four subperiods (1990–2007, 2007–2014, 2015–2019, and after 2020). It should be noted that 2007 and 2014 were selected as milestones considering that releases of the IPCC reports in these years might have triggered climate change research in Africa. It was possible to include sub-periods before 1990, but, as can be seen from the results in section Results and discussions, less research was published until 1990, not warranting further sub-periods. To understand the thematic shift during each period, term co-occurrence analyses were conducted for each sub-period.

Results and discussions

The trends

The growth trends of climate change adaptation and mitigation literature were examined from the initial starting point of 1990. Figure 1 shows the total number of publications in the different time periods. It displays how climate change research in Africa has increased steadily across the three decades. The results show that the number of articles in this field has progressed through four stages: slow growth, rapid growth, explosive growth, and steady growth, with an average growth rate of 21%. During the first period (1990–2007), the number of articles was very small and growing slowly. More so, the publication volume within the years of this period was not very much different, indicating the very low volume of exploration. The second period corresponds to 2008–2014. In this period, an overall upward trend was observed, indicating an attraction of extensive attention from scholars worldwide, thus entering a period of expansion and promotion. In the third period (2015–2019), the number of articles significantly increased, especially after the publication of the fifth IPPC assessment report, indicating a highly productive period. The fourth and last period, 2020-2021, shows rapid growth, with 947 articles published in <2 years. The number of publications in the four study periods was 118, 684, 1,487, and 947, respectively. There is a significant increase in the growth of publications per year, with an annual average increase of 22.5%. It is evident that this is a young field as fewer papers were published from 1990 to 2007 compared to papers published from 2020 to November 2021. In fact, only 117 publications were made from 1990 to 2017, indicating the low relevance of the topic during this period compared to 947 publications for <2 years (2020–2021), indicating the current high relevance of the topic. The very slow growth in the first period was due to the limited theoretical understanding, while the significant increase in the subsequent periods could be attributed to general causes such as digital publication, the birth of new journals, and specific factors such as the release of the two IPCC assessment reports (fourth and fifth reports in 2007 and 2014, respectively). An implication is that climate change in Africa and its impacts are increasingly recognized together with the increasing significance of climate change adaptation and mitigation to curb these impacts.

Out of the 3,317 articles that were used in the analysis, the country focus was not uniform over Africa. There were 380 papers focused on South Africa alone. The second focus country was Ethiopia, with 301 (Figure 2). In West Africa, only Ghana has a high research focus with 242 articles, higher than Kenya and Tanzania. Surprisingly, the most populous nation, Nigeria, is not among the countries with a large number of publications. The high research focus on South Africa is likely because the universities in the country are among the leading organization in this field. For over three decades, African countries have received relatively low research focus. More research was done on Africa as a continent or on African regions than on specific countries. A total of 1,219 studies were focused on Africa and its sub-regions, excluding specific countries. Countries like Gabon, Libya, Eritrea, Chad, Central African Republic have so far had no research on climate change adaptation and mitigation (Figure 2). However, the ascending curve reveals, even if empirically, these numbers will continue to grow considerably, given the theme's relevance.

Looking at the thematic focus, 72% of the articles are on adaptation, 22% on mitigation, and 6% on both adaptation and mitigation. It, therefore, deserves attention that mitigation efforts are limited. We were also interested in knowing who the leading researchers in the continent were (in other words, authors that have published more papers on the topic). We noticed that researchers from the USA authored more publications ($N = 718$; 10%), followed by researchers from South Africa ($N = 660$; 9%), the United Kingdom ($N = 554$; 8%), Germany ($N = 420$; 6%), and Kenya ($N = 343$; 5%) (Figure 3). Researchers belonging to institutes based in Africa published 38.7%, while those from the West (America, Canada, Europe, and Australia) published 49%. The rest of the world (China, Indonesia, etc.) published 12.3%. Of the 54 African countries, 11% have not published anything on climate change adaptation and mitigation, 64% have carried out <100 case studies on their countries, while 9.2% have carried out above one hundred case studies in their countries. South Africa has the highest number

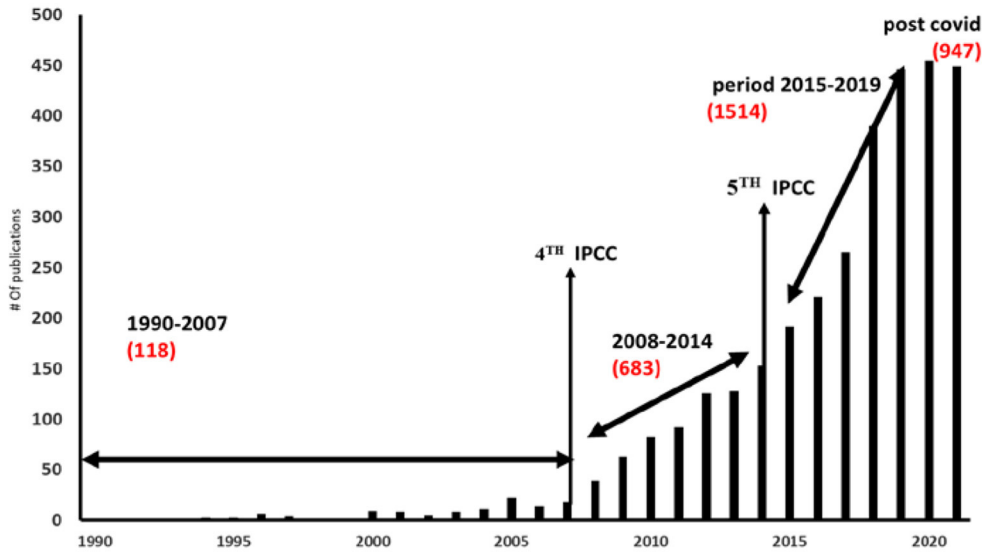

FIGURE 1
The number of articles published per year and the different periods considered in this research.

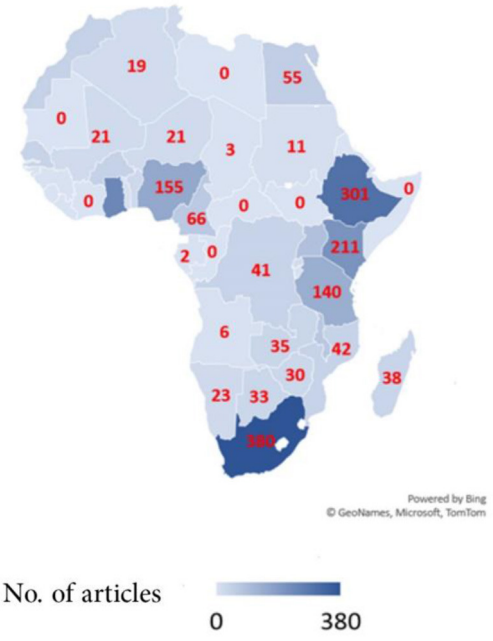

FIGURE 2
Geographical presentation of country focus.

of publications because of its well-developed science system that underpins climate change scenarios developed for South Africa. Authors based in England, South Africa, and Tanzania are those with the greatest focus on adaptation strategies. The works of Germany, the USA, and Kenya were mainly concentrated on food security, and those of Australia, Ethiopia, and China on carbon sequestration. However, a huge research gap exists on mitigation.

Regarding geographic focus, South Africa, Ethiopia and Ghana have received more attention (Figure 2). In contrast, less attention has been paid to Tanzania, Kenya, and Nigeria. Also, no case studies were found on the Central African Republic, Somalia, Gabon, Ivory Coast, Libya etc (Figure 2). Overall, it can be seen that climate change is poorly studied in the continent, and there is a gap in consideration of adaptation and mitigation policy designs.

Climate change is a global threat that can stress various sectors and deteriorate the sustainability of diverse sectors worldwide. Specifically, the vulnerability of the agricultural sector is globally concerning because of insufficient production and supplies. In effect, the global feeding patterns are challenged particularly in African countries where agriculture is an integral part of the economy. Therefore, mitigating the impacts of climate change is of great importance and requires global commitment.

The overall thematic focus of the literature on climate change adaptation and mitigation in africa

The overall thematic focus (1990–2021)

Based on the term co-occurrence analysis, there were four main clusters: blue, red, yellow, and green, each representing a different research focus. These clusters have been identified

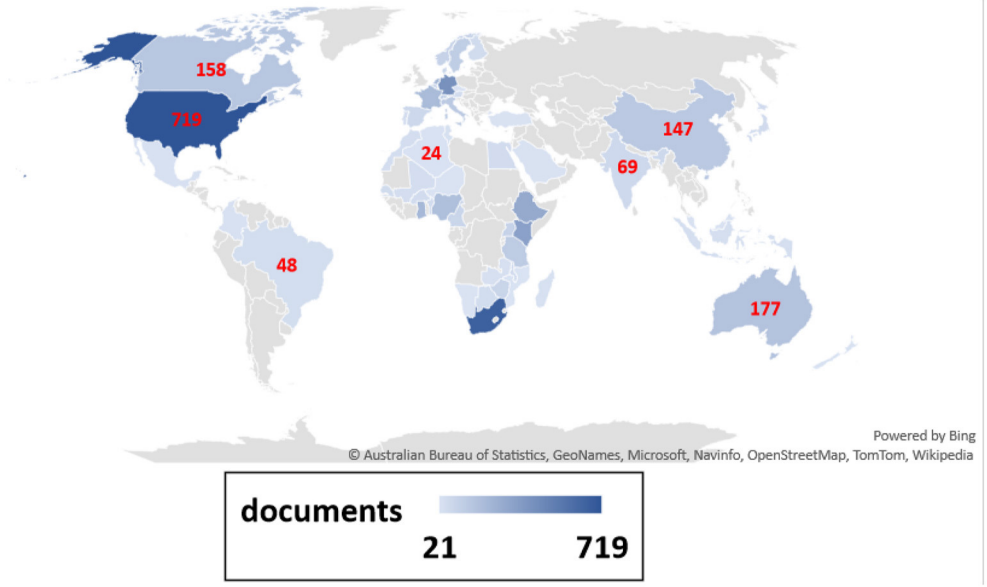

FIGURE 3
Global research on climate change adaptation and mitigation in Africa (Publications by countries).

by the software based on the co-occurrence frequenct and the strength of connection between terms.The size of each node reflects the frequency of appearance. A term with a larger node, is a research hotspot. The thicker the line, the more frequently the terms have co-occurred. The co-occurrence analysis showcases that there has been more attention on vulnerability (blue), agriculture (red), forest management and sequestration (green), and sustainability and energy-related climate mitigation (yellow). It should be mentioned that what is discussed in the following sections is not exhaustive. While there could be other important issues related to climate change adaptation and mitigation, we have mainly focused on those key topics that were highlighted in the outputs of the bibliometric analysis.

The adaptation/vulnerability cluster (blue)

The blue cluster highlights the vulnerability of households and farmers due to climate variability and the poverty it has inflicted on communities. The literature on this cluster is centered on the vulnerability of Africa to climate change impacts. From the blue cluster, it is visible that researchers are interested in studying adaptation from the gender, household, indigenous knowledge, and livelihood perspectives that are considered to be important factors for vulnerability (Jost et al., 2016; Flatø et al., 2017). The dominance of the terms climate variability, vulnerability, and resilience is not surprising, considering that a lot of research has been done on climate variability and the risks faced by farmers and smallholder farmers in Africa (Bryan et al., 2009; Müller et al., 2011; Adenle et al., 2017; Siderius et al., 2021). For instance, cocoyam farmers in Nigeria face challenges adapting to climate (Ifeanyi-Obi et al., 2017). Meanwhile, in Ghana, maize productivity has been affected by changes in climate (Aidoo et al., 2021). This has further warranted research on the vulnerability of households and how resilient they are to climate change. Gezimua (Gezimua, 2021) examined the prevalence of household food insecurity and vulnerability to climate change in East Africa and showed that households' adaptive capacity plays a significant role in reducing the prevalence of food insecurity (Gezimua, 2021). Researchers have preferred to study vulnerability and resilience from an adaptative perspective, as seen in Figure 4. Nyboer et al. (2019) presented a climate change vulnerability assessment of 85% of Africa's freshwater fishes. They concluded that vulnerable species are found in the African Rift Valley lakes, the Congo River drainage, and the coastal rivers of West Africa (Nyboer et al., 2019). A study on the degree of vulnerability and its impacts on human health in Central Africa showed that, the mean monthly household cooling energy demand is expected to significantly increase by 2,046, resulting in major energy security issues (Nematchoua et al., 2019). There have also been studies of vulnerability at different levels. Vulnerability has been more researched from the perspective of gender perception (Descheemaeker et al., 2016; Tesfaye et al., 2019). For instance, changes in temperature characteristics were highly perceived among female farmers in Ghana (Appiah and Guodaar, 2021). Another study done in Ghana found that there were gender-specific differences in the use of some adaptation practices

(Jamal et al., 2021). Another term that stands out is poverty, indicating how researchers are interested in knowing if poverty is contributing to vulnerability and if poorer households are prioritized for interventions that increase adaptive capacity (Williams et al., 2019).

From this cluster, we see how local and international scholars investigate how communities' efforts and changes in livelihood can display different degrees of resilience by employing different strategies. African communities are resilient to climate change through their attitudinal shifts and local technology innovations to better curb the impacts of climate change (Simpson et al., 2019). Communities build on their perceptions about past practices, skills, and knowledge to build adaptive capacity and resilience to suit their current life (Gandure et al., 2013; Perez et al., 2015; Elum et al., 2017; Talanow et al., 2021). Climate resilience is improved by incorporating gender perspectives (Perez et al., 2015; Adzawla et al., 2019a).

In addition, barriers hindering successful adaptation strategies were an area of consideration (Murkowski, 2000; Betsill and Bulkeley, 2007). Some of the barriers that have been hindering adaptation strategies are limited financial resources, government structures, and challenges with capacity development. An issue that needs to be noticed is that despite the increasing concerns about extreme heat and its impacts on human health, related terms did not emerge from the term co-occurrence analysis. This indicates the lack of research on this issue as also highlighted in other studies (Harrington and Otto, 2020; Ncongwane et al., 2021). More research on the adaptation to extreme heat in the context of Africa is, therefore, needed.

The food security cluster (red)

This cluster showcases the interest in understanding climate change's general impacts on food security. From Figure 4, most of the research is on the impacts of climate change on agriculture and its contribution to food security (Figure 4). The overwhelming concern of scientists is whether increased temperatures are impacting African agriculture and contributing to high levels of food insecurity (Sultan, 2012; Connolly-Boutin and Smit, 2016; Douxchamps et al., 2016). There have also been studies on the uncertainty of climate impacts and the extent of their impacts on food security (Ahmed, 2020; Mekonnen et al., 2021). The next concern from this cluster is the types of agricultural approaches used to increase food security. Conservation and smart agriculture are the main focus areas (Branca et al., 2021; Thierfelder and Mhlanga, 2022). Another thematic focus that has attracted publication is models and simulation. Researchers are keen to develop and use different climate change models to predict temperature and rainfall trends and yield productivity to better understand how to address climate change challenges (Jones et al., 2005; Araújo and Rahbek, 2006; Lobell and Burke, 2010; Semenov and Stratonovitch, 2010). Sub-Saharan Africa, particularly West and Southern Africa, have been the focused regions in this cluster (Brown et al., 2009; Müller et al., 2011; Shindell et al., 2012).

The forestry and sequestration cluster (green)

Cluster green is centered around the concept of climate change mitigation (Nyong et al., 2007; Syampungani et al., 2010; Tschora and Cherubini, 2020), which is focused on reducing GHGs emissions (Friedrich and Trois, 2011; Tongwane et al., 2016; Tongwane and Moeletsi, 2018). There have also been studies on how climate change impacts ecosystem services (Sintayehu, 2018). For instance, in Tanzania and Kenya, a key carbon sink, biomass has been reduced by 76% (Wilson et al., 2021). Tuli-Karoo transboundary aquifer in Southern Africa has been studied to understand the interaction between groundwater ecosystems and climate change (Majola et al., 2021). Furthermore, a considerable amount of mitigation research focuses on carbon sequestration (Adetoye et al., 2018; Gonzalez-Sanchez et al., 2019), soil organic carbon (Vågen et al., 2005; Swanepoel et al., 2016), REDD, and REDD+ (Rahlao et al., 2012; Soliev et al., 2021). The Congo Basin, Cameroon, Madagascar, and Zambia are often the focus areas of such research that generate knowledge regarding the role of forests in climate change mitigation (Somorin et al., 2012; Bele et al., 2015; Soazafy et al., 2021). Agricultural soils in Africa have been studied and found to generally have potential as a carbon sink (Vågen et al., 2005; Swanepoel et al., 2016). Different countries in Africa have demonstrated the different costs of carbon sequestration. For example, carbon sequestration cost in Botswana is $16.75 and in Congo DRC $16.77, the highest in the continent, while lower costs are reported in Nigeria at $7, and Mali at $8 (Adetoye et al., 2018). Policy implementation processes and institutional interactions have been examined in Cameroon and are known to shape Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Gakou-Kakeu et al., 2022). In Nigeria, it was noticed that the payment of monetary incentives does not necessarily motivate communities to participate in the REDD+ program (Isyaku, 2021). Here we see a link between mitigation and ecosystems services which is under-explored to the best of our knowledge. Research in this cluster improves governance of social-ecological systems at the local, regional and landscape levels.

Mitigation policy cluster (yellow)

This cluster is mainly focused on mitigation policies related to the energy sector and renewable energies. It shows how researchers are attracted to sustainability challenges faced by African countries (Beg et al., 2002; Ozturk, 2017). Researchers are also interested in the sustainable management of forests since they are the main absorbents of CO_2 (Teketay et al., 2010; Njana et al., 2021). The main link in this cluster is between institutions and policy. This is an indication that researchers are

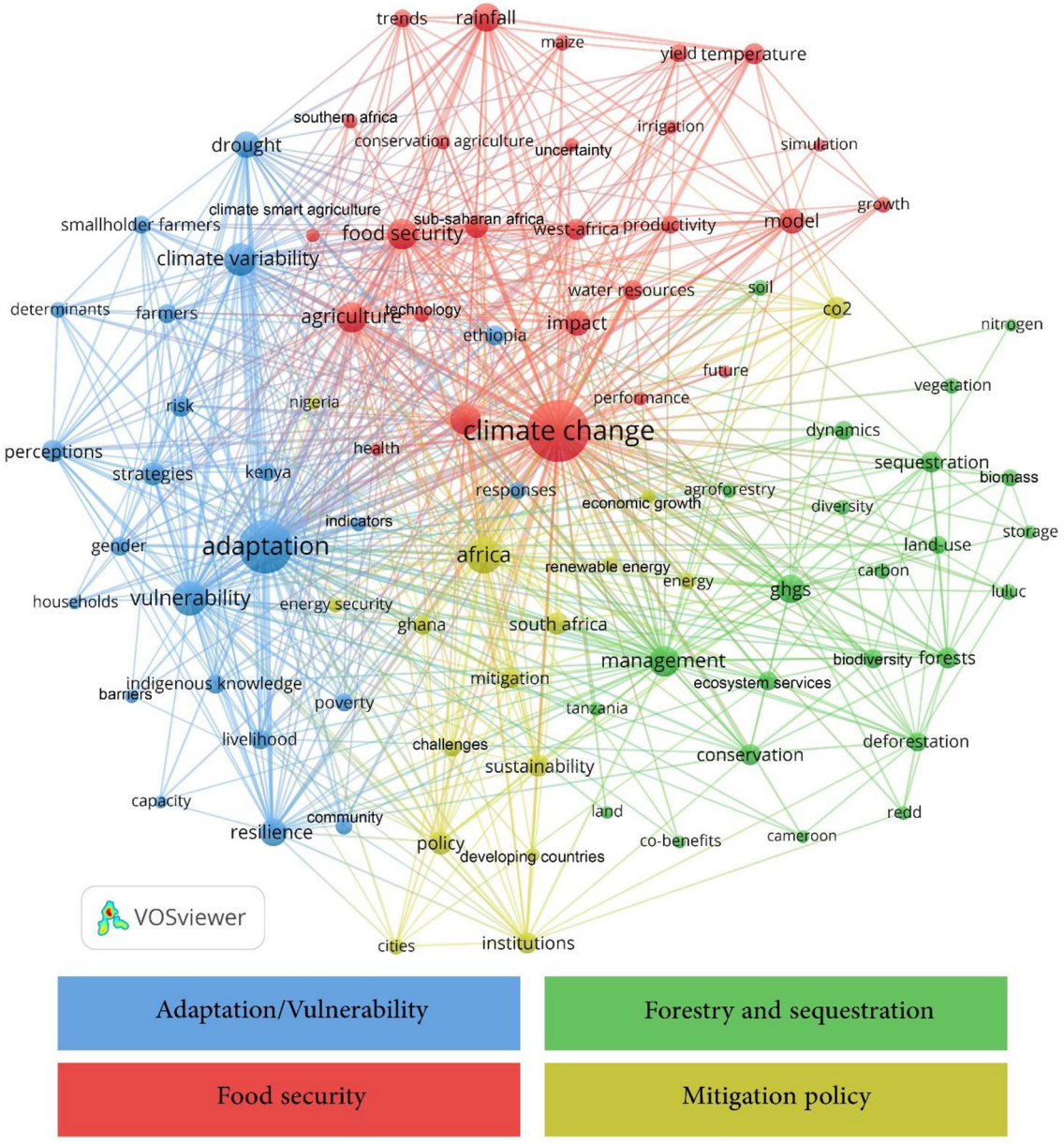

FIGURE 4
The output of the term co-occurrence analysis for the whole study period (1990–2021).

exploring climate policy designs and the institutions involved in policy making (Leal Filho et al., 2018; Epule et al., 2021), and the virtue of the importance of GHGs, mainly CO_2, in climate change policy. Despite the significance of mitigation policies, relatively limited research has been conducted on these issues. The Economic Community of West African States (ECOWAS) Renewable Energy Policy has shown a significant and positive impact on primary energy (Ali and Yu, 2021). In Nigeria, policies on ways to stimulate solar technology business are missing in the national solar energy policy document (Ozoegwu and Akpan, 2021). The results of Müller and colleagues agree with ours in that literature of renewable energy policies in African states are rare (Müller et al., 2020).

Thematic focus transitions over time

Four specific periods were investigated to see if some research topics have fluctuated, remained stable, or changed over time. Period one starts from 1990 to 2007, with 2007

corresponding to the release date of the fourth IPCC assessment report. Period two starts from 2008 to 2014, with 2014 corresponding to the publication of the fifth IPPC assessment report. Period three, from 2015 to 2019, and the fourth period from 2020, is referred to as the post-pandemic period in this study.

First period (1990–2007)

A total of 117 articles were published during this period. Although the concept of climate change can be noted as early as 1990, research focus on it was very low, as seen from the few occurrences of relevant terms (Figure 5). Adaptation has been the focus area since the first period, as seen in Figure 5. Concepts of vulnerability (blue), sustainability (red), and climate variability (green) have appeared during this period (Bohle et al., 1994; Schulze, 1997; Dixon, 2003; Ogunseitan, 2003). The blue cluster insinuates how agricultural practices had become vulnerable to climate change during this period. Therefore, more research had begun to be carried out on the impacts on agriculture. There was also the emergence of studies on the sensitivity of water resources to climate change. The centrality of water resources is relatively low during this period, showing less connection with other topics. Studies on policy formulation and implementation relating to climate change also gained attention. The green cluster is focused on CO_2 emissions and their related studies, which further triggered studies on carbon sequestration. During this period, CO_2 as the main greenhouse gas and its impacts on biodiversity were among the major priority research topics (Olivier et al., 1999; Blignaut et al., 2005).

There were also studies specifically focused on modeling the optimal mitigation of the potential impact of climate change (Jenkins et al., 2002). For example, in 2000, Zheng and Neelin used the atmosphere–land–vegetation model to explore vegetation–climate interactions in African savanna (Zeng and Neelin, 2000). It is evident that studies were more on forestry, and its absorbing nature was seen as a mitigating measure. For instance, in 1992, sources and sinks of carbon dioxide and methane exchanges were studied in the Mayombe forest, which was proven to be a net sink of atmospheric methane (Delmas et al., 1992). In this period, main research themes are not closely linked and are weakly related to external topics. This period coincided with the increasing prevalence of the term sustainability, which will be seen in subsequent analysis to dominate the thematic focus of climate change research in Africa. The importance of climate change was further recognized with the signing of the Kyoto Protocol (1992)[2], which gradually accelerated academic discussion of climate change in the continent as well as the meetings of COP 1 in 1995 to COP 13 in 2007. The release of the IPPC fourth assessment report in 2007 was also a game changer as will be seen in the next period.

Second period (2007–2014)

This period witnessed a rapid growth of publications in the red, green, and blue clusters. This rapid growth might have been triggered by the publication of the fourth IPPC assessment report in 2007. The red cluster had seemingly gained more attention this time. Interestingly research on food security emerges. This is a keyword that was absent in the first period. During this period, it is noticed that there is more research on the climate-stressed water resources presenting a challenge for protecting food security. In the previous period, research was focused on the sensitivity of water resources to climate change, while in this period, water resources and food security are closely linked (Yang et al., 2003; Ngigi, 2009; Sheffield et al., 2014). Studies on food security have attracted further research on the impacts of climate change on soil. A study on Ethiopian soils showed soil losses were 35.4 t ha^{-1} yr^{-1} under changing climate conditions (Lanckriet et al., 2012). There are also other studies focused on soil. For instance, a study was carried out on ferrasols of coastal West Africa to examine soil fertility under global warming (Amouzou et al., 2013). This period sees a shift from carbon sequestration models to models that detect the sensitivity of various alimentary crops. For instance, in Benin, high-resolution regional climate models were used to detect the sensitivity of alimentary crops to changing climate conditions (Paeth et al., 2008). A robust model application to several African crops showed that, except for cassava, there is a 95% probability that climate change damages to crops exceed 7% (Schlenker and Lobell, 2010). Scientists are, therefore, interested in simulating the impacts of climate variability on changing crop yield (Kurukulasuriya and Mendelsohn, 2008; Knox et al., 2012; Ahmed et al., 2015). There is also a shift in research from water resources-from the adaptative perspective- to the food security perspective, which has gained more prominence compared with the previous period. Urama and Ozor carried out a study on the impact of climate change on water resources from the adaptative perspective and found that rising temperatures of 1.5–2°C affects fisheries in West African lakes (Urama and Ozor, 2010). It was suggested by Ngoran et al., that looking beyond command and control policy will be a better regulatory measure to mitigate climate change on water resources (Ngoran et al., 2015).

There is robust information in the blue cluster to understand climate variability and trends, a requirement to draw a context-specific climate change adaptation intervention. For instance, in 2010, Tshiala and Olwoch studied the relationship between tomato production and climate variability and found a positive trend (Tshiala and Olwoch, 2010). While some keywords continue to be dominant and prominent, like sustainability, climate variability, and vulnerability, several new keywords

2 https://unfccc.int/kyoto_protocol?gclid=CjwKCAjw-rOaBhA9EiwAUkLV4lwCd7zjxPdYULehR8k0wOCej_nVq5gL4YMU0B1-lIol5qgiRceuLxoCfn0QAvD_BwE

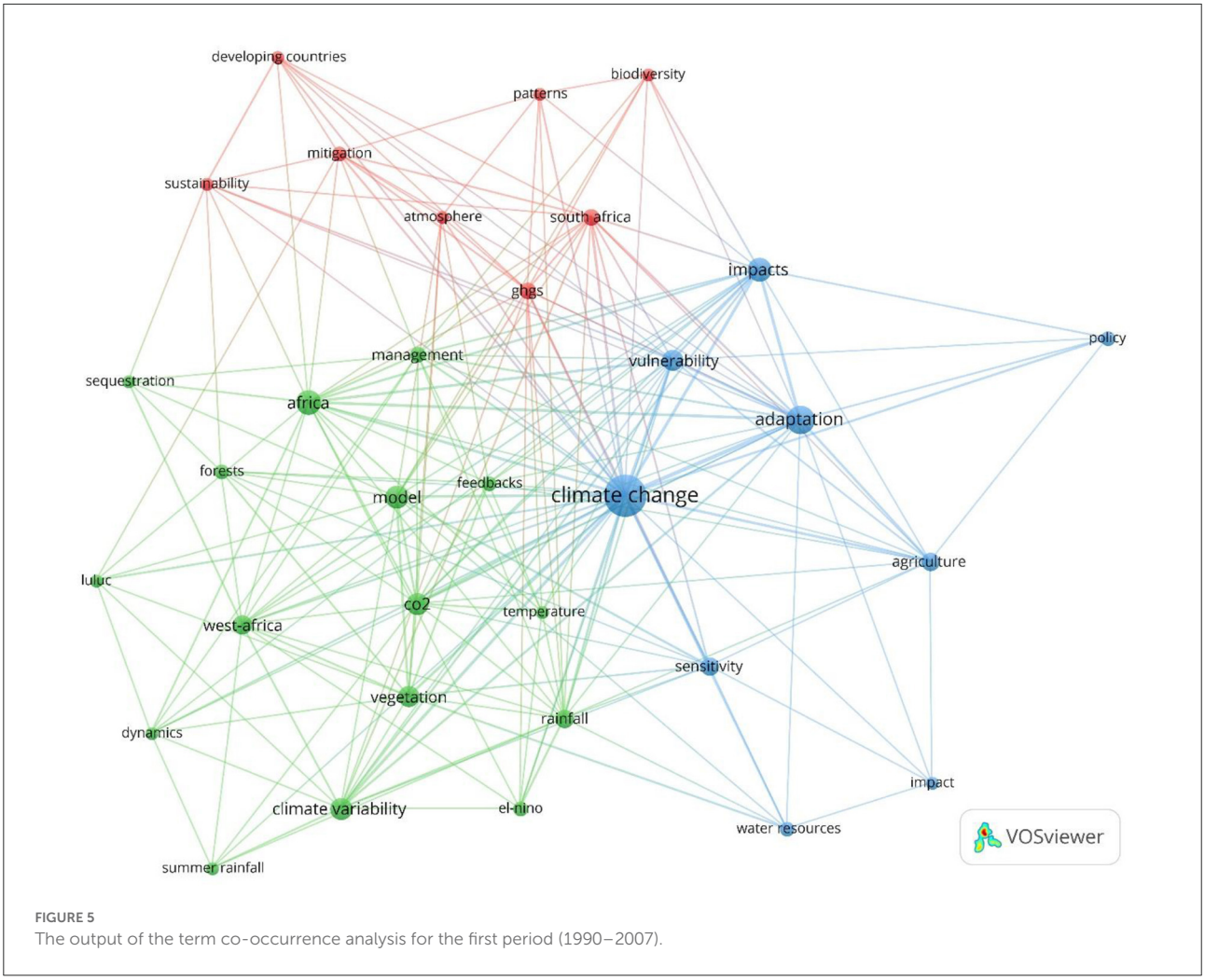

FIGURE 5
The output of the term co-occurrence analysis for the first period (1990–2007).

emerge: energy security, ecosystem services, bioenergy, biomass, productivity, deforestation, conservation, resilience, etc. The emergence of these keywords shows how much attention has been given to the study of climate change. Some or most of these keywords will gain greater momentum in the subsequent periods, as will be discussed in the following sections. There is a drive toward studies on bioenergy (green cluster) that is considered to be an innovative approach in global climate mitigation efforts. There is mainly a new drive toward studies that primarily encompass biofuels produced from forest resources with simple and indigenous technologies (Adedayo et al., 2010; Langat et al., 2016). Bio-energy is very potent in reducing atmospheric methane emissions (Weiland, 2006). There is also the emergence of studies on policies to offset climate change impacts on ecosystem services. In South Africa, two key policies emerged: National Climate Change Response White Paper and South Africa's Second National Communication (Ziervogel et al., 2014). In Ethiopia, providing farmers with farming equipment is a policy tool to facilitate farmers' adaptation to climate change (Bryan et al., 2009). As seen in Figure 6, it is evident that a significant increase has occurred in research on local perceptions about environmental awareness, attitudes, beliefs, and risk perception. Studies on the green cluster have maintained steady growth while the red cluster has bulged. Almost all themes are closely linked and strongly related to the external topics with more attention and influence compared with the first period. The research intensity during this period changed with an increase in the development and maturity of themes.

Third period (2015–2019)

The third period has witnessed explosive growth with the birth of a new cluster (Figure 7). The new yellow cluster focuses on renewable energy, showing a shift from conventional energy consumption to more renewables. The specific renewable

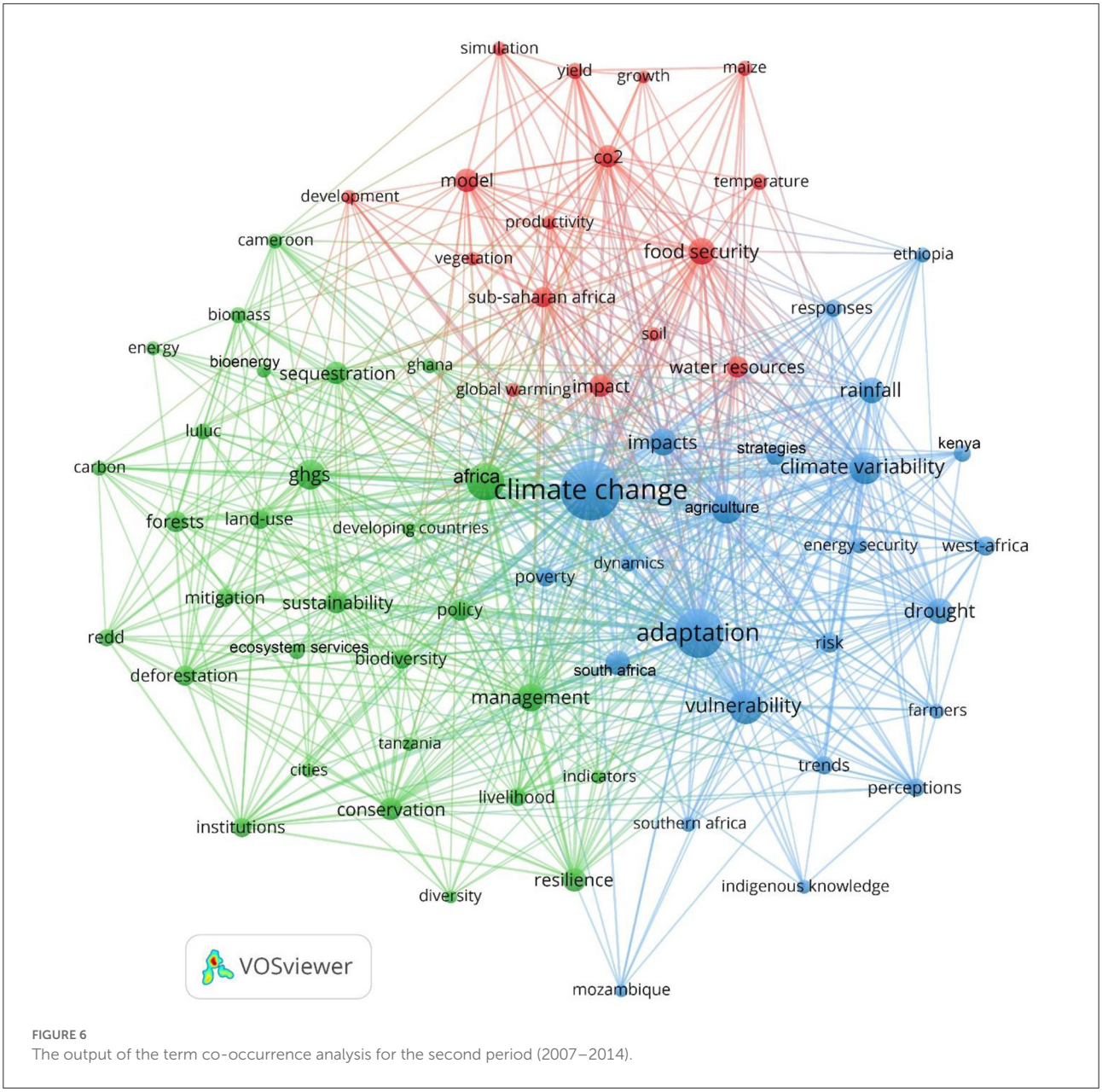

FIGURE 6
The output of the term co-occurrence analysis for the second period (2007–2014).

energies used in Africa are solar, wind, and hydropower. Nigeria, Angola, DRC, Sudan, and Zambia are leading countries in hydropower, with Angola and DRC generating a net capacity of 2,763 and 2,750 MW, respectively (Frangoul, 2019). Meanwhile, solar and wind energy South Africa, Morocco, Ethiopia, Mozambique, and Egypt are leading states, with South Africa having the highest maximum net capacity of 6,065 MW followed by Egypt with 4,813 and Ethiopia with 4,351 (Frangoul, 2019). The period sees the addition of some new keywords. Among the new keywords are agroforestry, economic growth, smallholder farmers, and conservation agriculture.

Multiple studies have explored the link between climate change and economic growth (Abidoye and Odusola, 2015; Alagidede et al., 2016; Adzawla et al., 2019b). A study in 2015 shows that climate change has a negative impact on economic growth in Africa, such that a 1°C increase in temperature reduces GDP growth by 0.67% (Abidoye and Odusola, 2015). Arndt et al. note that climate change impacts from 2007 to 2050 will lead to a loss of USD 610 million in Malawi (Arndt et al., 2014). According to Radhouane in 2013, a 1°C rise in temperatures in the Northern African countries in a given year reduces economic growth by 1.1 points (Radhouane, 2013). The intensification of studies related to renewable energy is a shift from conventional exhaustible energy resources. Conventional sources raise serious environmental concerns while hampering sustainable economic growth. In Mozambique, there have been

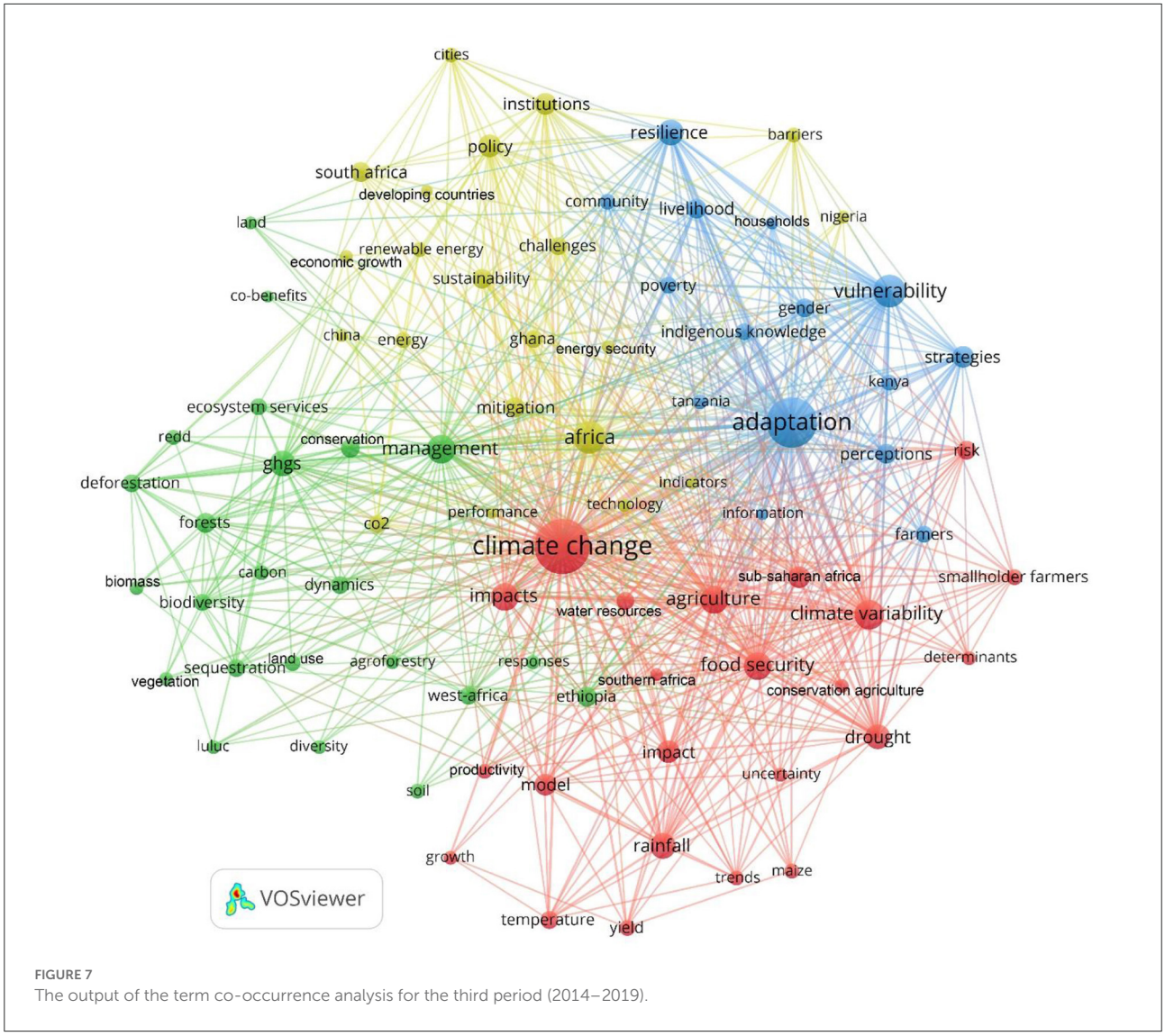

FIGURE 7
The output of the term co-occurrence analysis for the third period (2014–2019).

advancements toward using renewable energy for irrigation in the agriculture sector (Chilundo et al., 2019; Mahumane and Mulder, 2019). Renewable energy policies in Ghana have also been reviewed, and a lack of policy implementation was one of the reasons for a slow transition toward sustainable electrification (Sakah et al., 2017). Another stream of research in the energy discourse mainly focuses on the relationship between renewable energy consumption and economic growth. Arguments on this particular theme emphasize how renewable energy consumption will increase renewable energy production as a measure of environmental sustainability and how this will impact economic growth in Africa (Alper and Oguz, 2016; Bhattacharya et al., 2016). Aly et al., investigated the techno-economic feasibility of solar power in Tanzania and found that the net capital cost for an optimized plant in 2025 will be 4680 $/kW at 7% interest rate (Aly et al., 2019).

During this period, there has been a clear focus on adaptation strategies used to deal with climate change and adaptation capacities employed by communities (blue cluster). The main adaptation link occurs with risks and strategies. This observation suggests the propensity to design strategies for climate change adaptation and their interests in how to thwart or be prepared for the likely risks this entails. For instance, developing cultivars is one of the adaptation strategies applied in Northern Cameroon, which shortens the time of cotton maturity and causes a shift in the rainy season without affecting cotton yield (Gérardeaux et al., 2018). The word perception is also associated with risk perception. This indicates the increasing number of studies on indigenous knowledge and how farmers perceive risks where their activities are undertaken (Leal Filho et al., 2022b). Ayanlade and colleagues studied farmers' perceptions in Nigeria and confirmed that 67% of farmers had

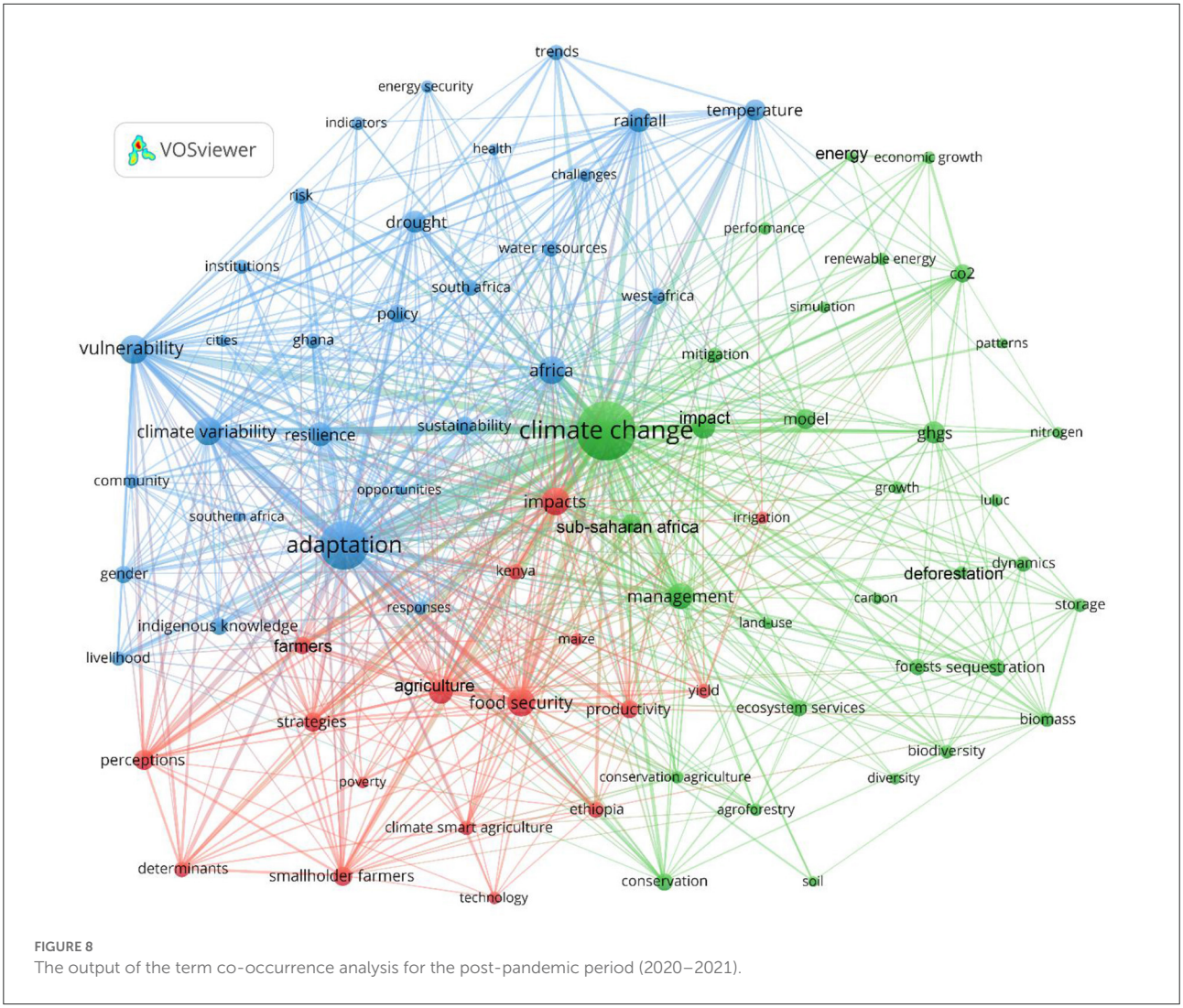

FIGURE 8
The output of the term co-occurrence analysis for the post-pandemic period (2020–2021).

noticed fluctuations in early and late growing seasons (Ayanlade et al., 2017). In South Africa, 77.3% of potato farmers and 66.7% of cabbage farmers experienced extreme temperatures, which led to a fall in their farm productivity. Potato farmers turned to integrate pest management to deal with climate risk, while cabbage farmers turned to planting drought-tolerant varieties (Elum et al., 2017). More studies have adopted a holistic approach to climate change by considering stakeholders' perceptions. For instance, a heat management policy was advocated when mining workers in Ghana suffered heat-related illnesses after a stakeholder consultation meeting (Nunfam et al., 2019). During this period, researchers appear to prefer studying climate change resilience from the adaptation perspective under full consideration of vulnerability. The overwhelming concern of researchers is the socio-environmental impacts on agriculture from extreme events like floods leading to food security issues under different climate variability scenarios. The next most frequent concern in dealing with food security is a shift in focus from agriculture to conservation agriculture. Overall, adaptation-related (blue cluster) studies shrunk while research on food security (red cluster) bulged and research on green cluster maintained a steady growth. The release of the fifth IPCC assessment report, with its scientific information, and technical and socio-economic relevance, triggered a good number of articles based on scientific research about adaptation and mitigation strategies. Thus, in this period, climate change studies have been increasing and becoming more diverse in Africa. These studies incorporated new concepts that allow the topic to be addressed from a range of different disciplines. The fifth IPPC assessment report in 2014 was a critical scientific contribution that led to the successful agreement on the Paris Climate Change accord, producing more research impetus.

Post pandemic period (2020–2021)

During this period, the green cluster and its related sequestration studies continue to attract more relevance (Figure 8). Compared with the previous period, the blue cluster

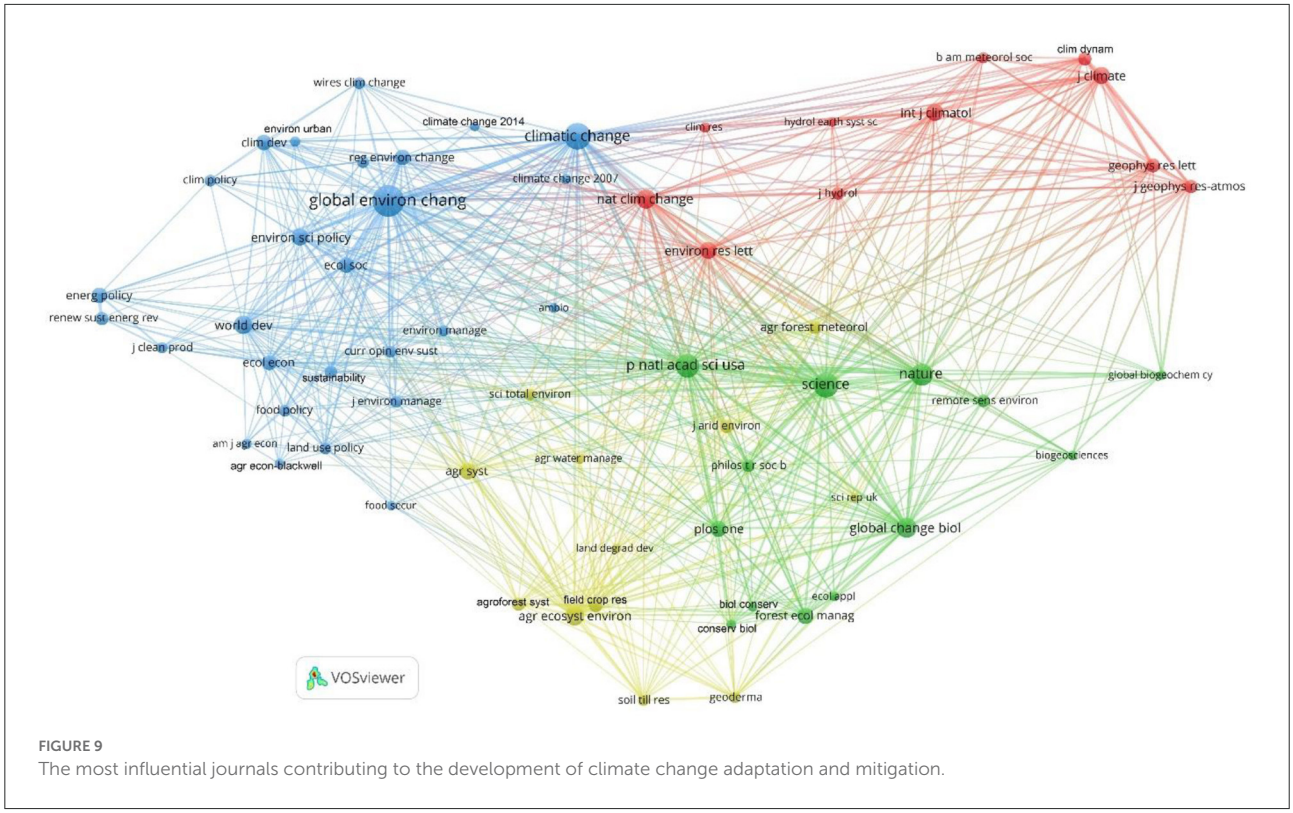

FIGURE 9
The most influential journals contributing to the development of climate change adaptation and mitigation.

has expanded, while studies on the red cluster begin to receive less relevance. Publications on sustainability, vulnerability, and resilience continued to increase from an adaptation perspective. As seen from the green cluster, ecosystem services and conservation agriculture were studied more closely. Climate-smart agriculture (CSA) is a new area of research receiving more relevance and is widely studied under the red cluster. Among the climate-smart agricultural practices adopted by African farmers are diversification of crops, change of planting time, and crop rotation/mixed cropping (Nyang'au et al., 2021). Climate-smart agricultural practices are recognized as one of the best adaptative strategies because they boost agricultural productivity, increase resilience, and reduce greenhouse gases that cause climate change (Anuga et al., 2020). The yellow cluster that was found in the previous period now merges with the mitigation cluster, and studies on renewable energy continue to rise. Mukoro et al.'s (2021) work predict that by 2040, renewable energy capacity in Africa is expected to reach 169.4 GW from 48.5 GW in 2019. Specifically, in South Africa, as of 2021, a total of 6,422 MW of power has been acquired across 112 renewable energy Independent Power Producers (Ayamolowo et al., 2022). The inevitability of more frequent and more extensive floods, displaying the inherent variability of climate, continued to be studied under the blue cluster (Ficchi et al., 2021; Petrova, 2022). Ethiopia's location indicates it is more worried about climate effects on food security (red cluster). At the same time, South Africa and Ghana are also concerned about vulnerability issues (blue cluster). But the main concern of Sub-Saharan Africa is mitigation issues (green cluster).

The outset of the pandemic positively impacted climate change research as researchers were able to develop new ideas seen from the rise in publications in <2 years. Unfortunately, the unending lockdowns have drawn attention away from climate change policy nationally and internationally. Environmentalists wonder why there has not been a pandemic preparedness for climate change as it has been for the COVID pandemic (Phillips et al., 2020). Pandemic recovery measures could be one of the solutions to climate change in Africa and the world. A complementary strategy is to use opportunities and lessons provided by the pandemic to accelerate the decline of carbon-intensive industries, technologies, and practices (Rosenbloom and Markard, 2020). Amid the pandemic, agricultural innovation and technologies have been promoted in Africa. The African Development Bank has helped increase the uptake and use of proven high-yielding climate-smart maize technologies by smallholder farmers in Sub-Saharan Africa (Fernando, 2020).

Influential sources

The co-citation analysis was used to find out which journals have contributed the most to the development of the field. Here, the size of the nodes is proportional to the number of citations,

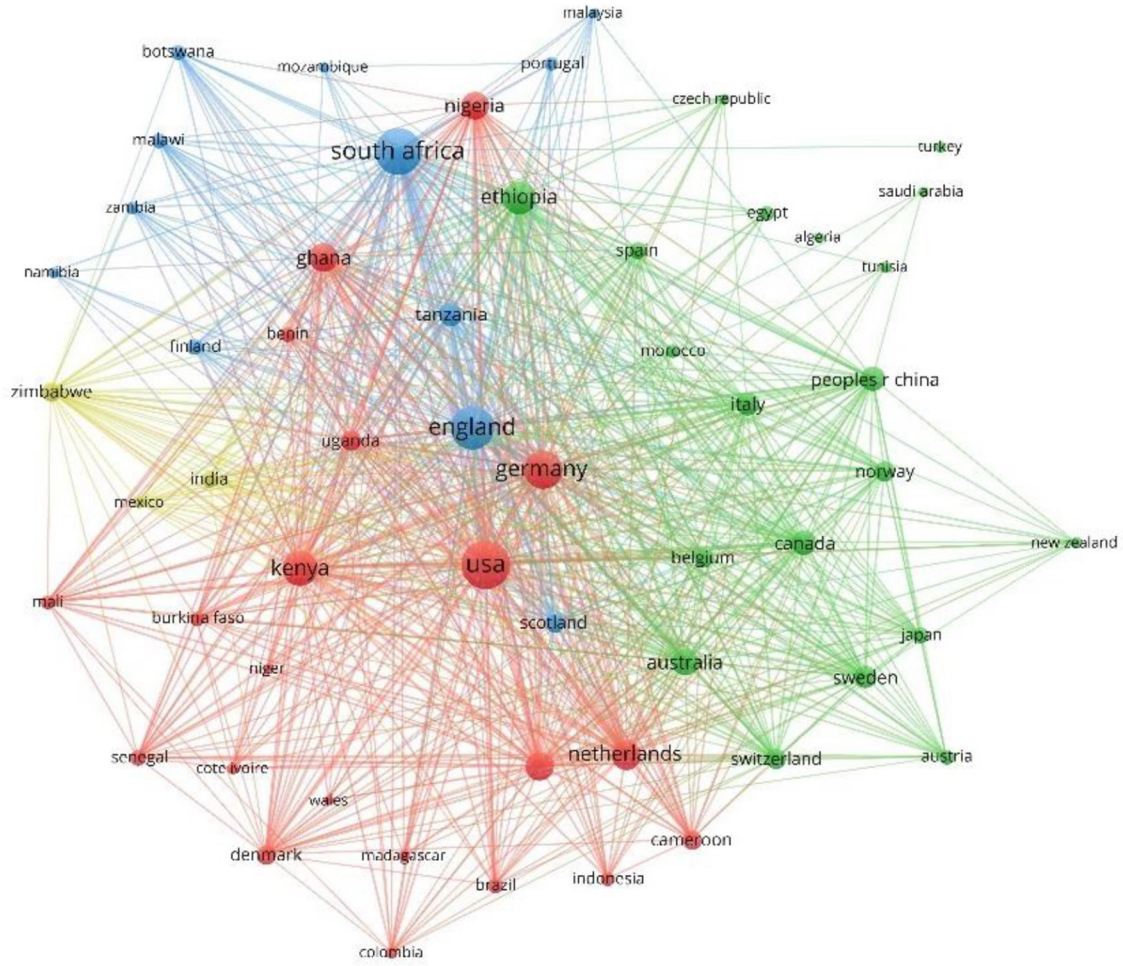

FIGURE 10
Countries have significantly contributed to the climate change adaptation and mitigation research in Africa.

and link width is proportional to the strength of the connection between two nodes. Four major clusters can be identified from the results of the co-citation analysis (Figure 9). The colors of these clusters are consistent with those reported for the term co-occurrence analysis. The largest cluster (blue) includes journals that are mainly focused on adaptation and vulnerability aspects. As expected, journals with a key focus on climate change and environmental issues have played a significant role in advancing Africa's knowledge of climate change adaptation. The most prominent journals in this cluster are Climatic Change, Global Environmental Change (GEC), Environmental Science Policy, and World Development. The results show that mitigation (green cluster) has mainly been addressed by journals such as PNAS, Science, Nature, and Forest Ecology and Management. The yellow cluster is dominated by influential journals like Agriculture, Ecosystem and Environment journal, Agricultural Systems, Field Crop Research, and Science of the Total Environment. The red cluster is dominated by journals like Nature Climate Change, Environmental Research Letters, and the Journal of Climatology.

Overall, the journals that have contributed the most to this literature include Global Environmental Change, PNAS, Climatic Change, Science, Agriculture, Ecosystem and Environment, Energy policy, Environmental Research Letters, Forest Ecology and Management, and Climate while the journals with the most documents are Climate and Development and Sustainability with totals of 131 and 121 documents, respectively.

An interesting observation here is the multidisciplinary nature of this field of knowledge. As seen in Figure 9, all articles are distributed and disseminated through 66 journals, which involve different fields of application, with emphasis on food security, climate change adaptation, and mitigation studies. This requires that future studies/efforts actively involve the

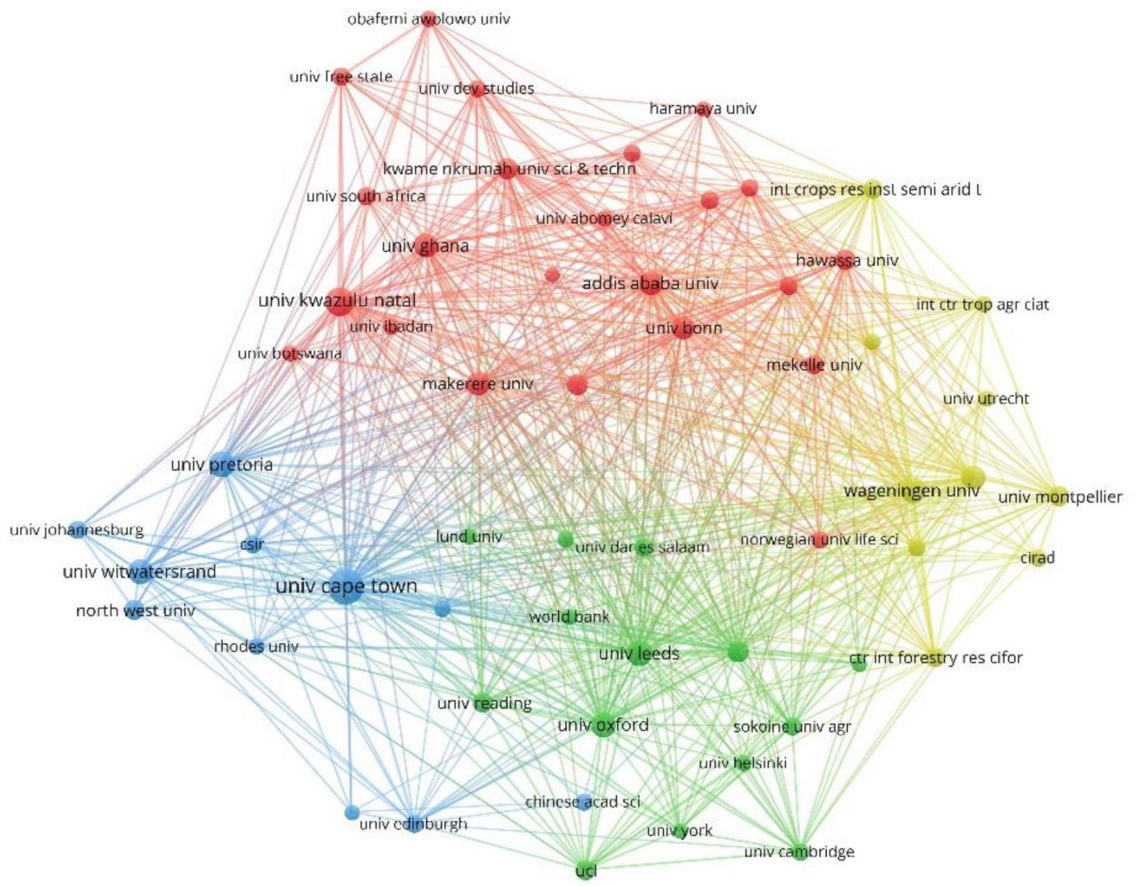

FIGURE 11
Organizations that have made significant contributions to the advancement of the field.

participation of several professionals to add learning in such a complex decision environment.

Major contributing countries and institutions

To recognize the most prominent countries that have contributed to the field, a bibliographic coupling analysis was conducted (Figure 10). The list of the top 20 most prominent countries with the number of documents, number of citations, and total link strength is presented in the Supplementary Table S1. It is noted that countries like the USA, South Africa, England, Germany, Kenya, and Ethiopia have published more on this topic (Figure 10). The USA, the UK, and South Africa ranked highest in terms of the total number of citations. Interestingly, while developed countries have contributed more, several African countries have also been highlighted. South Africa, Botswana, and Tanzania are some of the African countries with a close collaboration on adaptation, while Kenya, Cameroon, Ghana, and Nigeria have some research interests in food security. Ethiopia, Morocco, Egypt, Tunisia, and Algeria are interested in mitigation research, and Zimbabwe in the energy issues (Figure 10). The first 10 publishing African universities are shown in the Supplementary material with universities from South Africa taking the lead (Supplementary Table S2). Universities in South Africa are ahead of other African universities. An overwhelming number of African universities have not yet contributed to this literature.

International organizations like the World Bank, the Center for International Forest Research, World Agroforestry, etc. (Supplementary Table S3) made significant contributions, while international universities from Europe and the USA were prominent contributors (Supplementary Table S4). The focus of most African universities was on food security and adaptation, while that of some international organizations was on mitigation (Figure 11).

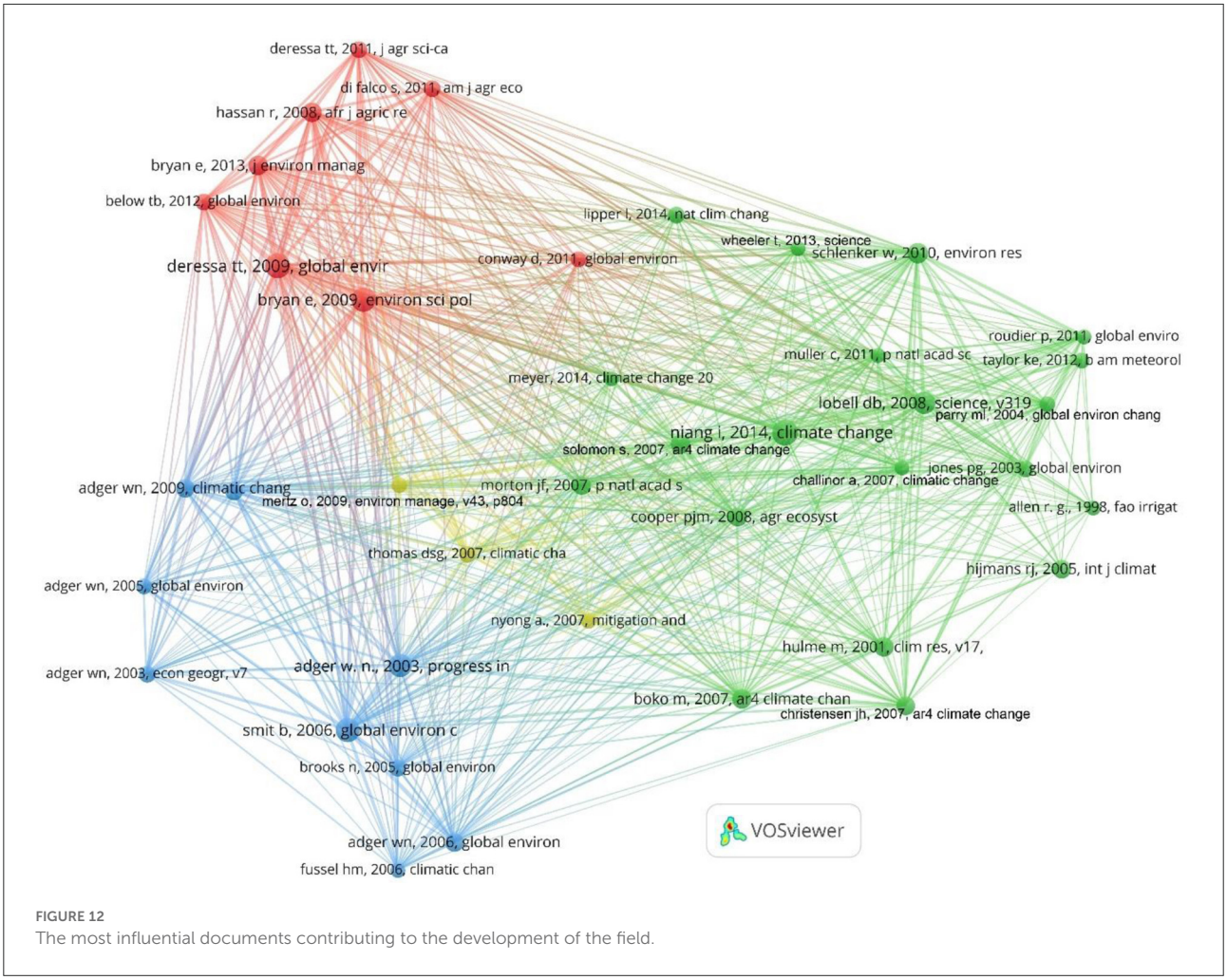

FIGURE 12
The most influential documents contributing to the development of the field.

Influential documents

The blue and yellow clusters include studies that were mostly done from 1990 to 2007 (Figure 12). Obviously, their focus on fundamental adaptation concepts has played an important role in guiding adaptation and vulnerability research. The red and green clusters include studies that were mostly done in the second period (2008–2014). The works of Roudier et al. (2011) stand out in the green cluster. This work predicted 11% yield loss in West Africa due to climate changes, with a higher yield loss of 18% in Northern West Africa (Roudier et al., 2011). Still, in the green cluster, the study by Lobell et al. (2008), concluded that there is a 95% chance that climate change will harm Southern Africa's maize and wheat, which are seen as the most important crops in need of adaptation. In the red cluster, the work of Deressa et al. (2009) is influential. They assessed the barriers to adaptation in Ethiopia. The result showed that the main barrier to adaptation was a lack of information and finance (Deressa et al., 2009). The work of Brooks et al. (2005) provided a robust assessment of vulnerability to climate-related mortality. They noted that the most vulnerable nations are those situated in sub-Saharan Africa experiencing conflict (Brooks et al., 2005).

Influential authors

The most published authors were Neil Adger, Philip Thornton, Temesgen Deressa, David Lobell, Elizabeth Basauri Bryan, Mike Hulme, Lal Rattan, and Barry Smit (Figure 13). The works of Adger are mostly on the vulnerability of communities and ecosystems to unforeseen climatic changes, causes and consequences of these vulnerabilities, and adaptation strategies (Adger and Barnett, 2009; Adger et al., 2009). Thornton, is interested in the impacts of climate change on livestock and livestock systems in developing countries and also curious to know how some African crops respond to climate change (Thornton et al., 2009a,b). These results are in line with Nalau and Verrall (2021), where Adger is also seen as the most prominent author in climate change adaptation research. Our

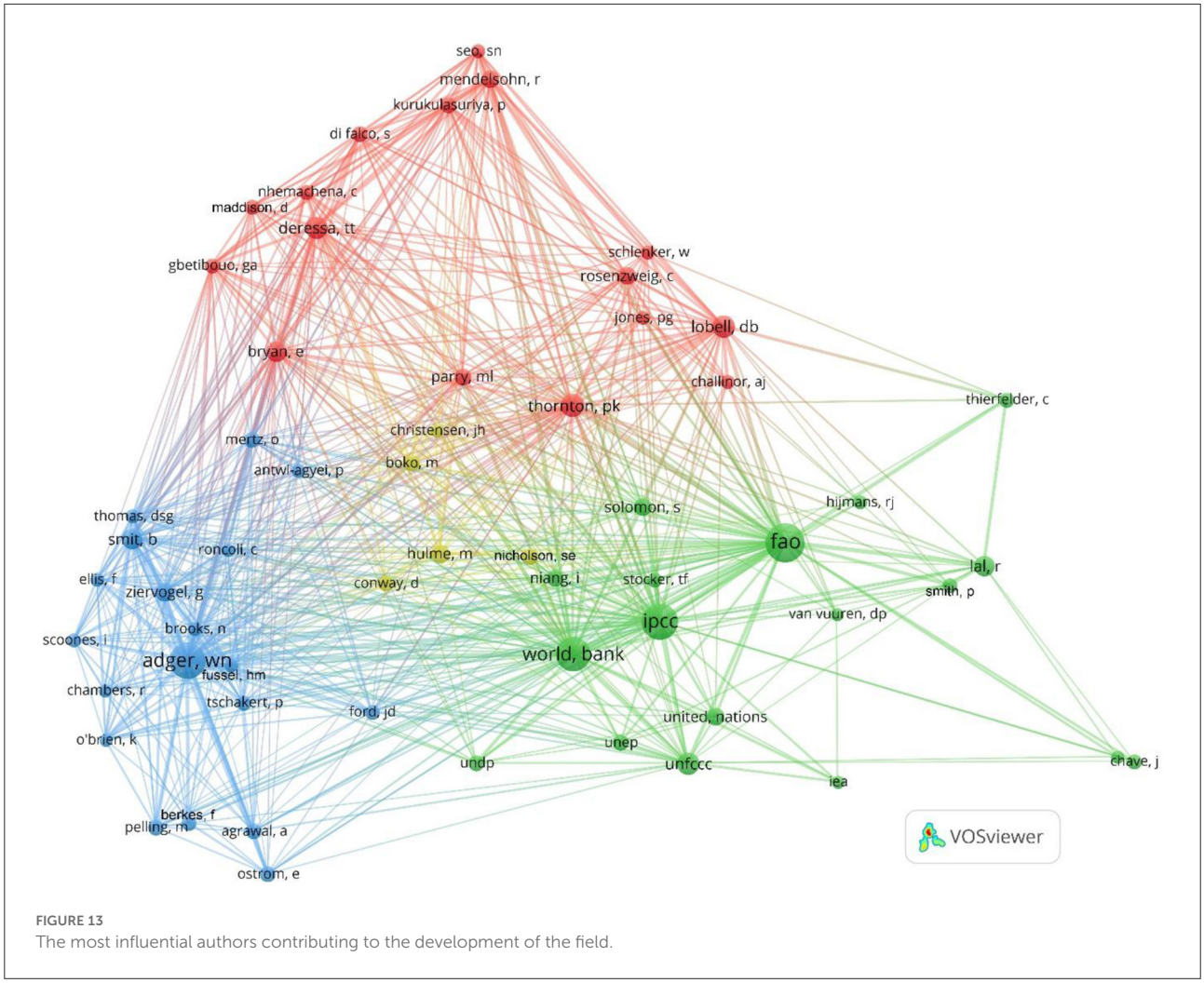

FIGURE 13
The most influential authors contributing to the development of the field.

results are consistent with the authors' publication record. For instance, Adger is a famous author in climate change adaptation, Lobell is noted for his writings on climate change mitigation, while Deressa and Bryan are noticeable for their publications on the impacts of climate change on food security.

Conclusion

This overview analysis echos a clear penchant to study and understand local adaptation capacities in Africa in the face of extreme events given that the impacts of climate change are irreversible. The most common unbiased objective in the documents is to determine how people cope with climate change based on their location. Clustering results of the literature suggest that studies on climate change adaptation mainly focused on agriculture and agroforestry, forestry, food, water and energy security. The focus is mainly on climate change adaptation in the agricultural sector. In contrast, less attention is paid to mitigation. Therefore, more research on this topic would be needed.

Woefully, most African institutions lack adequate research, which hampers efforts to address climate change in the continent. Adaptation and mitigation policies need to be developed based on regional and local characteristics, and the promotion and funding of research in this domain led by local experts for the building of a green Africa. African institutions should improve their ability to conduct research on climate change adaptation and mitigation, enter corresponding climate adaptation and mitigation cooperation, and ensure research in this field is relevant and fruitful. Africa, with the highest population and urban population growth rates globally, is likely to have major implications for climate change. However, it did not emerge from our analysis.

The more that is known about climate change adaptation and mitigation in the African continent, the greater the understanding and support will be to make feasible decisions. There will also be more motivation to engage in local climate

change adaptation and mitigation actions. Local knowledge and cultural practices should be recognized because they can complement scientific information in the design of adequate and effective adaptation and mitigation policies. Knowledge and technology gaps in African countries should be overcome to promote climate change mitigation research, whose progress is still due to inadequate analytical infrastructure to conduct the required measurements to assess the impacts of climate change which act as a prerequisite for adaptation planning. African countries need to enhance their research ability in the field of climate change mitigation through international cooperation and other extensive methods. This will bring more focus on African problems and, therefore, find solutions suitable to African characteristics. There is a need for a closing window of opportunity to avoid worse case scenarios in the continent. Collaboration, determination and trust across countries and amongst stakeholder groups will one way in meeting the challenge.

This study conducted statistical analysis on the data of SCI/SSCI published from 1990 to November 2021 through keyword retrieval. The study found that the publication volume of climate change adaptation and mitigation research in Africa has risen rapidly in recent years. Despite this rapid increase, some countries have contributed less to the publication volume. It is necessary to implement regional cooperation on climate change adaptation and mitigation in the region and improve the research capabilities of African countries in this field. Research on climate change adaptation and mitigation in African countries is of great concern and future research should pay more attention to African countries that have contributed less to the publication volume. In the end, it should be noted that this bibliometric review had some limitations. Using only English papers and sourcing data from the web of science database means that other potentially relevant studies published in local journals not indexed in the web of science could have been missed. Examining such sources would allow gaining a more comprehensive understanding of the structure and trend of the literatyre. Apart from articles published in local journals, the exclusion of gray literature was due to quality concerns and also because such studies are not indexed in formats compatible with the bibliometric analysis software tools. However, since our aim was to understand the overall structure and we already have a large number of articles in the database, we argue that the impacts of these limitations on the results are minimal.

Author contributions

Conceptualization, methodology, and software: AS. Formal analysis: AS and YB. Writing—original draft preparation: YB, AS, ST, NNG, and NG. Writing—review and editing: AS and ZA. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2022.976427/full#supplementary-material

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