

Review

# Review of Publications on the Water-Energy-Food Nexus and Climate Change Adaptation Using Bibliometric Analysis: A Case Study of Africa

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**Abstract:** Access to clean water, reliable energy services and adequate food supply are basic needs for life and contribute to the reduction of national and global levels of human poverty and forced migration. This study concentrated on reviewing progress made in understanding the relationship between the Water-Energy-Food (WEF) nexus and climate change adaptation, using Africa as a case study. The method used to achieve this objective was the bibliometric analysis, covering the period from 1980–2021. Data used for this study were acquired from the Web of Science (WoS) and Scopus databases. Initially, 95 documents were retrieved from the WoS and Scopus core collection databases, but 30 duplicates were removed, and 65 documents were used. The outputs were further analysed using the bibliometric R package and VOS viewer. Analysis of the top 100 keywords in the 65 publications that link WEF nexus with climate change adaptation for Africa showed that 46 keywords fall under the application of WEF nexus, 31 keywords under the implementation of WEF nexus and 23 keywords under the implication of WEF nexus. Researchers from countries around the world have published the WEF nexus work undertaken on the African continent. Countries with the highest number of publications were South Africa, the United Kingdom, the United States of America, Germany, Kenya and Zimbabwe. Thematic analysis was used to explore the conceptual structure of WEF publications, and it produced four themes: (i) well-established concepts appropriate for structuring the conceptual framework of the field of WEF nexus in Africa; (ii) strongly developed concepts but still marginal for the field of WEF nexus in Africa; (iii) not fully developed or marginally interesting concepts for the field of WEF nexus in Africa, and (iv) significant cross-cutting concepts in the field of WEF nexus in Africa in relation to climate change adaptation. This study contributes to the growing body of literature on the WEF nexus by pointing out dominant themes from those that are still emerging in the scholarly work done in Africa.

**Keywords:** bibliometric analysis; water; energy; food; integrated systems; governance; adaptation; nexus

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## 1. Introduction

The water, energy, and food (WEF) nexus is deeply complex [1] and interconnected, as actions in one sector will inevitably affect actions in the other two sectors, hence there are trade-offs in the decision-making process. Because the production of food requires water, the management of water (extraction, treatment, and redistribution) requires energy, and energy production, whether from coal, nuclear or hydroelectric power plants,

hydro-energy production (one of the major sources of energy in Southern Africa besides burning coal) requires adequate water supply [2–5]. Making the components of WEF accessible and affordable is vital for life and livelihoods. As such, access to all three sectors of the WEF nexus is crucial for progress toward achieving sustainable development goals (SDGs).

Africa's diverse ecosystems produce a wide range of goods and services that are crucial to supplying food, water, energy, medicine, and sustaining livelihoods on the continent [6]. However, due to the combination of multiple stresses, such as the impacts of colonization, dependence on climate-sensitive rainfed agriculture, poor infrastructural development, lack of functional institutional arrangements, low adaptive capacity and decades'-long failure by African leaders to adequately invest in their respective country's electricity and water sectors there is increasing uncertainty to the security of WEF components in Africa [7–10]. Furthermore, (i) the lack of coherent sub-regional plans, cooperative governance, and strategies for natural resource management, (ii) inadequate implementation, monitoring and evaluation of existing policies are contributing factors to the problems facing Africa.

Considering the mounting evidence of climate change impacts on the African continent, coupled with the growing population [11], a cross-sectoral approach such as the WEF nexus is necessary to facilitate sustainable growth and development. There is a need for comprehensive analytical and socio-economic development tools that allow decision-makers to understand trade-offs and synergies of natural resource management. Such tools will contribute to prudent resource allocation, use and management. As a socio-ecological systems approach, the WEF nexus offers a sustainable solution to complex problems, such as climate change adaptation [4], while still promoting economic development across different geographical areas.

It is worth pointing out that as WEF sectors are interconnected, so are the challenges facing the policies, conceptualisation, planning, implementation and governance of the WEF nexus. As such, focusing on one sector of the nexus can potentially aggravate and/or transfer stress to another sector of the nexus [12]. Some of these challenges facing the WEF nexus include re-establishing suitable nexus governance and institutional structures/arrangements, bridging the science-policy interface, constructing institutional and human resource capacities for nexus-integrated planning and management, and incentivizing the private sector to invest in, and spearheading nexus-related projects [13]. Although the WEF nexus does have challenges, its adoption is crucial for Africa. This is because Africa has an abundance of natural resources, and these need to be managed for the benefit of African populations. Against this background, the adoption of the WEF nexus approach would certainly help build resilient socio-economic systems, reduce duplication of efforts, improve resource mobilization, enhance institutional and human capacity, harmonise interventions, and manage and achieve the trade-offs that support sustainability [14].

The aim of this paper is to characterise efforts that have gone into understanding the WEF nexus and climate change adaptation in Africa. To that end, we aim to identify patterns of focus by various authors whilst identifying topics/themes that have received more attention between 1980 and 2021. The intention was to identify prominent areas from those that are still emerging to better identify gaps in the existing literature on the WEF nexus in Africa.

The paper is structured in the following manner: we start by providing an outline of different nexus studies that have been done in Africa, this is followed by a bibliometric analysis used to assess the WEF nexus empirical research in Africa to elucidate the underlying intellectual patterns. In particular, the scientific mapping of the WEF nexus community includes trends, networks, keywords, and thematic analyses of intellectual performance. Furthermore, in this review, we examine different changes and adaptation strategies in WEF nexus studies in Africa.

## 2. Variations of WEF Studies in Africa

In this paper, we recognise that in Africa there have been several studies on the various combinations of the WEF nexus (Table 1), as different authors have viewed the WEF nexus from various perspectives. The variations of nexus studies that have been conducted in Africa include Food-Energy-Water (FEW/WEF) nexus [15–27]; Energy-Water-Food-Waste and Sanitation (EWFWS) nexus [28]; Water-Land-Food (WLF) nexus [29]; Water-Energy-Food-Biodiversity-Health (WEFBH) nexus [28]; Soil-Food-Water (SFW) nexus [30]; Water-Energy (WE) nexus [31]; Water-Energy-Climate Change (WECC) nexus [32].

**Table 1.** Drivers of change and adaptation strategies in WEF nexus studies in Africa. Articles used in developing this table were randomly selected.

Authors	Adaptation Strategies	Type of Nexus	Drivers of Change	Variables
1. Ding et al., [15]	-Adaptive water -Tariff programs	FEW Nexus Food-Energy-Water		Food: Agriculture Energy: hydroelectric generation
2. Naidoo et al., [18]	-Enabling environment -Institutional arrangements -Resource security -Equitable sustainable growth -Healthy environment	WEF Nexus Water-Energy-Food	-Water, energy, and food security -Sustainable adaptation -Job and wealth creation	
3. Nhamo et al., [28]	-Nexus Planning -Copping (reactive) adaptation -Incremental (Planned) adaptation -Transformational adaptation	Urban Nexus Energy-water-food-waste and sanitation	-Climate change -Migration -Industrialization -Modernization -Globalization -Governance	Energy, water, food, and material provisioning systems.
4. Tantoh et al., [29]		WLF Nexus Water-Land-Food	-Increasing population -urbanization -increasing standards of living -increasing demand for food	
5. Liphadzi et al. [19]		WEF Nexus Water-Energy-Food		
6. Hirwa et al., [28]	-Sustainability -Security -Governability -Scenario development -Technology and innovation -Policy strategy, laws and finance	WEFBH nexus Water-Energy-Food-Biodiversity-Health	-Climate change -Climate variability -Rise in economic growth (CO <sub>2</sub> ) -population growth -water population -Land degradation -Biodiversity loss -Ocean acidification	-Water: water security -Energy: energy security -Food: food security (cereal) -Biodiversity: ecological security (forest) -Health: water, sanitation and hygiene
7. Mabhaudhi et al., [20]	-Poverty reduction -Resilience & adaptation -Environment and human health	WEF Nexus Water-Energy-Food	Environmental Drivers -Climate change -Biodiversity loss -Sea level rise -Water & land degradation Societal Changes -Population increase -Urbanisation	

			-Globalisation -Dietary changes -Technology advancements	
8. Knight [30]		SFW nexus Soil-Food-Water	-climate change -land degradation -geological changes	Soil: Edaphic factor, geological factors Food: ecological and land-use factors, agronomy factors Water: socioeconomic and management factors, climatic factors
9. Mpandeli et al., [21]		WEF nexus (Water-Energy-Food)	-climate change -population change -environmental degradation -political insecurity	
10. Terrapon-Pfaff et al., [31]		WE nexus (Water-Energy)		-Water: Water quality -Energy: solar power plant
11. Nhamo et al., [22] (a)	-Environment feedbacks -socio-economic feedbacks	WEF Nexus Water-Energy-Food	-Climate change -Resource degradation -Biodiversity loss -Cultural change -Nutritional change Population increases	
12. Nhamo et al., [25] (b)		WEF Nexus Water-Energy-Food		
13. Mabhaudhi et al., [24]	-Poverty reduction -Water, energy and food security -Increase resilience	WEF Nexus Water-Energy-Food	-Climate change -Socio-economic insecurities -Sea-level rise -Extreme weather events	
14. Mathetsa et al., [32]		WECC Nexus Water-Energy-Climate change		-Water: water availability -Energy: hydropower, pump-storage, coal-generated electricity -Climate change: increased temperature, drought episodes
15. Simpson et al., [25]	Nexus assessment	WEF Nexus Water-Energy-Food		
16. Ding et al., [16]		FEW Nexus Food-Energy-Water		-Food: Agriculture -Energy: hydroelectric generation from reservoirs -Water: water use by urban residents, agricultural water use by vineyards
17. Seeliger et al., [26]		WEF Nexus Water-Energy-Food		-Water: Breede river catchment -Energy: -Food: grapes, Fruit
18. Ozturk I [17]		FEW Nexus Food-Energy-Water		
19. Gulati et al., [27]		WEF Nexus Water-Energy-Food	-Climate change -Population -Economic growth	-Water: water extraction, treatment, supply, desalination

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 -Urbanization

-Energy: biofuel

-Food: Food quantity and quality, virtual water

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Our review of the literature, showed that in Africa, WEF/FEW nexus studies contributed 68.6%, and the rest of the nexus variations contributed about 5.3% each. The major motivation drivers of change in nexus studies in Africa were climate change; increasing population; water, energy, and food insecurity; land degradation; biodiversity loss; urbanization; job and wealth creation; sustainable adaptation. Among these studies, climate change is a recurring driver of change in most of the nexus studies in Africa.

It is important to put adaptation measures in place to prevent or minimize the impact of climate change and other drivers of change. In this review, various adaptation strategies were identified, which were not necessarily determined by the type of nexus but partly by what works well in different environments and partly by the policy in place. Adaptation strategies identified in some nexus studies on Africa include adaptative water, tariff programs, enabling environment, nexus planning, institutional arrangement, resource security, etc.

### 3. Materials and Methods

#### 3.1. Study Area

Africa is the world's second-largest continent with a landmass of about 30.37 million km<sup>2</sup>. Africa is exceptionally vulnerable to the impacts of climate change. This is because the average maximum temperatures in the whole of Africa are rising more rapidly than the global rate, and in some places, at twice the global rate of warming. The frequency and severity of droughts have increased in Africa since the 1970s, leading to land degradation and migration. Imminent rainfall variability is predicted to increase over most areas, with most models indicating fewer but higher amounts of rainfall events [33]. Climate change affects the distribution, pattern, and intensity of rainfall with severe consequences for smallholder farmers and marginalised communities.

#### 3.2. Materials

The databases that were used for this study were the Web of Science (WoS) and Scopus. WoS and Scopus are considered to have the largest collection of abstracts and citations of peer-reviewed scientific articles, books, and conference proceedings spanning a wide range of scientific disciplines, including science, technology, social sciences, medicine, and anthropology, among others. As such, bibliometric research has been extensively used from both WoS and Scopus resources [34]. The use of both WoS and Scopus databases helped to include several topics, thus limiting the risk of not capturing certain documents in the field search [35,36].

The following keywords were entered both in the Scopus and WoS web portals: "Water-Energy-Food nexus", OR "Food, Energy, Water nexus", AND "climate change", AND "adaptation", AND "vulnerability", AND "disaster", AND, "sensitivity", AND "Africa". These keywords were combined like "Water-Energy-Food nexus", AND "climate change", AND "adaptation", AND "Africa", we searched all the English-medium publications on Africa on WEF nexus plus climate change adaptation. Documents that were searched covered a period spanning four decades, from 1980–2021. Initially, 95 documents were retrieved from the WoS and Scopus core collection databases, but 30 duplicates were removed, and 65 documents were used. Table 2 gives a summary list of the documents retrieved, such as articles, book chapters, conference papers, reviews, etc.

**Table 2.** Documents considered in WEF nexus mapping.

Document Type	Number of Documents
Articles	42
Book Chapter	2
Conference Paper	1
Proceedings Paper	5
Review	15
Total	65

Note: The documents used in this research are not the only available documents on WEF nexus studies in Africa since this study used the ones available on the WoS and Scopus databases. Furthermore, keywords indicated earlier were searched based on the title of the documents, it is however possible to have some documents addressing WEF nexus in Africa, but the WEF concept is not indicated in the title of the documents.

### 3.3. Methods: Bibliometric Analysis

We used the bibliometric mapping technique on the 65 documents to analyze and visually represent the bibliographic data that were collected from the two databases. Bibliometric methods are statistical and mathematical (quantitative) methods that are used to analyze (scientific) publications. They map the process of publication, physiognomy, and the progress of knowledge within a research field [37]. Bibliometric techniques can be utilized to categorize and quantify collaborations between journals, publications, authors, institutes, and countries, and they can also be used to assess their contribution to definite topics [33]. The bibliometric techniques could be logical at stages of titles, keyword lists, publications summaries, or even the entire citation records to salvage the definite topics and subject categories assigned to publications [34]. In addition to demonstrating the diversity of research themes, the co-occurrence of keywords recognizes the multidisciplinary nature and potential directions (sub-areas/areas) for further advancement of a field [25]. It allows researchers to identify the leading topics, latest advancements and existing gaps in a certain area of a research discipline vividly and graphically [38]. Various authors have used it to support their decision-making processes [36].

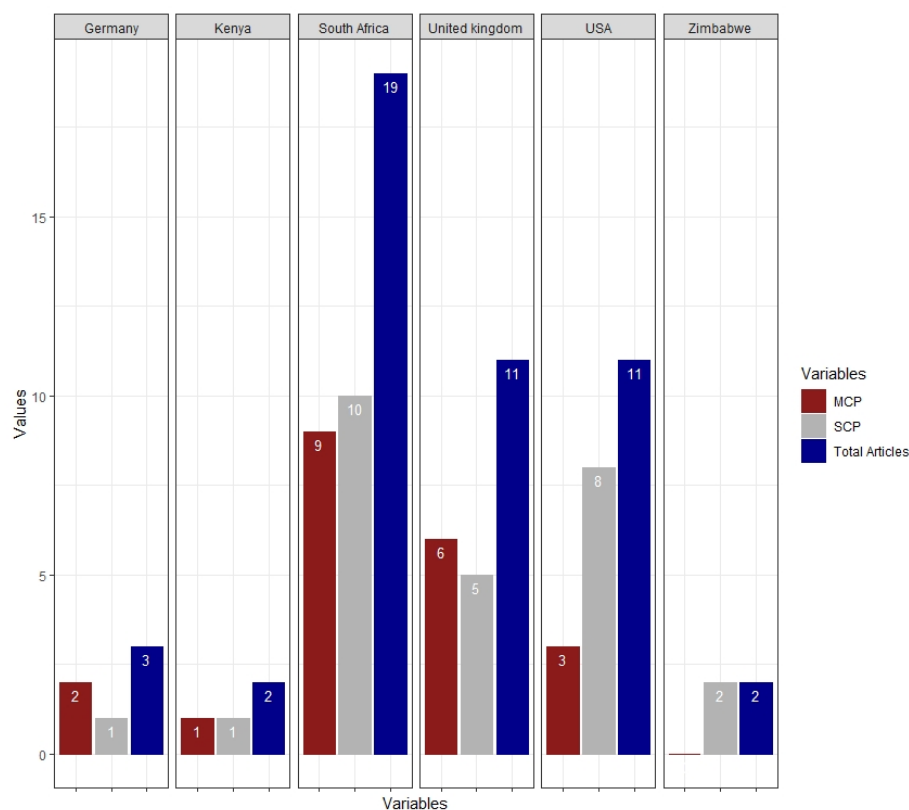
The use of the bibliometric mapping technique was undertaken in this study to visually represent scientific information by using bibliographic data, which was carried out using quantitative approaches [37]. Based on the bibliometric R software package [39], WEF nexus information was analyzed, whereas bibliometric network maps were developed using VOSviewer (i.e., Visualization of Similarities) [35]. In this research, the bibliometric analysis focused on the overall intellectual structure of the WEF nexus through the lens of climate change adaptation during the selected study period (1980–2021). A set of analyses that included analyzing the annual production of scientific publications, the most productive countries and their collaborations, keyword occurrence, and thematic progression of research were conducted.

## 4. Results

### 4.1. Publications on WEF Nexus in Africa

Figure 1 displays countries that carried out studies on WEF nexus in Africa only or African countries (Single Country Publications (SCP)), and those studies which focus on Africa or African countries along with other countries (Multiple Country Publications (MCP)) from 1980–2021. According to Figure 1, the top 6 most productive countries in the production of WEF nexus articles are South Africa, the United Kingdom, the USA, Germany, Kenya and Zimbabwe. Figure 1 shows that South Africa is the country with the highest number of published articles with 19 publications, 10 of which were published under single-country multi-country collaborations and 9 through multi-country collaborations. With 11 publications, the United Kingdom and the USA rank second with 5 and 8 single-country publications, respectively, and 6 and multi-country publications

respectively. It's important to note that the ranking of countries depends on the affiliation of the main author at the time of the publication.



**Figure 1.** Top 6 Most productive countries in research on climate change adaptation through the lens of WEF nexus in Africa (1980–2021). Multiple Country Publications (MCP), Single Country Publications (SCP).

#### 4.2. Trends in Publications of WEF Nexus in the World, Africa and South Africa

Figure 2 illustrates the temporal and geographic distribution of articles published in Scopus and WoS in the World (976 documents were used), Africa (65 documents were used) and South Africa (18 documents were used) from 1980–2021 on WEF nexus and climate change adaptation. Globally, studies on the WEF nexus started as far back as 2007 (Figure 2A), with a considerable rise in the number of studies starting in 2013. From the year 2015 to date, there has been a continuous rise in the annual publications on WEF nexus worldwide. The annual percentage growth rate of nexus studies at the global level is 44.68% for the period 1980 to 2021.

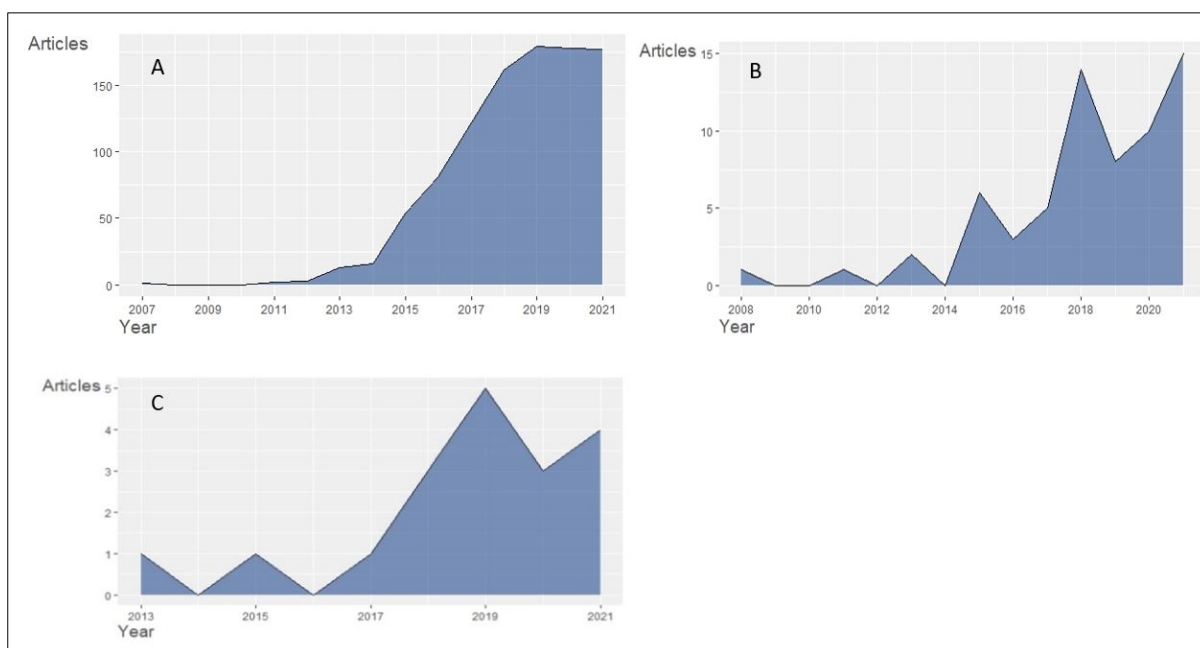
Our results showed that research into the WEF nexus in Africa began to emerge in 2008. Similar to the trend observed in global publications on the WEF nexus, Africa displayed a considerable increase in WEF nexus publications from 2008 to 2021, as demonstrated by an overall growth rate of approximately 23.16% in scientific publications each year. However, in contrast to the relatively smooth increase in global publications, WEF nexus publications in Africa show year-to-year fluctuations.

WEF nexus studies conducted in South Africa began in 2013, and their temporal distribution shows a pattern that is similar to that of Africa (Figure 2C). From 2016 to 2021, there has been a considerable rise in the number of publications produced in South Africa (Figure 2C). The annual growth rate of nexus studies in South Africa for the period 1980 to 2021 is 18.92%.

It is worth noting that there is a huge difference in the number of studies published in the World compared to those published in Africa in the period considered for this study (1980–2021). In that period, hundreds of publications were published in the World, while

far less than that were published in Africa. This considerable difference in the number of publications is evident despite a relatively similar period of starting to publish on the WEF nexus between the World (2007) and Africa (2008) (Figure 2A,B).

This is evident in Figure 2, where Figure 2A shows that global studies could be as high as 180 publications a year (this was recorded in 2018), while the highest number of recorded articles for Africa was 14 publications a year (also in the year 2018 (Figure 2B y-axis). South Africa is the highest producer of WEF nexus publications in Africa, with 5 publications a year (Figure 2C y-axis).

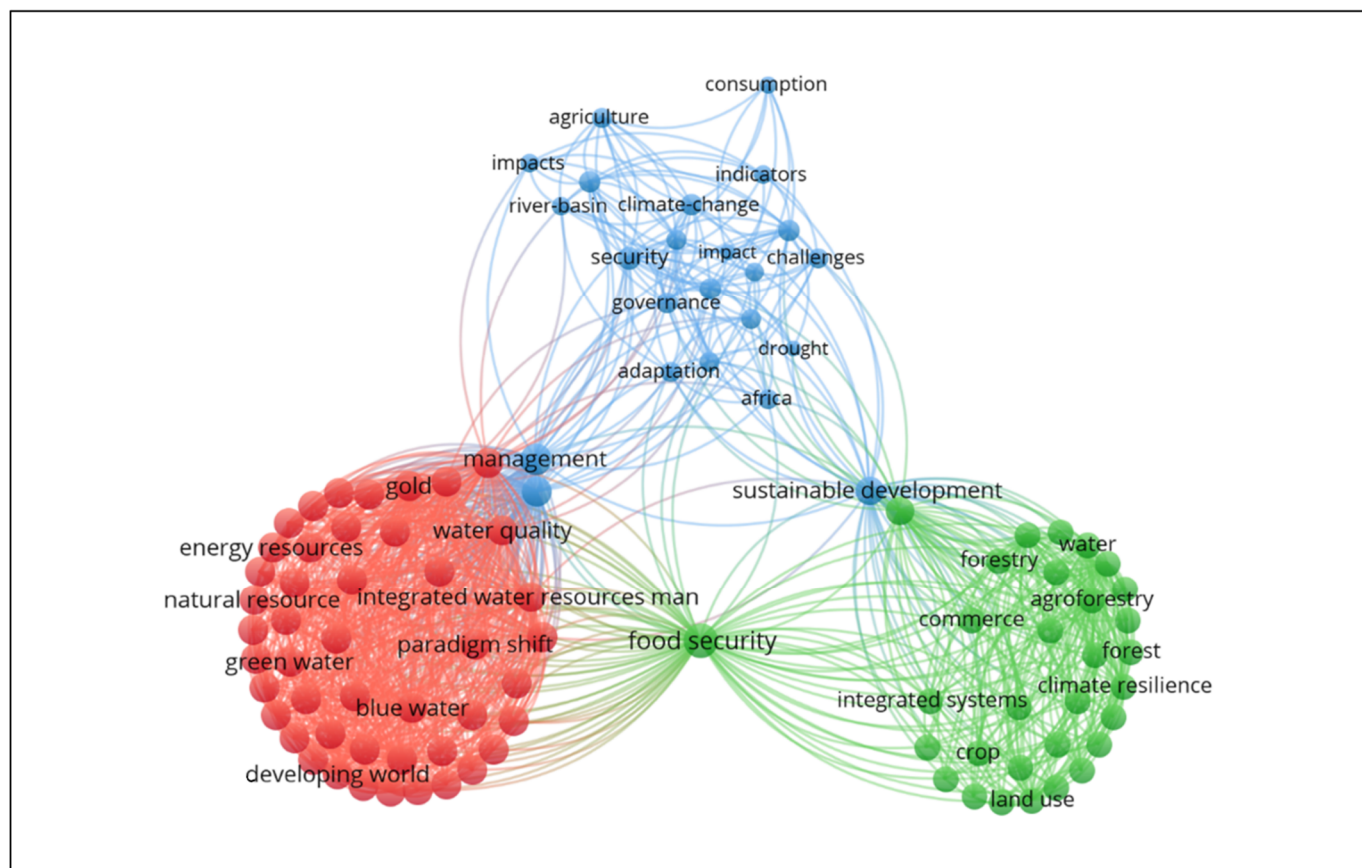


**Figure 2.** Annual distribution of publications published in (A) Global, (B) Africa and (C) South Africa.

#### 4.3. Analysis of Keywords

In Figure 3, the co-keyword network shows three distinct clusters from 100 top keywords having a total of 3656 links. Each cluster characterised a subfield of the field of WEF nexus. Suitable labels for the three most important clusters could be allotted to each of them by analyzing its main node circles. Within each cluster, different sizes of circles were used to represent the frequency that each keyword was used in the 65 analysed publications. For example, a large circle indicates that the keyword has been used more frequently in the publications. The topic similarity and relative strength of the two keywords were demonstrated by their distance from each other.





**Figure 3.** Top 100 Keywords used in publications that link Water-Energy-Food nexus with climate change adaptation from 1980–2021. Man = Management. Red cluster represent keywords that are related to the application of the WEF nexus; Green cluster represent keywords that are related to the implementation of the WEF nexus; and Blue cluster represent keywords that are related to the implications of the WEF nexus.

Keywords have been extracted from the titles or abstracts of the 65 analysed publications (these are the author’s keywords) and were grouped into 3 clusters (red, green and blue) using a strength association methodology. The circles with the same colour suggested a similar topic among the publications. The red cluster represents keywords that are related to the application of the WEF nexus. The green cluster represents keywords that are related to the implementation of the WEF nexus, while the blue cluster represents keywords that are related to the implications of the WEF nexus (Table 3).

**Table 3.** Clusters and their key messages.

Clusters	Links	Key Messages from Figure 3
Red	2223	Application of WEF nexus
Green	1023	Implementation of WEF nexus
Blue	410	Implication of the WEF nexus

From the 65 articles that were analysed, we found a total of 3656 links between the top 100 keywords (Table 3). The largest number of links between the top 100 keywords were found in topics on the application of WEF nexus, and these were almost five-fold higher than those on the implication of WEF nexus (Table 3).

Figure 3 shows the top 100 keywords used in publications that link Water-Energy-Food nexus with climate change adaptation from 1980 to 2021 for Africa. The results show that 46 keywords fall under the red cluster (application of WEF nexus), while the green

cluster (implementation of WEF nexus) contained 31 keywords and the blue cluster (implication of WEF nexus) showed 23 keywords (Figure 3).

#### 4.4. Thematic Progression Analysis

An approach that was used in bibliometrics to explore the conceptual structure of a given research area is called thematic analysis [40]. With this approach, it is possible to create graphical representations containing a summary of the main points in a body text. Moreover, the extracted topics could be classified according to their structure and role within the network as a whole. Thematic mapping allows four different typologies of themes to be visualized, as shown in Figure 4. A thematic map is developed using the Keywords Plus field [41]. During this process, the title of all references is reviewed and highlights additional relevant but overlooked keywords that were not listed by the authors. Keywords Plus is normalized differently from the author's keywords. An article's content can be captured with greater depth and variety using Keywords Plus terms. Each theme quadrant is organized following its centrality and density rank value, as well as vertical and horizontal centrality and density [35]. Spheres (circles) have dimensions proportional to the number of documents that correspond to each keyword in each quadrant.

The motor themes or hot topics appear in the upper-right quadrant (Figure 4) [39]. They are distinguished by values that have both high centrality and high density (Table 4). They are well established and appropriate for structuring the conceptual framework of the field of WEF nexus in Africa. Motor themes for this analysis contain seven themes (Table 5). The most recurring words associated with the cluster sustainability development for the period of this study were "challenges", "energy", and "adaptation" (Figure 4).

Located in the upper-left quadrant are the niche themes (Figure 4) [39]. They have a lower value of centrality and higher values of density (Table 4). They are strongly developed but still marginal in the field of WEF nexus in Africa. The niche themes in this analysis contained seven themes, as presented in Table 5. The niche themes quadrant contains two main clusters, as displayed in Figure 4. The most recurring words connected to the sustainability cluster for the period of this study were "food security", "irrigation", and "water management" (Figure 4). The most recurring word associated with the cluster drought is "food production".

**Table 4.** Centrality and density of themes in WEF nexus in Africa.

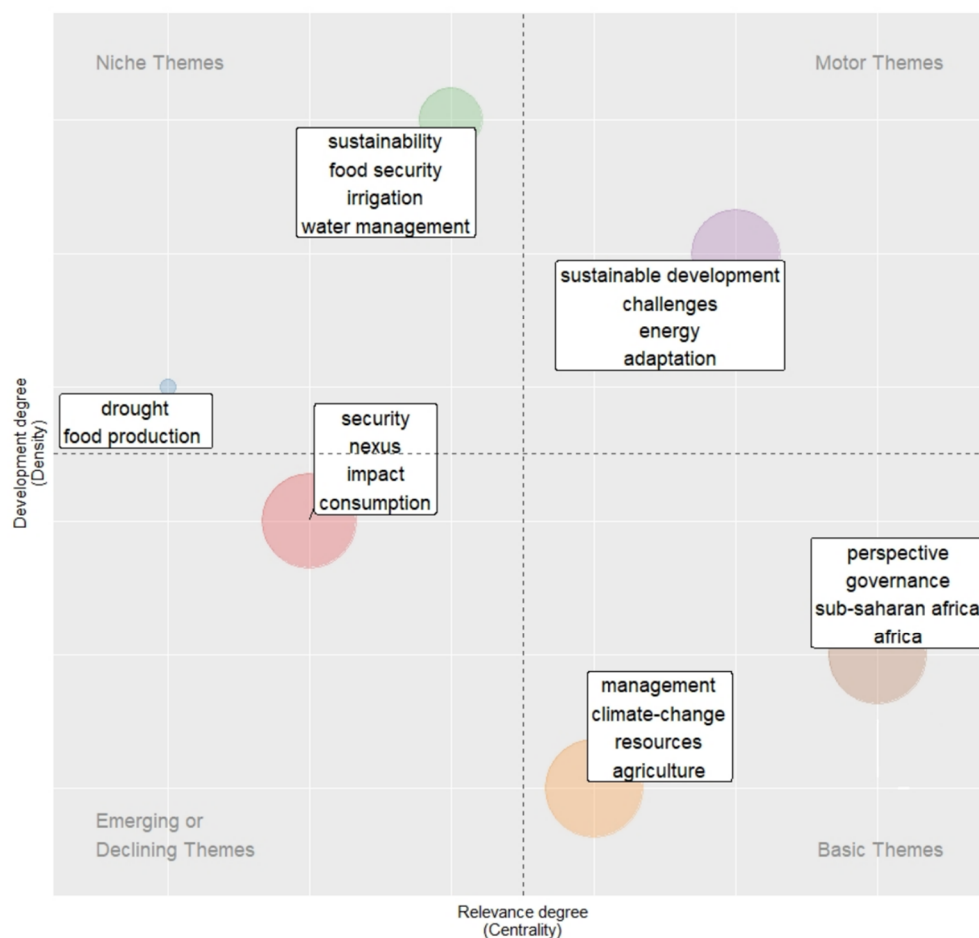
	Centrality	Density	R Centrality	R Density	Label	Color	Name	Themes
1	6.65	193.49	2	3	1	Rose	security	Emerging or declining theme
2	1.10	220.83	1	4	2	Blue	drought	Niche theme
3	8.36	619.10	3	6	3	Green	sustainability	Niche theme
4	11.13	289.28	5	5	4	Violet	Sustainable development	Motor Theme
5	9.12	126.46	4	1	5	Orange	management	Basic theme
6	14.90	191.17	6	2	6	Brown	perspective	Basic theme

In the lower-left quadrant are the emerging or declining themes (peripheral topics (Figure 4)) [39]. They have lower values of centrality and density (Table 4). They are not fully developed or marginally interesting for the field of WEF nexus in Africa. The emerging or declining themes for this study are six themes (Table 5). The most recurring words connected to the security cluster for the period of this study were "nexus", "impact", and "consumption" (Figure 4).

**Table 5.** The four themes identified by the thematic analysis from WEF nexus publications (1980 - 2020) in Africa and the most recurring words in each theme.

<b>Motor Themes (Well Established)</b>	<b>Niche Themes (Strongly Developed but Still Marginal)</b>	<b>Emerging or Declining Themes (Not Fully Developed or Marginally Interesting)</b>	<b>Basic and Transversal Themes (Significant and Cut across Different Areas of the Nexus)</b>
Sustainability development	Sustainability	Security	Management
Challenges	Food security	Nexus	Climate change
Energy	Irrigation	Impact	Resource
Adaptation	Water management	Consumption	Agriculture
Food nexus	Integrated water resource management	Emissions	Impacts
Land use	Drought	Poverty	Basin
Indicators	Food production		Land
			Rainfall
			Perspective
			Governance
			sub-Saharan Africa
			Africa
			Analytic hierarchy process
			Policy
			River
			Vulnerability

Finally, the lower-right quadrant shows the themes that are basic and transversal (Figure 4) [39]. They have higher values of centrality and lower values of density (Table 5). These are themes that are significant to the field of WEF nexus in Africa and cut across its different areas. The basic themes for this study contain 16 themes (Table 5). The most recurring words associated with cluster management for the period of this study were “climate change”, “resources”, and “agriculture” (Figure 4). While the most recurring words connected to the cluster perspective for the period of this study were “governance”, “sub-Saharan Africa”, and “Africa”.



**Figure 4.** Thematic progress of WEF nexus research in Africa. Located in the Upper-right quadrant is the motor themes; located in the upper-left quadrant is the niche theme; located in the lower-left quadrant is the emerging themes and located in the lower-right quadrant is the basic themes.

## 5. Discussion

This study focused on progress made to understand the WEF nexus using Scopus and Web of Science publications for the period 1980 to 2021, with Africa as the case study. According to this review, researchers have explored different combinations of the WEF nexus in Africa (see Table 1). Our results indicate that the WEF combination remains by far the most dominant combination among the nexus publications; as more than half of the studies (52.8%) used the WEF combination, followed by the FEW combinations with 15.8% and the rest of the various combinations contributing 5.3% each. This is in line with the work of Keairns et al. [42], who concluded that the WEF nexus is rapidly expanding among scholarly literature.

Globally and in Africa, WEF nexus studies are relatively new as the first publications occurred in 2007 and 2008 in Africa. This pattern may reflect the emergence of systems thinking in the treatment of sustainability issues in literature. Our results that South Africa has the highest number of publications on the WEF nexus in Africa, this result is similar to that of Botai et al. [1]. These results are encouraging as South Africa has committed to addressing what it refers to as the country's 'triple challenge'—poverty, inequality, and unemployment—by the year 2030. These challenges are of course intricately linked with the WEF concept. That said, the driver for the high number of publications on the WEF nexus in South Africa is not obvious. It is likely that this pattern was caused by the availability of funds to conduct research in this field. Funding for research has been highlighted as one of the limiting factors to focus and sustain research efforts [1,22].

According to the trend analysis for publications on the WEF nexus in this study, the annual growth rate of the WEF nexus globally is 44.7%, 23.2% in Africa and 18.9% in South Africa. However, there is a high disparity in the number of annual WEF publications in the World (180 articles annually), Africa (14 articles annually) and South Africa (five articles annually). Both results, the percent annual increase of publications and the total number of annual publications on the WEF nexus should challenge researchers in Africa and on Africa to invest more effort in publishing in this field to inform decision-makers that are grappling with the provision of these basic needs to the communities. More information on the WEF may increase awareness about the WEF concept, and that may contribute to breaking down the inertia of African decision-makers in effective investment in these sectors for the benefit of African communities.

Climate change impacts on the WEF nexus at national and continental levels are multi-layered. Breaking down keywords from WEF nexus publications that link the WEF nexus with climate change adaptation in Africa was divided into three broad aspects: application of WEF nexus, implementation of WEF nexus and implication of the WEF nexus. Our results showed that the research on the WEF nexus in Africa has focused on the application aspects of the nexus, followed by the implementation aspects of the nexus. In our view, this is an important finding as the focus on the application and implementation of the WEF nexus considering the changing climate shows that researchers are grappling with approaches for translating the conceptual underpinnings of the WEF nexus to solutions for improving the lives of African communities.

The four themes obtained from the thematic progression analysis of concepts of the WEF nexus proved very useful to understand the scope, the focus and the gaps in the literature that addresses the WEF nexus in Africa. It is worth noting that the water component of the WEF nexus is absent among the most recurring words in the theme on well-established concepts and is appropriate for structuring the conceptual framework of the field of WEF nexus in Africa. While the energy component of the WEF nexus is absent among the most recurring words in two themes, that on strongly developed concepts but still marginal for the field of WEF nexus in Africa and on the basic and transversal theme. This pattern suggests that research on the WEF nexus in Africa rarely places equal focus and balances all three components of the WEF nexus.

## 6. Conclusions

According to the NIC [43], WWF and SABMiller [38], the population of Africa is on the increase, and the demand for water, energy and food will continue to increase. Alahacoon et al. [39] showed that in the northern and central regions of Africa, rainfall has increased statistically significantly, while the Southern and Eastern regions of Africa did not experience any statistically significant changes in rainfall. Moreover, according to FAO [44], there is an increase in the undernourished population in Africa as such, food security in the continent is not improving. Meanwhile, according to a global dashboard dedicated to registering progress on energy access across Africa known as Tracking SDG7: The Energy Progress Report, which was last updated in 2019, the African continent currently has the worst electricity access in the world. A study by Moussa et al. [45] showed that population growth has outpaced growth in electrification in recent decades, leading to an increase in the number of people without electricity, this study revealed that more than 60% of the African population does not have access to electricity.

From this study, it is evident that Africa needs to sustain and improve the momentum of publications on all three components of the WEF nexus. This study did not look at the dissemination of results from research on the WEF nexus. Access to the results of this research by civil society and decision-makers may assist in designing and developing solutions to enable the implementation of the WEF concept to improve the lives and livelihoods of African communities. From this study, we can conclude that there is a need for:

- more studies on the WEF nexus in Africa.

- these studies should focus more on the application or practice of WEF nexus considering the impacts of climate change.
- detailed studies to balance under-represented concepts as shown in the thematic progression analysis of concepts of the WEF nexus in this study.

African governments, African civil society organisations, academia, the private sector and international partners that work in Africa should pay attention to information that comes from WEF studies and make use of the suggested solutions as Africa advance its efforts towards sustainable development.

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