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Review article

Systematic review of climate change impact research in Nigeria: implication for sustainable development

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ABSTRACT

There is evidence that Nigeria is already experiencing environmental challenges attributed to climate change (CC) and its impacts. This has clearly highlighted the need for knowledge-based strategies to help plan adequate mitigation and adaptation measures for the country. One of the basic requirements to ensure such strategies is the development of a database of national CC research. This will aid in the assessment of past and present scientific publications from which directions for future study can be mapped. The present study used standard, systematic, and bibliographic literature reviews to analyse the trend, focus, spatial variability, and effectiveness of published research on CC impacts in Nigeria. Four thematic areas of CC impact research were defined: Agriculture, Environment, Human and Multi-disciplinary study. A total of 701 articles were found to be relevant and the review shows that CC impacts and adaptations in the literature vary across research categories and locations. The period between 2011 (68 studies) and 2015 (80 studies) showed a tremendous rise in CC impact research with a peak in 2014 (84 studies). Studies in the agriculture category had the highest publications in 23 States of Nigeria. The review revealed three research gaps: (1) lack of research that investigated the magnitude of present and potential future impacts in the aquatic environment (2) little attention on CC impacts and adaptation in the Northern regions of Nigeria (3) absence of study investigating the effects of multiple variables of CC at the same time. The findings suggest that it would be useful to advance CC research in Nigeria beyond perceptive approaches to more quantitative ones. This is particularly important for highly vulnerable animals, crops, locations, and for better planning of adaptation strategies.

1. Introduction

The impacts of climate change (CC) have been experienced globally, especially in the tropics (Idowu et al., 2011; Williams et al., 2018). These have triggered a wide variety of physical and biological changes across the world with negative effects on agriculture, humans, and the environment (IPCC, 2014). It is important to note that while the vulnerability to CC impacts is higher in lower-middle- and low-income countries, particularly Africa, the readiness to improve resilience ranks very low in such countries (ND-GAIN, 2021). A recent report, for example, shows that Nigeria is one of the top ten of the most exposed countries to the effects of CC, with about 6% of its land area estimated to be exposed to extreme weather events (World Bank, 2019). A significant increase in rural-urban migration (Cattaneo and Massetti, 2019) and reduced streamflow (Akinwumi et al., 2020), among other impacts of CC in Nigeria, have also been documented.

Several incidences of environmental change in Nigeria include drought, flood, irregular rainfall pattern, deforestation (Audu et al., 2013; Elias and Omojola, 2015; Onyekuru and Marchant, 2016), desert encroachment, and housing problems (Olaniyi et al., 2019). And just like

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in India, Sudan, and other top vulnerable countries, these have significantly influenced land use and land cover, human health, and livelihoods in the country with little or no indication of appropriate adaptation plans (Jibrillah et al., 2018; Pandey et al., 2018; Olaniyi et al., 2019; Omerkhil et al., 2020; Giri et al., 2021).

In the Southern areas of Nigeria (predominantly known for high rainfall), vegetation is currently grappling with fluctuations in the sequence of rainfall. In the savanna vegetation zone, severe heat waves are seriously confronting the area. Similarly in the Sahel region, there is a risk of losing about 30 ha of cropland per year to desertification (Obioha, 2008; Ragatoa et al., 2019). In the same vein, it is evident that Nigeria's water and wetland supplies have been impacted by climate fluctuations. Many large water bodies are experiencing marked reductions in flow rate and network length in reaction to decreased rainfall and higher evapotranspiration (Obioha, 2008). These have in turn impacted crop and animal productivity both directly and indirectly (Fitton et al., 2019).

Crop production occupies approximately 94% of Nigeria's agricultural sector. CC impact is significant in this category as some regions of the country already suffer about a 20% decline in the cycle of growing days (Ebele and Emodi, 2016). Moreover, many forest resources are also gradually going extinct due to CC impacts (Onyekuru and Marchant, 2016). By 2050, Jones and Thornton (2003) predicted that crop harvests in Africa will be as low as 50% due to CC impacts. Consequently, increased risk of low output, crop loss, and death of livestock are also expected (Morton, 2007; Harvey et al., 2014). In animal production, the soaring temperature has affected productivity, especially poultry, swine, cattle sheep, and goats. About 15% reduction in production has been reported per annum (Idowu et al., 2011; Gbenga et al., 2020).

Apart from agriculture and environmental impacts, CC constitutes a threat to humans with diverse negative social and health impacts (Pittock, 2005). In coastal areas of the world, sea-level rise at 2m could result in '*forced displacement*' of about 187 million people by 2100, and up to 430 million at 6m rise (Rowley et al., 2007; Nicholls et al., 2011). In Africa, about 75 to 50 million individuals will be prone to increased effects caused by weather extremes by 2022 (IPCC, 2007). In Nigeria, available literature shows that about 27–53 million people in the coastal area have been displaced due to sea-level rise (USAID, 2012).

On human health, the World Health Organization (WHO) estimated that at least 150,000 deaths each year could be traced to the outcome of CC. Moreover, this figure is expected to double by 2030 with connections to flooding and water-related diseases (WHO, 2021). Studies have claimed that climate change-related torrential flooding has led to disease outbreaks in various regions of the globe (Lisle, 1995; Rose et al., 2000). Consequently, the Nigerian population could be exposed to such threats.

The impacts of CC experienced in the developed countries are less serious compared to the developing countries (Maikasuwa, 2013). Although the developed countries are the key contributors, they have over the years developed advanced adaptation technologies, productive research, and working institutional policies. This has enabled adequate adaptive responses and reduced the outcomes of CC effects (Jagtap, 2007; Enete and Amusa, 2010; Ebele and Emodi, 2016; Elum and Momodu, 2017). In developing nations like Nigeria, these modern adaptation technologies are limited. This informed this study to further investigate CC adaptation strategies, their effectiveness, and implications.

Considering the fact that the impacts of CC are not uniform throughout the globe, it is imperative to understand the situation at different spatial scales. Although several studies have assessed CC impacts across Nigeria, it is as important to assess how the research evolved and whether it reflects the level of preparedness towards projected future trends. Our aim, therefore, is to assess the status of research on the impact of CC in Nigeria. We also analyze the trend, focus, spatial variability, and effectiveness of CC research and adaptation strategies in Nigeria. Through this analysis, we aim to identify the current research gap, and the findings are expected to present a baseline from which further research should be considered. It is hoped that such contributions will help to better guide research towards boosting the resilience of food and environmental systems for sustainable development.

This study is organized thus: In section 1, we introduce the research topic and gave an overview of the CC Impact research in Nigeria. Next, we explain the methodology and criteria for study inclusion and exclusion. Section 3 reports the results: the trend of publications, the geographical distribution of research, most published theme/categories, analysis of selected documents, methods employed for CC research, adaptation strategies, and constraints reported. Section 4 discusses the underlying trends, what the methodology mostly employed implies, and implications for projected threats. We also reflect on the local impacts and discuss the adaptation strategies, their effectiveness, and implications on sustainable development.

2. Methodology

2.1. Study design

A mixed methods research design (Robson and McCartan, 2016) was used in this study. This included a literature search, systematic and bibliographic review of literature, literature assessment, and analysis of secondary data from published studies on CC impacts in Nigeria.

2.2. Literature search methodology

An electronic literature search was conducted using ISI Web of Science, Scopus, and Google Scholar databases. To establish the state of knowledge on the impacts of CC in Nigeria, a systematic review of the literature was conducted. This was with reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) procedures (Moher et al., 2009).

The search period was set to 1960–2019 in an attempt to capture all possible articles (book chapters, encyclopedia, conference abstracts, and info, likewise editorials were not included). To identify the trend, distribution, and focus of published studies, a literature assessment was conducted. This was then used in data categorization and analysis of relevant studies obtained during the study period.

The terms "climate change AND Nigeria", "global warming AND Nigeria", were used to obtain primary publications from the search databases between January 1960 and December 2019. The literature search was conducted in "Topics" for ISI Web of Science and in "Article title, Abstract, and Keywords" for the Scopus database; set at "All years" with no language restriction.

Scopus database search revealed 1132 items, while the ISI Web of Science database revealed 592 items. Additional search from Google Scholar revealed 1371 items. A step-by-step overview of the procedure followed for data search and collection is presented in Figure 1.

2.3. Eligibility criteria

For a study to be included as relevant, it was expected that the report would have examined the effects or impacts of CC. Such studies could be in any part of the country, regardless of the study characteristics. Studies considered for inclusion were required to address a specific impact posed by CC within and across all sectors in Nigeria. For a study to be excluded, there were absence of a concrete connection to CC or "No connection with climate change". Another reason for study exclusion was having a "false positive" result. This criterion included studies conducted on CC that did not have any connection to impacts of CC. Such excluded studies focussed solely on the general subject of CC. Studies found in other sources such as; books, book chapters, conference abstracts and info, as well as editorials, classified here as "Others", were also excluded from this study. Table 1 showed an overview of the criteria for study exclusion.

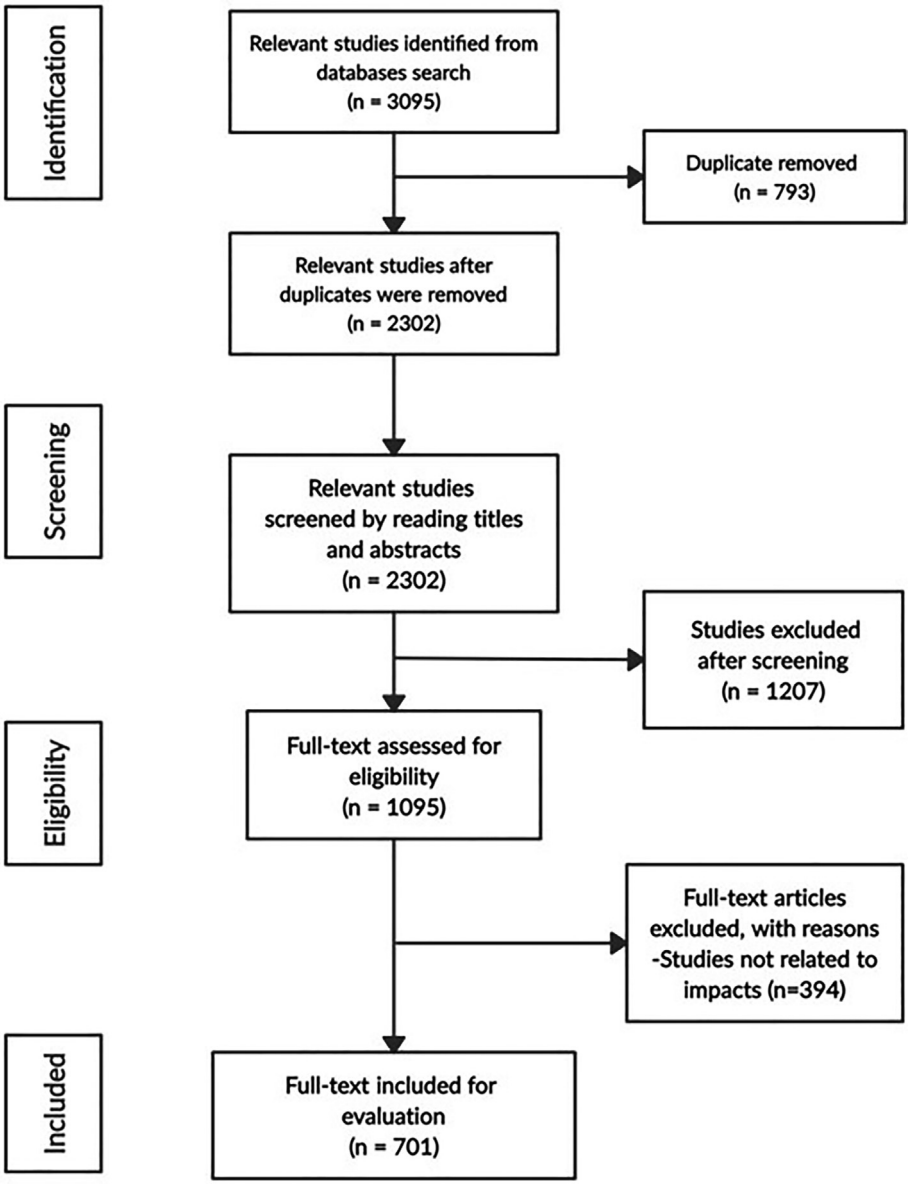

Figure 1. A step-by-step overview of the procedure followed for data search and collection.

Table 1. Overview of criteria for inclusion and exclusion of studies.

Criteria for inclusion	Criteria for exclusion
Studies specific to climate change impact	No connection with climate change
Impact focus on agriculture, environment, or human	False positive result
Studies conducted in any part of Nigeria	Studies conducted in other countries
Studies published in English Language Studies published not later than 2019	Others

2.4. Study selection

Study selection was conducted after duplicate reference items (793) were removed. Manual screening was then conducted for the remaining 2302 reference items by reading the titles and abstracts alone or after full-text assessment. After screening and full text assessment, reference items that did not meet the study inclusion eligibility requirements (1207 items) were rejected. Any discordance on the eligibility of studies was resolved by an external expert. Full-text copies of studies that met the eligibility criteria (701 reference items) were then assessed accordingly.

2.5. Data collection and categorization

Relevant articles used were original research and review articles. Only original articles were considered for analysis of research efforts from states and regions. Four (4) CC impact research categories were defined in this study; Agriculture, Environment, Human, and Multi.

"Agriculture" category included studies of impacts of CC on animal and crop production. The "Environment" category comprised studies of impacts of CC on land and resources, water, and resources, built environment, etc. "Human" category included impacts of CC resulting to human disease, migration, conflicts, poverty, etc. Relevant studies were independently extracted and categorized accordingly. The detailed

description of data according to category of study, research method, and impact reported can be found in the supplementary material.

2.6. Data analysis

Data collected was subjected to descriptive analysis using RStudio (version 3.5.2) open software, Microsoft Excel (2016), and ArcGIS 10.3.1. Quantitative data collected from the search databases were processed in Microsoft Excel (2016). This also involved manual data entry into the spreadsheet and data graphing accordingly. Analyses of most published research categories and distribution of research effort across the country were done using ArcGIS 10.3.1. For mapping of spatial distribution and most published research categories, values from each State were categorized. The values were entered for the different States and marked with different colours based on the categories. Administrative boundary of Nigeria was obtained from IGISMAP (www.igismap.com).

3. Results

This section presents the results of the trend of publications, the geographical distribution of research, most published themes/categories, analysis of selected documents, methods employed for CC research, adaptation strategies, and constraints reported. The results below clearly indicated that CC has impacted agriculture, the environment, and humans. Vulnerable areas particularly the Northern regions of the country lacked adequate research efforts relative to understanding CC impacts. Further details are presented in the sections below.

3.1. Trend of publications on CC impacts research in Nigeria

The first publication obtained on CC impact during this study was in 1962 and was a multi-location study. However, no publication was obtained from 1963 to 1993 (Figure 2). In 1994, only four studies on CC impact (reviews) were found, which stood as the highest number of publications until the early 2000s. The number of publications increased significantly from 2011 (68 studies) to a peak of 84 publications in 2014. This was a period that marked tremendous CC impact research in Nigeria, as observed in this study.

3.2. Spatial variation of CC impact research publications in Nigeria

Generally, the number of research publications on CC impact in different states increased from the Northern to the Southern region of Nigeria, with greater numbers found in the South-Western part. The least number of published studies (0–5) were obtained in 14 States. Of these States, the majority were from the North with 10 States, one each from the South-East (Ebonyi) and South-South, and two from the Middle belt (Figure 3).

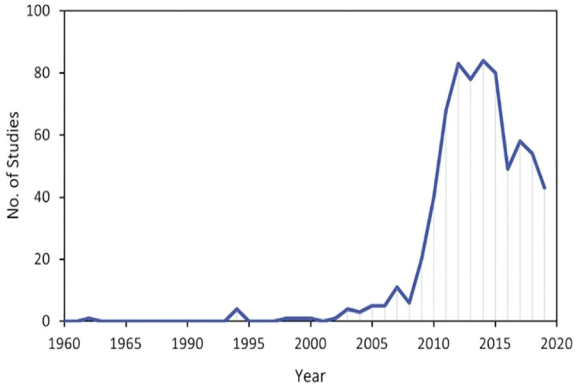

Figure 2. Trend of relevant publications on CC impacts in Nigeria from 1965 to 2019.

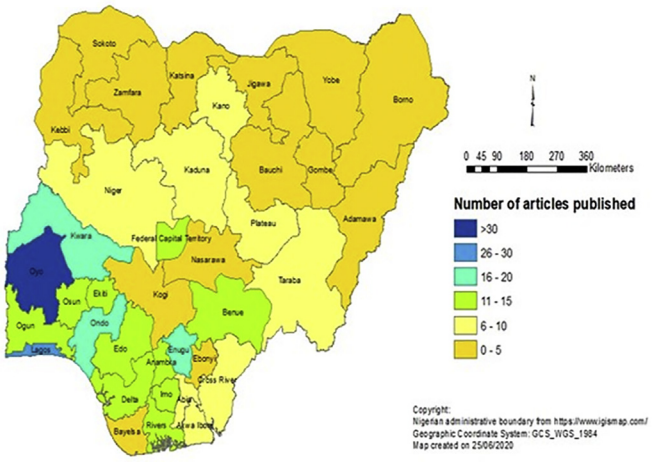

Figure 3. Distribution of research publications (original articles) on CC impacts in the 36 States and the FCT from 1962 to 2019.

Studies on CC impact in agriculture were the highest published research category in 23 States, including the Federal Capital Territory (FCT). This was followed by studies on more than one category, which was the highest published research category in 8 States (Figure 4).

Also, 6 states had the Environment category with the highest publication. Articles on agriculture were the most published research category in Zamfara State, although this was the only publication obtained for the State. Agriculture was also the most published research category in all the South-Western States except for Lagos and Ogun States, which focused more on the environmental aspect of CC impact.

In Lagos, 18 out of 25 studies (72%) were on the aspect of environmental impact. Similarly, in Ogun State, 8 out of 13 (62%) were on the aspect of environmental impact. Further, 4 out of 7 (57%) studies in Plateau State were on the aspect of the environmental impact of CC. In Enugu State, 16 out of 19 (84%) were studies on the impact of CC on agriculture. Furthermore, 5 out of 11 (45%) were obtained in Anambra State, 11 out of 19 (58%) studies were obtained in Kwara State, and 6 out of 11 (55%) studies in Rivers State. 4 studies out of 6 (67%) were obtained in Niger State, and 10 out of 11 (91%) in Ekiti State were on the impacts of CC on agriculture. Summary of results obtained based on the number of original studies on CC impact and most published categories are presented in Table 2.

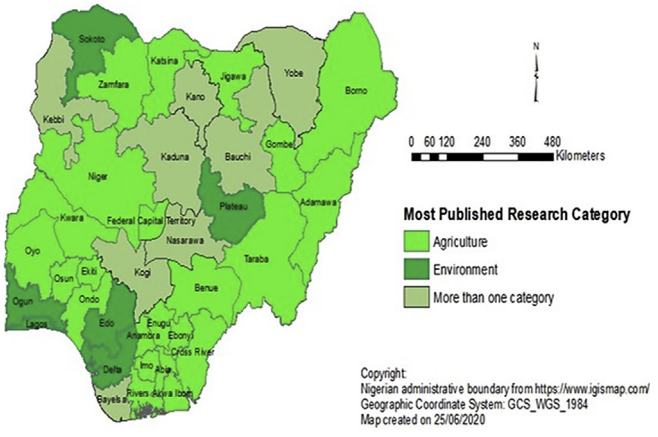

Figure 4. Most published research categories on CC impacts in Nigeria (1962–2019).

Table 2. Summary of original research obtained for studies published in Nigeria (1962–2019).

Location of study area	Agriculture	Environment	Human	Multi	Total
Abia	4	1	-	1	6
Adamawa	4	1	-	-	5
Akwa ibom	5	3	2	-	10
Anambra	5	4	2	-	11
Bauchi	1	1	1	-	3
Bayelsa	1	-	1	-	2
Benue	7	3	1	-	11
Borno	2	-	1	-	3
Cross River	5	2	2	-	9
Delta	5	6	-	-	11
Ebonyi	3	2	-	-	5
Edo	4	6	1	-	11
Ekiti	10	1	-	-	11
Enugu	16	1	2	-	19
Gombe	2	1	-	-	3
Imo	7	3	-	2	12
Jigawa	2	-	-	-	2
Kaduna	2	1	2	1	6
Kano	1	3	3	1	8
Katsina	2	1	1	-	4
Kebbi	1	1	-	-	2
Kogi	2	2	1	-	5
Kwara	11	4	4	-	19
Lagos	6	18	1	-	25
Nassarawa	1	1	-	1	3
Niger	4	2	-	-	6
Ogun	4	8	1	-	13
Ondo	10	5	3	-	18
Osun	8	2	1	-	11
Oyo	23	8	3	-	34
Plateau	1	4	1	1	7
RIVERS	6	2	3	-	11
Sokoto	-	3	-	-	3
TARABA	5	3	1	-	9
Yobe	1	-	1	-	2
Zamfara	1	-	-	-	1
FCT	9	1	2	-	12

3.3. Number of publications by geopolitical zones

Contributions from the geopolitical zones were conducted under the CC impact research categories defined in this study. Only research articles were considered here, and review articles were excluded from the geopolitical contributions. The results indicated that the South-West geopolitical zone had the highest contribution in all categories (agriculture, environment, and human impact studies) with 34%, 33%, and 35% respectively. This is presented in Figure 5.

In the agricultural impact category, South-East and North-Central geopolitical zones had 19% each of the total research contributions. The South-South had 13%, North-East had 9%, and the least was from the North-West, with 6%.

Studies on the impacts on the environment had 21% from the South-South, 18% from the North-Central, 12% from the South-East, 10% from the North-West, and 6% from the North-East. For studies on human impacts, the results were 21% for the South-South geopolitical zone, 16% for North-Central, and 9% each for South-East, North-East, and North-West. In total, 33% of the studies were from the South-West zone, followed by the North-Central zone (18%). South-South zone had (17%), South-East (16%), and the least was from the North-East and North-West zones with 8% each.

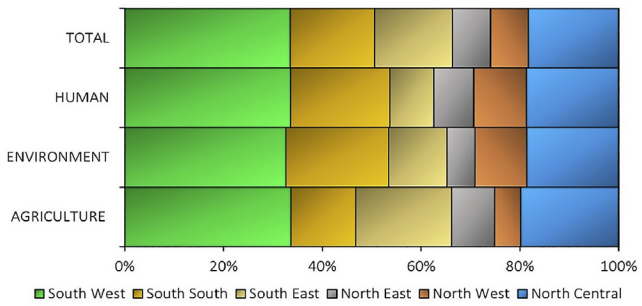

Figure 5. Contributions to CC impact research publications in Nigeria by Geopolitical zone (1962–2019).

3.4. Most published research categories and trend of publication per category

Out of the 701 articles, studies on agriculture were the highest with 355 studies (51%). This was closely followed by studies on the environment with 236 studies (34%). In the Human impact category, a total number of 79 studies (11%) were obtained. The least was in the Multi category with 31 studies (4%) as shown in Figure 6.

There was a general fluctuation of the result for the trend of studies in the four categories of CC impact research and publications in Nigeria (Figure 7).

For the Agriculture impact category, there were fluctuations in the number of studies with peak publication in 2012 (53 studies in total). This was closely followed by 50 studies (2014), then 35 studies (2015). The first study obtained for this category was in 1999. Between 2010 and 2019, 329 out of the 355 articles were published (93%) compared to studies between 1999 and 2009 (7%).

In the Environment impact category, the first study was obtained in 1962 which is also recorded as the first study obtained in this research. 209 articles (89%) were published between 2010 and 2019 while 22 articles (9%) were published between 2000 and 2009. Peak publication for the Environment impact category was 2015 with 36 studies, followed by 31 studies in 2013 and 26 studies in 2011.

In the Human impact category, the first study was obtained in 2006. Peak publication was in 2013 and 2014 (12 studies), followed by 2016 and 2017 (8 studies). Between 2000 and 2009, 4 out of the 79 articles were published (5%), while 75 articles (95%) were published between

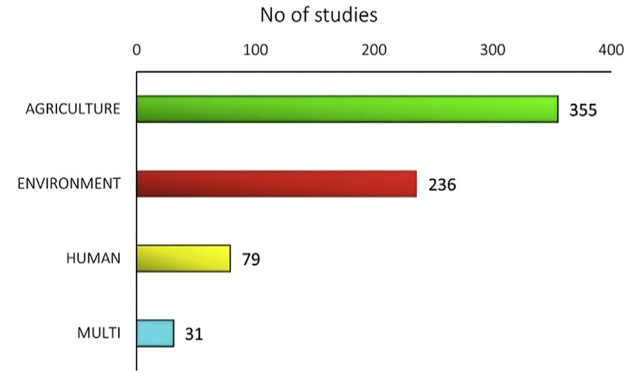

Figure 6. Number of CC impact research publications in Nigeria based on defined categories from original and review articles between 1962 and 2019.

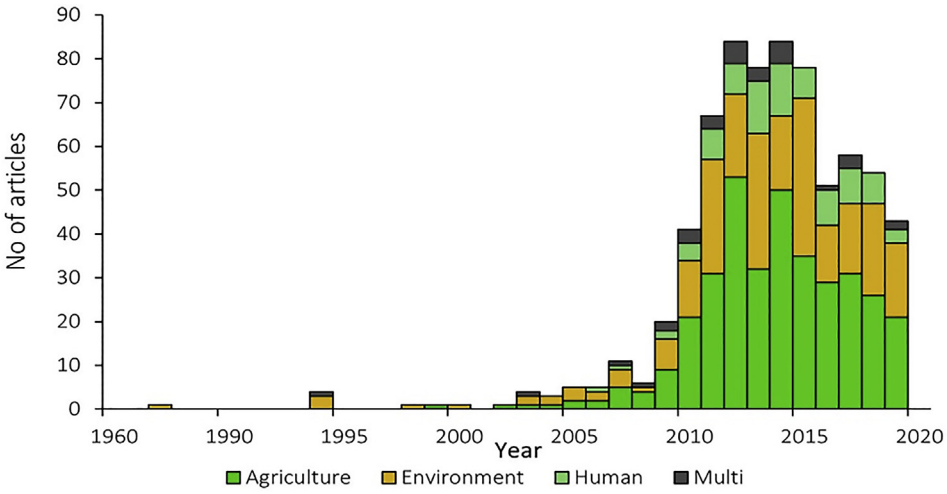

Figure 7. Trend of CC research publications in Nigeria for each defined category between 1962 and 2019.

2010 and 2019. The summary of the result obtained for review articles is presented in Figure 8.

The results showed that studies on the environment category had the highest reviews with 43 articles (39%). This was followed by reviews in the agriculture category with 36 articles (33%). Reviews in the Human impact category had 17 articles (16%), while reviews in the multi-disciplinary category were 13 (12%).

Results for studies under agriculture impact studies categories showed that 44 studies (12%) were on animal impacts, 218 Studies (61%) were on crops, while 78 studies (22%) were on both crops and animals. The remaining proportions were not available. This is presented in Figure 9.

Under the "animal impact" category, most of the studies (43%) were on impacts on aquaculture and fisheries. Studies on the impacts of CC on poultry and livestock were 9% each. Multi studies and bees made up 7% and 5% respectively.

Results for studies under "crop impact" categories indicated that maize had 14% of the studies under crops. Cassava, rice, yam, cowpea, and sorghum had 14%, 13%, 8%, 5%, and 4% respectively. Groundnut and tomato had 3% each, while millet, 'multi (more than one crop)', and 'others' were 3%, 8%, and 25% respectively (Figure 10).

Under the environmental impact category, 36% were studies on impacts on water and resources, 26% were on "Multi", 18% were on "Built environment", 11% were on "Land and resources", while 9% were on "Others". Results for the Human impact category showed that most of the studies (43%) were on impacts related to "Health and disease". Studies on "Poverty" made up 30%, while "Conflict", "Migration and settlement", and "Multi" were 8%, 6%, and 13% respectively. The results of this study also showed that CC impact on crops, animals, water and resources, built environment, land and resources were the top 5 most researched CC sub-fields respectively in Nigeria.

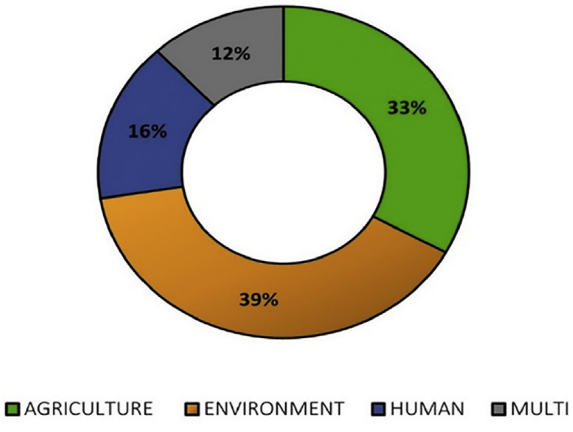

Figure 8. Summary of review articles for each of the defined categories between 1962 and 2019.

3.5. Analysis of selected documents in detail

The study further examined CC impacts reported in the included studies. The result showed that most of the researchers used interviews, focus group discussions, assessments of meteorological time series, and questionnaires.

The two studies in the livestock category, each in the North and South of Nigeria, used survey methods for data collection (details found in the supplementary). Bidoli et al. (2012) collected responses from 105 participants, while Chah et al. (2018) reported 80 participants. Their findings were however similar, with impacts on reproduction being reported by participants in each study. In addition to the reported impacts, Bidoli et al. (2012) further ranked effects with reduced feed intake as uppermost and ranked increased mortality as the least important. Other notable impacts include pests and vectors (Nwosu and Ogbu, 2011) and rearing changes (Etim et al., 2013).

For the poultry category, two of the three studies used surveys, and both found significant changes in egg production. In the other (Jeff-Agboola, 2015), an experiment was conducted by aqueous acetone and chloroform extraction method. It was found that climate change causes aflatoxin contamination through variations in location and seasons. Further significant impacts reported were reduced eggs and meat production, distribution and development of diseases (Issa et al., 2008; Adesiji et al., 2013), and heat-related losses (Liverpool-Tasie et al., 2019). Studies that focused on physiology such as impacts on metabolism (see Lee et al., 2021) and modelling in a typical commercial poultry house (see Izar-Tenorio et al., 2020), were unavailable.

In fish production, Obia et al. (2015) indicated late changes in fishing occupation. This report, however, was connected to unprecedented flooding attributed mainly to climate change. Highlights of other studies were changes in seasonality in fishing, loss of fishing input (Adewale et al., 2017), increased access/distance to fishing grounds (Ikehi et al., 2014), and low fish productivity (Adebo and Ayelari, 2011).

In agriculture, Akomolafe et al. (2018) used Autoregressive Distributed Lag (ARDL) Bound test approach to co-integrate and analyse the effects of climate change on agricultural productivity. The study projected an outbreak of heat-related diseases and water stress due to

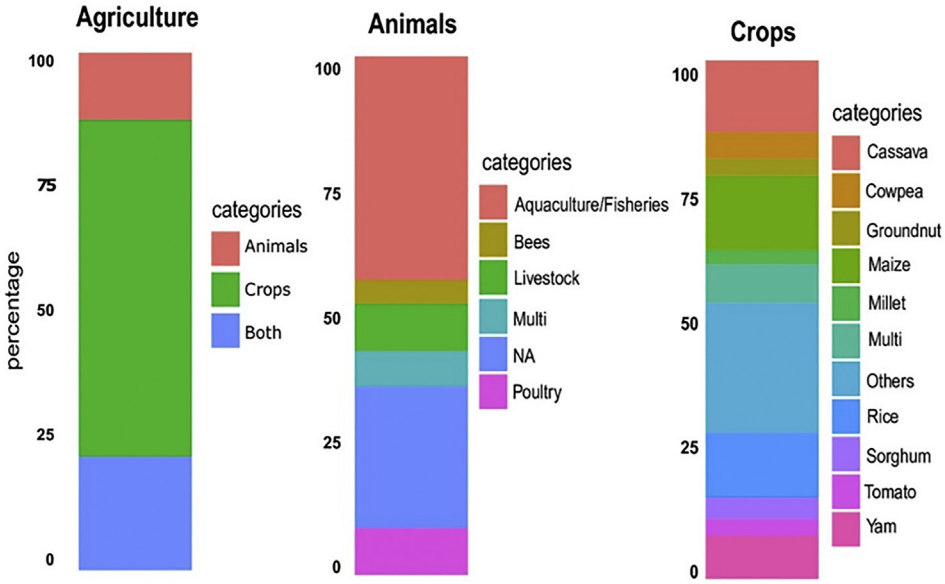

Figure 9. Summary of CC impact publications (1962–2019) in the agriculture category.

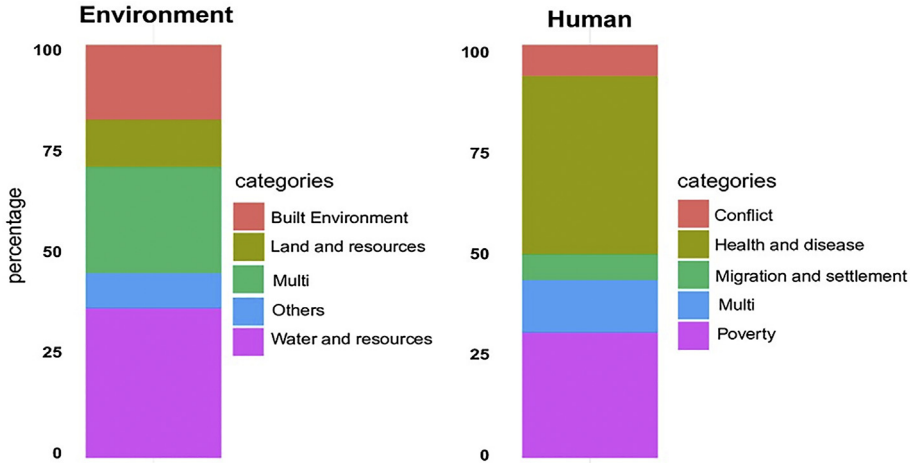

Figure 10. Summary of CC impact publications (1962–2019) in environment and human impact categories.

increased temperature. Given the predicted early cessation of rainfall, planting seasons were reported to be short; a situation that could lead to the possibility of food scarcity.

In maize production, a significant impact was observed to reduce maize productivity (Obasi and Uwanekwu, 2015). Delayed onset of rainfall and unpredictable dry spells after planting, as well as early cessation, have also reduced maize yield (Edem et al., 2016). Further, Craufurd and Wheeler (2009) reported late initiation of tassel due to an increase in temperature and temperature variability in maize and sorghum.

In cowpea, Oyerinde et al. (2013) observed that the population of insects associated with cowpea production increased on the field in a cropping season in response to changing climate. For rice, Ayinde et al. (2013) reported that a 1% increase in humidity reduced rice production by 17%, while a 1% increase in minimum temperature increased production by 52.3%. In cassava production, the number of roots, plant height, and fresh root yields varied among the seasons in response to climate change (Eke-Okoro et al., 2009).

For cocoa, Lawal and Omonona (2014) reported a decrease in yield due to excessive rainfall. However, some physiological processes for pod production in cocoa improved as relative humidity and temperature increased. These studies were mostly conducted through surveys or modelling exercises. The general findings revealed that reduced cocoa yield and increased incidence of black pod disease were the most reported impact, while other impact domains were directly connected to rainfall distribution patterns relative to climate change. Other studies revealed a reduction in the yield of fluted pumpkin (Ifeanyi-Obi et al., 2012) and oil palm (Okoro et al., 2017). In another study, Ezihe et al. (2017) reported that a 1% increase in temperature would significantly decrease groundnut output in the long run.

Under the environment category, there were cases of desert encroachment, loss of wetlands, loss of biota resources, and rapid reduction in the amount of surface water (Ebele and Emodi, 2016; Akande et al., 2017; Abdulkadir 2017). Other forms of impacts on the environment reported were; effects on infrastructures (Adegoke and Sojobi, 2015), built environment (Ede et al., 2013; Ezeabasili and Okonkwo, 2013), flooding (Adeoye et al., 2009), coastal erosion and vegetation change (Akinro et al., 2008). Climate change also resulted in freshwater scarcity (Audu et al., 2013) and affected rural water supply (Adebo and Sekumade, 2013), as well as soil degradation in the country (Usman et al., 2013).

Studies under the 'Human' impact category showed that some parts of the Nigerian population have been impacted in the form of forced

migration, and conflicts (Dillon et al., 2011; Abbas, 2017). Specifically, conflicts encountered were connected to the Fulani herdsmen and host communities (Folami and Akoko, 2010). The summary of the contents is presented in Table 3. Detailed analysis of selected documents is available as a supplementary article of this study.

3.6. Methods employed for CC impact research in Nigeria

The study found that different research methods have been applied by authors to investigate the impacts of CC across the different categories. The results revealed that authors are highly motivated to implement survey methods than experimental and modelling research methods. A total of 20% applied secondary data and only 4% applied experiments (both laboratory and field) as shown in Table 4.

Study results further showed that secondary data were majorly sourced from government agencies and meteorological stations. The majority of studies that employed meteorological data were for periods of more than 20 years (e.g., Enete 2014; Nwaiwu et al., 2014; Akinbile et al., 2015; Mijinyawa and Akpenpuun, 2015; Nwagbara and Ibe, 2015; Obasi and Uwanekwu, 2015; Oluwole, 2015; Edem et al., 2016; Olayide and Tetteh, 2017; Adeagbo et al., 2019). A few studies employed meteorological data for 10–19 years (e.g., Ayinde et al., 2011; Ibitoye and Shaibu, 2014; Zakari et al., 2014); and less than 10 years (e.g., Ayinde et al., 2013; Olabiyi et al., 2017). Studies that employed climate variable data were similar in one way or the other except Ayanlade et al. (2017). The study used ethnographic analysis, Rainfall Anomaly Index analysis, Cumulative Departure Index analysis, and correlation analysis to compare perceived impacts from farmers with meteorological data.

3.7. Adaptation strategies and constraints

Further analysis of included studies was conducted on adaptation strategies and associated constraints. The results show that many socio-economic, institutional, and geographic constraints limited adaptation capacity. Adaptation strategies mostly employed by fish farmers include; seeking early warning information, saving for the future, alternative businesses, and avoidance of areas susceptible to flooding (Arimi, 2014; Adewale et al., 2017). However, Magawata and Ipinjolu (2013) recognized that mitigation measures in fisheries are limited and called for proper integration of fisheries and aquaculture into the national policy.

Table 4. Summary of research methods employed in the included studies.

Research method	Number of studies applied
Surveys	352
Modelling	64
Secondary data	122
Experiments	26
Mixed method	36

Other than the above, destocking, use of nutrient-dense diets, improved management practices, use of shade, use of drinking water, and water immersion/sprinkling was used in livestock production. Such strategies not only help in reducing certain environmental constraints but also improved physiological adaptation (Esiobu and Onubuogu, 2014; Smiles et al., 2018). In poultry production, adaptation strategies employed include; stocking of local breeds, use of low energy bulbs, as well as air and water ventilation (Liverpool-Tasie et al., 2019).

Other forms of adaptation strategies observed in this research were insurance, soil fertility improvement measures, mulching, use of improved varieties of crops, and change in planting/harvesting dates. Farmers also engaged in diversification, use of cover crops, change in planting date, and increase in farm size. Planting of cover crops, tree planting, drainage/flood barrier construction, application of agricultural chemicals, irrigation facilities, and irrigation of crops were also reported (Ifeanyi-Obi, 2016; Iheke and Agodike, 2016). Figure 11 shows the links between CC and sustainable development, while a summary of the results of adaptation/coping strategies and constraints is presented in Table 5. The detailed analysis is available as a supplementary article of this study.

4. Discussion

4.1. Trend of CC impacts research publications in Nigeria

One way of disseminating knowledge for public awareness and government actions is through scientific research and publication of findings. It is a valuable tool for the development of any nation (Khan, 2015; Okokpujie et al., 2018). On a global scale, academic research at varying degrees has tremendously contributed towards better policies, strategies, performance, and current innovations (Hassan and Muazzam, 2013; Merigó and González, 2018).

Table 3. Summary of CC impacts in animal, crop, environment, and human subcategories.

Animal impact	Crop impact	Environment impact	Human impact
Increased parasitic incidence	Improved pod physiology	Declined vegetation cover	Migration burden of women
Flooding of fish farm	Increased pest incidence	Changes in soil properties	Reduced women productivity in farming
Reduced meat yield	Increased disease incidence	Increased transport fare	Decline in occupational activities
Shift in migration	Seedlings dry up	Gully erosion	Increased malaria incidence
Reduced birth frequency	Decreased root length	Reduced number of rain days	Reduced household income
Increased abortion	Decreased soil fertility	Decreased house rent	Destabilization of settlement
Low fish yield	Poor yield	Groundwater overdraft	Heat rashes
Reduced feed intake	Poor weed control	Heat stress	Increased fever
Increased disease distribution	Shortage of varieties	Flooding	Increased cholera incidence
Increased disease condition	Reduced grain availability	Drought	Induced occupational stress
Rivers and streams dry off	Poor germination	Soil salinization	High probability of hypertension
Disruption of heat period	Crop destruction	Sea level rise	Increased thermal sensation
Reduced egg yield	Crop withering	Reduced aesthetic quality	Increased catarrh among children
Reduced birth rate	Increased decay of plant materials	Road inaccessibility	Forced migration of residents
Reduced growth rate	Declined forest resources	Desertification	Reduced household health status
Changes in spawning time	Increased storage loss	Shorter harmattan period	Increased skin infection among children
Decreased juvenile availability	Poor growth rate	Migration of wildlife	Conflicts with herdsmen
	Ineffectiveness of agro-chemicals		Increased common cold
	Increased weed population		

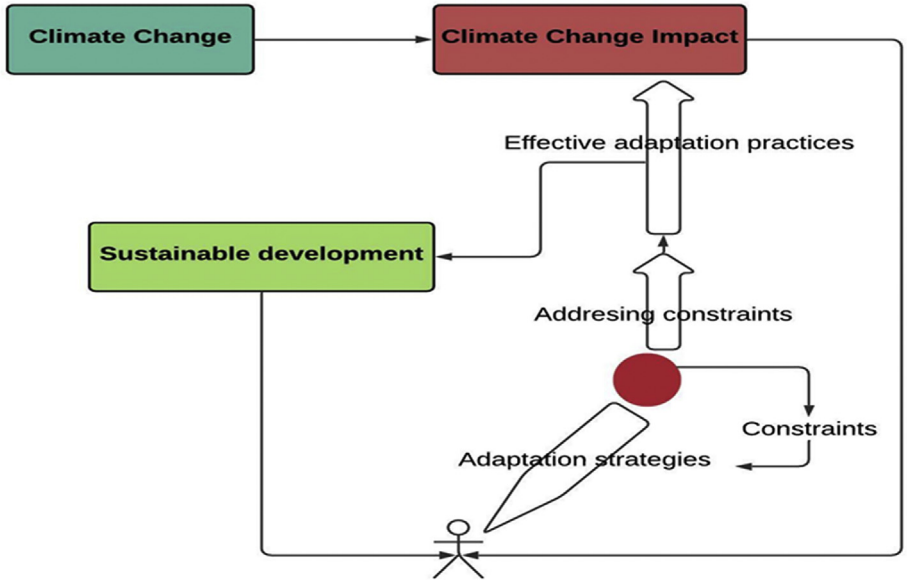

Figure 11. Conceptual diagram showing links between CC and sustainable development through effective adaptation by addressing the identified constraints (After Bizikova et al., 2007).

Research and publications, being a significant source of key information for development do not only stand as a base for understanding CC impacts in context but are also applicable for future efforts and directions. Understanding trends in research is vital as it provides the basis for future orientation based on past and present efforts. Hence, the trend of research and publications in our study reflects academic institutional efforts geared towards the subject of discussion in Nigeria. However, our results may be subject to a number of factors that could influence why more, or fewer efforts are being directed towards research in CC impacts in Nigeria. Such factors include, but are not limited to, researchers' interest and motivation, availability of grants and funding, and institutional platform (Zain et al., 2011; Ghabban et al., 2019). These factors have been shown to impact scholarly publishing. Besides, the presence and number of the research institution(s) in a State, as well as the researchers in the subject field, also influence research and publication outcomes as outlined by Carayol and Matt (2004).

The beginning of climate research and its impacts in Nigeria differs from those of other countries. It has been reported that late onsets of rains occurred in only a few areas between 1941 and 1970 (Haider, 2019). Temperatures were significantly higher than normal since the 1980s, with relatively higher figures in 1973, 1987, and 1998 (Enete, 2014; Federal Ministry of Environment, 2014). Further report of Haider (2019) indicated that late onsets of rains spread to most parts of the country from 1971 to 2000. This was in line with the results of our study where an extremely limited study on actual impacts was conducted. As impacts of CC were not pronounced, the interests of researchers might have been low. Besides, 1980 has been reported as the time when CC emerged as a new research field (Haunschild et al., 2016). Between 2000 and 2017 however, several studies reported that Nigeria experienced climate extremes during this period (Federal Government of Nigeria, 2013; Akande et al., 2017; Amanchukwu et al., 2015; Urama et al., 2019; Anabaraonye et al., 2019).

Within this period, our observed trend follows the global trend and corresponds with the increased number of publications. The literature growth during this period also agrees with the report of Grieneisen and Zhang (2011), where the number of publications on CC tremendously increased. The tremendous growth of CC literature within the period (similarly reported on a global scale), is possibly induced by the increasing influence of the IPCC Assessment Reports, which ultimately made CC research a hot topic. These reports revealed a strong need for

Table 5. Summary of adaptation constraints reported across the categories.

All categories	Crop production	Animal production	Environment
Poor government involvement	Lack of disease/pest resistant cultivars	Poor government involvement	Poor monetary support from government
Non-existence of cooperative societies	Limited availability of improved planting resources	Lack of access to supporting institutional facilities	Poor road network
Traditional belief/norm/practice/culture	Far distance of fertile farmlands from residence	Religious belief	
Lack of mechanized faring equipment	Practice of inheritance system of land ownership	Insufficient credit facilities	
Lack of access to weather forecast technologies	Inadequate extension services		
Insufficient storage facilities	High cost of irrigation facilities		
High cost of production resources	High cost of planting materials		
Poor communication between farmers and extension workers	Ineffectiveness of existing cooperatives		
High cost of transportation			
Low income of farmers			
Poor knowledge			

further research to ensure a better insight into the climate system and future impacts (Haunschild et al., 2016).

On a global scale, our results did not compare with the growth rate of CC impact publications. Between 1980 – 2012, over 30,000 papers were published (0.01% from Nigeria). Similarly, our results did not compare with the growth rate of the overall CC science, which is extremely high (Bornmann and Mutz, 2015; Haunschild et al., 2016). The total number of publications in Nigeria was exceptionally low compared to those obtained in the United States, UK, and China, etc. on the overall CC science. These countries have a long history of climate research, showed great interest, and have invested hugely in CC research. For instance, CC research is quantitatively dominated by the USA, followed by the UK. Also, between 2001 and 2005, over 2.5 billion RMB was invested in CC research in China through various technology development programs (Li et al., 2011; Haunschild et al., 2016). This has comparatively put Nigeria on a lower cadre in relations to investments, findings, and preparedness towards future trends. Thus, the recent decline in research and publications could be alarming in comparison with how adequate the country is prepared for future impacts. This study also observed that the recent declines (particularly in the last ten years) were not connected with adequate research findings, programmes, and implemented strategies to mitigate future occurrences. The result, however, may be connected to personal and institutional factors earlier highlighted, which might significantly impact scientific publications.

It is well known that research and publication objectives are not a direct representation of demand-driven efforts to tackle specific issues. Nevertheless, they are vital as most players and stakeholders required to combat the issue of CC impacts are in the academia. Therefore, there is a need to intensify research in this direction, particularly in regions highly prone to impacts. This will adequately complement the national CC policy response and strategy. To achieve this, considerations should be taken on the factors earlier highlighted for more effectiveness.

4.2. CC impacts publications and contributions between states in Nigeria

There is no doubt that the variation in our results could be a function of the availability of research institutions, the population size of researchers, and other factors which do stimulate and influence research culture (Tang et al., 2016). Our research confirmed that the years of institutional existence in the various States had a positive impact on the results of this study. For instance, more studies were obtained from relatively older institutions (e.g., the University of Ibadan, established in 1948) compared to the newly established ones.

In the Northern states, publications were relatively lower compared to the southern states. The result could probably be due to the higher number of academic institutions in the southern states (particularly the South-Western states). This would relatively mean more human resources, access to research facilities, and fundings.

4.3. CC impact publications and contributions between geopolitical zones in Nigeria

CC impact research, which is among the top 5 most researched CC subfields, is of high relevance and requires good attention, particularly in vulnerable regions (Haunschild et al., 2016). Consequently, the relatively low level of research in the Northern part of the country could be alarming. In particular, the least research effort among the geopolitical zones was the North-East zone. This zone is already identified as a “hot spot” of CC impacts (Diffenbaugh and Giorgi, 2012; Abdussalam, 2015). As earlier highlighted, most parts of the Northern states have already experienced significant impacts of CC (Federal Ministry of Environment, 2014; Madu, 2016) and studies have indicated that the region (particularly, the North-East and the North-West) are the most vulnerable (Busby et al., 2014; Haider, 2019). Therefore, these regions would require more attention and research investments to mitigate the likelihood of projected threats and vulnerability of livelihoods.

Factors earlier outlined for the Northern part explains why some parts of the Southern region had relatively sparse research in this study. However, this does not exempt the vulnerability of the region. Studies have shown that the South-East and South-West region are also vulnerable, although relatively less vulnerable compared to other regions of the country (Haider, 2019; Merem et al., 2019). Comparatively, the South-South region remains the most vulnerable within Southern Nigeria (Sayne, 2011; Federal Ministry of Environment, 2014; Matemilola et al., 2019). The Niger Delta region had been faced with myriads of environmental issues resulting from oil exploration activities (Ite et al., 2013; Nwaichi et al., 2016). Thus, the current level of scientific research and publications in the entire Southern region does not reflect the required inputs for adaptation and mitigation strategies.

Moreover, the most significant CC impact identified in this study varied across the geopolitical zones. In the South-West, the most significant CC impact was coastal inundation, reduced crop yield, increased flooding, increased incidence of pests and diseases, and damage to building infrastructure. In the South-East, the most significant CC impacts were increased flooding, widespread erosion, low crop yield, and high incidence of pests and diseases. The South-South geopolitical region also experienced increased flooding, reduced crop yield, increased pests and diseases, and coastal inundation as the predominant impacts.

In the North-West, the most significant CC impacts were drought and water shortages, a decline in vegetation cover, decreased soil fertility, increased thermal sensation, and change in soil properties. There were limited studies across the North-East zone. However, significant among the impacts were low crop yield, increased thermal sensation, and forced migration. In the North-Central zone, low crop yield, drought, and increased thermal sensation were identified as prevalent.

4.4. Most published categories across states and regions

This study has observed that CC has adversely and diversely affected different sectors of the Nigerian society (notably agriculture, environment, and in some cases human). High attention on climate impacts on the agricultural sector could possibly be connected to its importance in sustaining livelihoods in the country. The sector affected determines the focus of impacts and this varies across states and regions, depending on the perceived sector of high vulnerability by researchers. From this study, the focus from the Northern and middle belt regions were on the impacts of CC on agriculture. This could be quite understandable as studies have shown that over 70% of the nation's population is directly involved in agricultural activities as their primary means of livelihood (Shiru et al., 2019; Onwutuebe, 2019). Moreover, agriculture in the Northern and middle belt regions is highly susceptible, due to the predominance of rain-nourished agriculture as demonstrated by Atedhor (2015). This observation, in addition to the substantial number of agricultural activities in the North, explained why most research and publications focused on this sector. Few notable exceptions in the North were Plateau and Sokoto states, which published more on the environmental aspect. This could be connected to high industrial activities and related environmental susceptibility of the states.

In the Southern region, notably Lagos, Edo, and Ogun states, industrial activities in these states could be a driving force for researchers. According to Shiru et al. 2019, rapid population growth, and its commercial hub has caused insurmountable environmental challenges, including CC impacts on the built environment (Ede et al., 2013). Other than these states, agriculture and other cottage activities form a major part of activities engaged by the population. In Oyo state, for example, agriculture has been described as the major occupation in most parts of the State (Fasasi, 2007; Adebayo and Adeola, 2008). Hence, it was not surprising why research and publications tend to focus on this direction as impacts would relatively affect livelihoods more through agriculture. Similar motivations may be the drive of other states which were more inclined towards impacts on agriculture.

The top 5 most researched CC sub-fields in Nigeria are CC impact on crops, followed by impacts on animals, water and resources, built environment, and then land and resources. Multiple stressors on plants have increased as a result of climatic variability and environmental extremes. This has greatly affected crop production directly or indirectly in a number of ways. Direct impacts include morphological, physiological, and phenotypic changes, as well as plant productivity. Indirect impacts include soil fertility, drought, flood, heat, pests, and irrigation availability (Thornton et al., 2014). Water deficit and temperature extremes also influence the reproductive phase of plant growth. It was discovered that CC suppressed crop development, resulted in crop withering during heatwave episodes, and decreased productivity (Enete, 2014; Eludoyin et al., 2017). Ezihe et al. (2017) which had a significant effect on crop output, while Iloh et al. (2014) indicated decreased germination rate and root length of plantlets.

It is obvious that CC has negatively impacted the health and welfare of animals in Nigeria. A significant number of studies has previously shown that the projected CC will continue with negative effects on poultry, livestock, and aquatic species in Nigeria. These effects are suggested to be both direct and indirect on animals' health and welfare. As highlighted in Lacetera (2019), the primary direct effects may be due to increased temperatures and frequency and intensity of heatwaves, resulting in heat stress. Consequently, heat stress affects the health of animals by disrupting metabolism, generating oxidative stress, and suppressing the immune system, resulting in diseases and death. The indirect effects are mostly related to the quantity and quality of drinking water and feedstuffs, the distribution of pathogens and/or their vectors and their survival.

As earlier highlighted, CC can directly result in metabolic disorders and immune suppression. In order to avoid increased body temperature, homeothermic animals increase heat loss and reduce heat production in response to high temperatures. Such responses contribute to increased metabolic activities, decreased feed intake and subsequent metabolic disorders in heat-stressed animals. The function of the immune system may also be suppressed or impaired when animals are heat-stressed. Immune suppression exposes animals to infections, which reduces reproductive and production efficiency (Belhadj Slimen et al., 2016). Bidoli et al. (2012) and Chah et al. (2018) indicated that CC reduced growth rate, increased incidence of parasites, reduced feed intake, reduced birth rate, and increased mortality rate of animals.

CC impacts on water and resources were the third most researched CC sub-fields in Nigeria. The key CC impacts on water and resources were alterations in precipitation patterns, increases in the frequency of flooding and droughts, and increases in temperature (Lacetera 2019). As in animals, the impacts vary widely depending on the region in Nigeria. In higher temperatures, the hydrological cycle is intensified. The characteristics and severity of these impacts varied from region to region. For example, water shortages were observed in different areas across the country (Oloruntade et al., 2017; Shiru et al., 2019). When this is combined with rising demand, the number of people at risk of water scarcity is likely to increase. CC also have significant impacts on seasonal variations in groundwater levels (Ashaolu, 2015). Moreover, climate variation has also resulted in a significant impact on water yields in surface reservoirs. As a result, water availability becomes challenging. As CC increases the intensity and frequency of rainfall, there has been an increase in the incidence of flooding, increased water temperature, and coastal inundation which affects coastal aquatic life. In some regions, groundwater recharge has been affected by a decline in the availability of groundwater for drinking water.

The fourth most researched CC sub-field in Nigeria is CC impact on the built environment. Studies show that CC has not only had a significant impact on natural resources but also on human settlement and infrastructures. The reported effects of CC on the built environment included increasing thermal discomfort, flooding/urban drainage, and damage to infrastructures. In the future, buildings with reduced carbon dioxide emissions, improved ventilation, and those that provide a high-quality indoor environment, are imperative towards a sustainable built environment (Celadyn, 2018; Sojobi and Zayed, 2021). In addition, weather data is also required to evaluate how water delivery systems and urban drainage would function in future (Ezeabasili and Okonkwo, 2013).

Moreover, CC impact on land and resources completed the top 5 most researched CC sub-fields in Nigeria. In the forest zones, CC strongly influences species composition, frequency, the magnitude of disturbances, and forest productivity. The effects are mostly observed in the form of a decrease in diversity and forest productivity such as vegetation cover (Ammer, 2019). In addition to the direct impact of CC on diversity and vegetation, the frequency and intensity of forest disturbances are also influenced by CC. Hence, timber production, species composition, carbon storage, and water yield are all affected (Backlund et al., 2008). In Nigeria, Jibrilah et al. (2019) reported a gradual but persistent decline in vegetation cover driven by changing climatic conditions. Although the study employed modelling techniques, it suggests how CC would drive changes in land cover, associated resources, and soil/soil properties as reported by Usman et al. (2013).

4.5. Methods employed for CC impact research in Nigeria

Methods employed for CC impact research could influence the outcome. In line with Maharjan and Maharjan, (2018), our study has shown that various research methods, tools, and models have been utilized for CC impact studies in Nigeria. The criteria for such selections however depend largely on the research contexts. In agreement with Maharjan and Maharjan, (2018), each research method has its own unique implications for climate impact research, whether utilized singly or in combination. For instance, a report by Hinkel and Bisaro (2015) showed that multiple research methods are associated with complexities and complications. However, such complexities seem complicated and challenging to compare and exchange arguments from findings (Maharjan and Maharjan, 2018).

With the current global issue of CC, both qualitative and quantitative data have formed the centre of CC research. This includes CC impact studies over the years. Some researchers (Näslund, 2002; Petticrew et al., 2008) have argued that quantitative research is better and more scientific compared with qualitative research. However, other researchers are of the opinion that both methodologies are the same and neither is better than the other (Dawson, 2009). For studies that assess CC impacts, the reliance on data collection on "perceptions from respondents" could be limited to respondents' level of knowledge and awareness. As obtained in this study, this may present low validity and reliability. Due to the peculiarity of this area of research, surveys may not present a real-life scenario, mechanism, or processes associated with CC impacts. The same scenario could apply for methods such as; the use of secondary data, co-integration, and error correction model, given the country's poor investment in data generation (Ohiri et al., 2016). This calls for a need for more empirical data to allow for a clear distinction between the perceptions and realities of CC impacts (Fagariba et al., 2018).

Methods such as field experiments have been employed to complement model projections of future impacts. Notably, challenges associated with these assessments include the means by which such effects could be detected. In reality, they are hampered by multiple, often interconnected non-climatic forces that simultaneously interfere with the systems. An attempt to overcome such challenges is the use of indicator species to detect such responses, particularly, on natural systems. This allows researchers to infer a more general impact compared to the use of surveys (Ahmad et al., 2001).

Studies have also employed climatic variables to ascertain the impact relative to changes. According to Smith et al. (2001), there is a strong connection between CC and environmental responses over a span of temporal scales. Such connection requires long periods of study to allow for a more precise conclusion when compared with observed impacts. As observed in this study, the application of long study periods by authors for CC impacts was in line with the recommendation of Smith et al.

(2001). Nevertheless, long temporal studies with a larger spatial dimension in the future will make the results more vigorous.

Based on the current context in Nigeria, the combination of scientific and local knowledge would facilitate real-life understanding of experiences, risks, and adaptation strategies. In particular, such a combination could be applied to methodology and approaches that complement each other (Sterrett 2011; Devkota 2014; IUCN, 2015; Lockwood et al., 2015). Furthermore, an improvement on impact modelling such as process-oriented models is important, instead of models based only on correlations of climatic limits (Ahmad et al., 2001). This has been applied in China (Saddique et al., 2020), the United States of America (Chien et al., 2013), and other countries. On the global scale, Haunschild et al. (2016) showed that studies that employed modelling techniques for CC research ranked the second largest with over 47, 000 papers between 1980 and 2012.

4.6. Local impacts of CC in Nigeria

The nature and sensitivity of agriculture to CC impacts is well known globally (von Braun, 2020). This relates to why a lot of studies have been conducted to investigate how CC has impacted this sector including Nigeria. This study has shown that CC has already impacted agriculture in Nigeria. Taking the varied environmental vulnerability into considerations, the reported impacts vary in scale comparatively. These were similar to observations in other developing countries like Afghanistan (Omerkhil et al., 2020) and Iran (Karimi et al., 2018; Balkanlou et al., 2020); ranging from low yield to ecosystem services.

Impacts reported in this study from deforestation pose a great risk to the potential of key ecosystem services such as supply of freshwater, stability to the hydrological system, and water cycling in the country (Leal Filho et al., 2021). Chakravarty et al. (2012), showed that Nigeria has been ranked among the five countries with the biggest annual loss (−3.7%) of wooded land areas. This has implications on ecosystem services such as provision of habitats for fauna and flora, balancing of hydrological regime, and protection against weather extremes. In other countries including the Indian Himalayan, farmers have been well informed of the provisioning (financial) function of agroforestry such that they utilize it as a coping strategy. This coping strategy has allowed the farmers to benefit from various agricultural products directly and at a little cost (Pandey et al., 2017).

Besides local impacts on agriculture, CC has been shown to expose humans to disease and other health disorders. Climatic variations influence the distribution of many disease vectors such as Anopheles mosquitoes (malaria vector). It could also interact with accumulated stresses and other vulnerabilities such as immune status. Moreover, it could also directly affect the transmission and virulence of diseases. These could be connected to the increased malaria and other disease prevalence reported in the studies included. Specifically, the various diseases reported in this study are potentially important components of CC impacts. However, such impacts may not be used as practical indicators of the direct impacts of CC, as causes of human disease are multifaceted and vary constantly (Ahmad et al., 2001).

The general effects of CC across sectors could limit sustainable development in a number of ways. This is because CC and sustainable development are increasingly being recognized as being intertwined. Specifically, CC influences prospects for sustainable development, which in turn, not only determines future CC but also influences adaptive capacities and mitigation outcomes (Downing et al., 2003; Bizikova et al., 2007). Environmental destruction, biodiversity loss, and dwindling water supplies, all have a negative impact on food security, particularly in developing countries (Pachauri et al., 2014). In developing countries such as Nigeria, which depend solely on rainfall for agricultural production, the direct impacts are mainly concerned with output and income loss. This definitely draws a setback to the United Nation's sustainable development goals on poverty and hunger.

Taking adequate actions is therefore imperative for sustainable production and consumption, thus, reducing poverty and promoting health. This will also support the development of more sustainable production and environments. Again, CC governance that will deal decisively with the economic and ecological impacts of CC is imperative for sustainable development. Likewise, policies that improve on the synergy between sectoral impacts and climate governance is essential for a sustainable future (Uitto et al., 2017). CC impact in each geopolitical region and the pragmatic mitigation methods is presented in Table 6.

4.7. Impact of CC on aquaculture

Aquaculture no doubt has been impacted by CC in various ways in Nigeria. As outlined by Froehlich et al. (2018), there is a greater probability of aquaculture decline under CC. Food security could be affected by such projected declines (particularly from marine aquaculture). Despite such effects on one of the fastest-growing food sectors, relatively little effort has been committed to research on such impacts, both spatially and temporally, in aquaculture in Nigeria.

On the one hand, exposure of aquaculture systems to environmental factors puts pressure on adequate research. On the other hand, research needs to be specific for different aquaculture species due to differences in physiological functions, sensitivities, and tolerance levels. In view of this, recent research in developed and advanced countries have focused on various aquaculture species using diverse modern techniques and biotechnologies to better understand their responsibilities and coping mechanisms (Brauner et al., 2019; Loughland et al., 2021). Comparatively in Nigeria, this form of research is limited, probably due to lack of adequate equipment, unavailability of skilled research personnel, and/or funding. Therefore, it is essential that researchers in the aquaculture field in Nigeria embrace more international collaborations to advance their research and knowledge base. Research institutions may also need to develop better frameworks to encourage high-quality research funding in the country. Government should also avail funds for research institutions to acquire modern research equipment for researchers to utilize. With the current and increasing role of aquaculture in the Nigerian food production system, it is critical to gain a deeper understanding of CC effects on aquaculture. Furthermore, understanding how impact factors compare and relate to aquaculture and other food systems will be crucial to evaluate the full scope of possible future impacts.

As obtained in other developing and developed nations, CC has impacted aquaculture in Nigeria. Studies have reported considerable changes in environmental processes, resulting in changes in primary production. Obia et al. (2015) indicated late changes in fishing occupation. The changes, however, were connected to unprecedented flooding attributed mainly to climate change. Adewale et al. (2017) reported changes in seasonality in fishing, loss of fishing input, while Adebo and Ayelari (2011) and Ikehi (2015) reported low fish productivity and increased access/distance to production/fishing grounds respectively.

Although increases in precipitation-induced floods are of concern to some types of aquaculture and systems (e.g., ponds), they could be of benefit to other types (e.g., coastal). Flooding can have a number of advantages, including recharging wetlands, recharging groundwater, generating floodplains, establishing wildlife habitats, and improving fish productivity (Poff, 2002). But most often, the negative impacts override these potential benefits. Flooding can result in the introduction of predator species into culture ponds, pond water contamination, and fish escapes (Adhikari et al., 2018; Casimiro et al., 2018; Kais and Islam 2018).

In pond culture and hatcheries, flood-related mortalities are also common and may occur due to several reasons, of which low oxygen levels in floodwaters predominates (Bell et al., 2009; Idris et al., 2014). In the long run, these impacts are likely to predominate in developing countries like Nigeria, adversely affecting sector production and growth. Therefore, it has become critical to address the accompanying challenges of CC, which are likely to worsen in the future.

Table 6. CC impact in each geopolitical region and the pragmatic mitigation methods.

Geopolitical zone	State	Impact reported	Mitigation method	References (for mitigation methods)
South-West	Ondo	Effects on egg and meat production pattern, increased distribution, and development of poultry diseases.	Use of advanced techniques, such as genetic markers.	Kumar et al. (2021)
	Oyo	Reduced yield, heat stress.	Use of mesh-like structures to prevent fish escape in the case of flooding, development of mechanisms to reduce water temperature e.g., pumping freshwater to cool down the temperature in fishponds.	Adhikari et al. (2018)
	Ekiti	Poor yield, shortage of varieties, increased pest and diseases, poor germination, plant nutrient loss.	Development of improved plant varieties that are tolerant to drought, salinity, and heat stress.	Pareek et al. (2020)
	Lagos	Flooding, reduced yield, reduced income, destruction of crops.	Increased irrigation, developing robust computational modelling, protection of existing cultivated soils and soil organic matter.	Gomez-Zavaglia et al. (2020)
	Lagos	Reduced water availability and supply resulting in groundwater overdraft.	Use of collective efficacy in modelling.	Pakmehr et al. (2020)
	Oyo	Flooding resulting in damage of structures and infrastructures within the University.	Embracing effective horticulture and greening of the environment, efficient waste management.	Cirella et al. (2019)
	Ogun	All time steps (3, 6, 9, 12, and 24 months) from Standardized Precipitation Index calculation showed an increasing trend signifying excess rainfall and flooding in years to come. Periods of severe dryness also predicted for the year 2045.	Use of collective efficacy in modelling.	Pakmehr et al. (2020)
	Osun	Reduced resilience of road and drainage projects due to climate variability and the associated negative impacts.	Conservation of environment and natural resources, improving on the ideology of 'green environment'.	Tang (2019)
	Ogun	Malaria, cough, common cold, and fever relative to climate change.	Improving housing standards, community awareness on the health impact of climate change, improvement of the health system.	Tong and Ebi (2019)
	Ondo	A 1 °C increase in air and sea surface temperature resulted in a 56.4% and 15.4% increase respectively in monthly malaria occurrence in the humid forest zone of Ondo State.	Development of mathematical models for understanding geographic shifts.	Parham and Michael (2010)
South-East	Enugu	Weight loss, poor feed intake, disruption of animal heat period, miscarriage due to high temperature.	Dietary manipulation through increased green fodder, improving rumen fermentation through efficiency, proper housing, and introduction of the use of heat ameliorative measures.	Das (2018)
	Abia	The result for time trend, that showed a positively signed coefficient for temperature and negatively signed coefficient for rainfall, affected cassava output.	Development of training programmes with meteorological agencies to intimate farmers on the effect of climate on cassava production, access to credible weather information.	Mahama et al. (2020)
	Anambra	Decreased soil fertility, reduced yield, and grain quality, high incidence of pests, diseases, droughts, floods, and weeds in rice fields.	Planting date alteration and proper nutrient management.	Boonwichai et al. (2019)
	Anambra	Flooding resulting in displacement from homes, submerging of farmland, destruction of infrastructures, and overcrowding in shelter camps.	Embracing effective horticulture and greening of the environment, efficient waste management.	Cirella et al. (2019)
South-South	Delta	Low yield from fish culture.	Eco-friendly aquaculture production systems, use of tolerant species to a wide range of environmental conditions and stressors, farming of low-trophic-level species and water-smartness.	Fersoy and Jorgensen (2021)
	Akwa Ibom	Poor yield, soil erosion, increased outbreak of pests and diseases.	Development of improved plant varieties that are tolerant to drought, salinity, and diseases.	Pareek et al. (2020)
	Akwa Ibom	Increased rainfall and surface run-off leading to incessant and severe flooding situations.	Building of check dams, percolation tanks, terracing, nala bunds, and storage tanks.	Gamage et al. (2016)
	Cross River	Reduced yield. Problems encountered by cassava farmers in coping with climate change impacts relate to infrequent training on climate change pestilences, non-access to meteorological data, labour shortage, inefficient extension system and traditional land tenure system.	Improved irrigation, development of training programmes with meteorological agencies to intimate farmers on the effect of climate change.	Rayamajhee et al. (2021); Mahama et al. (2020)
	Rivers	Reduced yield and family income, weed infestations, discoloration of leaves, low maturity and increased cost of pods, stunted growth, increased pest and disease incidences, ineffectiveness of agro-chemicals, and drying up of seedlings after germination.	Use of climate smart pest management system.	Heeb et al. (2019)

(*continued on next page*)

4.8. Local adaptation strategies, effectiveness of current adaptation methods, and implications of wrong adaptations

For adaptation to be successful, it requires strategic approaches that identify measures that would be appropriate and taking the present and future needs into consideration. With the uncertainties in CC scenarios, flexible adaptation strategies are required. The differences in the adaptation measures used in this study, suggests that the inhabitants of the studied area respond to CC by employing techniques that work in their domain. Such adaptation measures may not be effective in other geographical locations. This suggests the need for more research to identify the location-specific adaptation strategies. As indicated in the

Table 6 (*continued*)

Geopolitical zone	State	Impact reported	Mitigation method	References (for mitigation methods)
North-Central	Federal Capital Territory	Rise in temperature, solar radiation, decrease rainfall and the presence of excessive nitrogen as a result of climate change is affecting agricultural production.	Adopting climate smart agriculture methods e.g., engagement in practices (food waste and lost, reducing deforestation etc.) that foster reduction of GHG emission.	Loboguerrero et al. (2019)
	Kogi	Variations in both rainfall and temperature are directly related to variations in output and yield.	Practice of conservation agriculture.	Jug et al. (2018)
	Niger	Minimum temperature had a positive effect (1% increase in minimum temperature increased production by 52.3%). Humidity had a negative effect (1% increase in humidity reduced production by 17%).	Improved irrigation.	Rayamajhee et al. (2021)
	Federal Capital Territory	Increased flooding resulting in gully erosion.	Building of check dams, terracing, nala bunds, percolation tanks and storage tanks.	Erena and Worku (2018)
	Plateau	Significant association between climatic variations and monthly malaria cases at different time lags and locations.	Stop water pollution, proper waste disposal, and improved sanitation.	Gamage et al. (2016)
North- West	Jigawa	Increased disease condition, reduced growth rate, increased incidence of parasites, reduced feed intake, reduced birth rate, increased mortality rate.	Improving animal nutrition, housing, and health.	Sejian et al. (2015)
	Kaduna	Fluctuations of yearly productivity of eggs.	Nutritional strategies (early feed restriction, electrolyte, vitamin, and mineral balance), environmental modifications (early heat conditioning, open sheds, and cooling systems), genetic markers and thermotolerance.	Nawab et al. (2018).
	Katsina	Reduced crop yields, decreased soil fertility, declined forest resources, declined water shortages.	Development of improved plant varieties that are tolerant to drought, salinity, and diseases.	Pareek et al. (2020)
	Sokoto	Significantly impact on water yields in surface reservoirs due to weather and climate variations.	Model simulation e.g., reservoir capacity yield model	Mohammed and Scholz (2017)
	Kebbi	Change in soil and soil properties (mass movement of soil particles, leaching, soil erosion, development of gullies) resulting to poor soil quality.	Soil carbon sequestration.	Amelung et al. (2020)
North-East	Adamawa	Reduced growth and yield of sugar cane. Critical factors influence crop yield: minimum temperature at germination stage, and pan evaporation at the 'boom' stage.	Development of improved plant varieties that are tolerant to drought, salinity, and diseases. Improved irrigation.	Pareek et al. (2020); Rayamajhee et al. (2021)
	Bauchi	Increased thermal sensation as individuals were not in thermal acceptable conditions within their residences.	Use of thermal friendly design methods and green infrastructure (e.g., albedo reduction of sidewalks, albedo reduction of building walls, grass planting, tree planting).	Park et al. (2020)
	Taraba	Increased malaria morbidity and mortality along the decade.	Improving housing standards, community awareness on the health impact of climate change, improvement of the health system.	Tong and Ebi (2019)
	Borno	Migration of residents due to low agricultural productivity especially rainfed agriculture.	Improved irrigation.	Rayamajhee et al. (2021)

results for adaptation, many farmers have already employed some of the different strategies against CC. Some local communities have also developed traditional strategies to cope with CC impacts and the role of these adaptation strategies is also well known. However, the adoption of more strategies depends largely on government intervention by improving and strengthening human capital, extension services, and infrastructures at every level. Farmers clearly pointed out that the lack of such facilities has hindered the adaptation of farmers to CC impacts. For instance, the lack of a proper road network has limited farmers from practicing the land fallow system which is one of the climate-smart strategies.

Our study showed that farmers in Nigeria adopted various climate-smart adaptation strategies such as changes in cultivation practices. Similar to our result, adaptation measures taken by farmers in Afghanistan involved changes in cultivation practices. Other measures employed in Afghanistan included scientific techniques for crop cultivation, cultivation of new crop(s) and drought-resistant varieties, and migration of family members. However, to remain effective, these strategies were required to evolve over time following the discourse of CC and society (Omerkhil et al., 2020); an approach that is similarly applicable in Nigeria. In Pakistan, Bakhsh and Kamran (2019) showed that adaptation strategies adopted by farmers involved labour-intensive farm practices such as soil bund-making, deep ploughing, and crop diversification. A variety of socioeconomic factors however influenced farmers' responses to adoption. Of the three practices highlighted above, only crop diversification was employed by farmers in Nigeria. In the Gamo Highlands of Ethiopia, farmers adopted sustainable land management practices as adaptive strategies (similarly employed in Nigeria), and effects on food production vary according to the practice adopted (Cholo et al., 2019). Although the magnitude and consequences of adaptation demands seem to be larger in the Asia-Pacific countries, they have a higher capability for adaptation, than in Africa (Mertz et al., 2009). As a result, more strategic and futuristic development plans are imperative as obtained in some developed countries.

In the UK for instance, there are timely, far-sighted, and well-informed decisions in tackling the issues of CC across sectors. An environmental plan has been developed to create or restore wildlife habitats by 2042. Improvements on flood and coastal defences are also consistently made to strengthen adaptations. Climate models are improved with up-to-date observational records. Moreover, an evaluation of adaptation policy is conducted every two years, and highlights of current "most urgent" risks are identified for actions and research priority (Carbon Brief, 2018; Howarth et al., 2018).

Besides the UK, other developed countries and/or their organization have devotedly developed tools for evaluating adaptation options and setting priorities to cope with CC. Such tools include the Digital Adaptation Compendium (EU ADAM project 2009), the Adaptation Decision Explorer (weADAPT), and the Adaptation Wizard (UKCIP) (Isoard, 2011). In France, criteria have been developed for ranking sectoral adaptation options with a long-term planning horizon. In the

Table 7. List of selected current adaptation methods, their effectiveness/ineffectiveness and appropriate adaptation methods.

Current adaptation methods	Effectiveness/ Ineffectiveness	Appropriate adaptation method	References
New technology to rural farmers	Ineffective	Consideration and integration of indigenous knowledge with modern technology.	Ajani et al. (2013)
		Requisite education and training of local farmers as well as strengthening of extension services.	Anabaraonye et al. (2019)
Irrigation practices	Ineffective	Government implementation of accessible and sustainable irrigation schemes among farmers.	Nikolaou et al. (2020)
Restriction of water use	Ineffective	Political buy-in through education programmes, human, and financial resources.	Mukheibir (2008)
Use of improved agricultural inputs	Effective		Akintonde and Shuaib (2016)
Mixed and over cropping	Effective		Apata (2011); Eludoyin et al. (2017)
Changes in planting and harvesting dates	Effective		Eludoyin et al. (2017)
Enterprise diversification	Effective		Ozor et al. (2015)
Construction of barriers against flood	Effective		Iheke and Agodike (2016)
Social capital through organizations, societies, and groups	Effective		Owombo et al. (2014)
Water related and nutrient related technologies	Effective		Ayanlade et al. (2018)
Irrigation practices	Effective		Olayide et al. (2016)
Heat resistant roofing materials	Effective		Ezeabasili and Okonkwo (2013)

Netherlands, a route planner has been developed to assess and rank adaptation options based on specific criteria (van Ierland et al., 2006; Hallegatte et al., 2008). These examples, frameworks, and approaches are required to be incorporated or tailor-made in the Nigerian context for our adaptation objectives to become more effective.

Although some of the reported adaptation strategies in this study were found to be effective, our study observed that some of the current adaptation methods were not effective (Table 7). For instance, irrigation of pasture during the dry season was not effective (Tologbonse et al., 2011). Others were reported in the form of low resilience or unlikeliness to reduce climate risks. This was in line with the study of Antwi-Agyei et al. (2018) in Ghana, where adaptation responses could sometimes lead to maladaptive outcomes. Particularly, such maladaptive outcomes were related to specific limitations such as poor access to information, poor access to credit, poor government involvement, among others. In these circumstances, government efforts towards adaptation and response strategies were reported to be uncoordinated, thus, limiting the proper implementation of response plans.

Adaptation strategies may increase the vulnerability of other groups, sectors, or systems if they have high opportunity costs or set paths that limit the choices available to future generations (Barnett and O'Neill, 2010). Moreover, disproportionate burdening of the most vulnerable sector/groups may also occur in events of meeting the needs of one sector/group. In other cases, energy-intensive adaptation actions could lead to increased emissions of greenhouse gases, while reduced incentives to adapt could unnecessarily change behaviour. These five pathways to maladaptation are implications of wrong adaptations to CC (Barnett and O'Neill, 2010). As highlighted in this study, adaptive responses employed in Nigeria include the reduced number of bathes taken (i.e., reduce incentives to adapt); a scenario where rainfall harvesting could serve as a supplementary water source (Balogun et al., 2016). There were also cases of restriction of water use for specific purposes, which suggests that there has been a distinct and negative change in social norms. Such changes were classified as maladaptive with reference to adaptive responses to water stress in Australia (Barnett and O'Neill, 2010).

Maladaptation does not only affect the short-term adaptive capability but also in the long-term. In the long-term, individuals depending heavily on the natural environment are likely to be more affected, as they would have the least resources to cope. The number of health-related challenges would likely increase. There could also be changes in the distribution of some disease vectors and water-borne illnesses. Sectors that rely strongly on temperature and rainfall (e.g., agriculture, energy, tourism, forestry) could experience increased impacts. Some plants and animal species could struggle to cope with changing environmental conditions. Besides, all sectors could directly and/or indirectly experience economic losses in various ways. Therefore, as highlighted by (Boko et al., 2007), future adaptation strategies in developing countries like Nigeria, need to also focus on improving various sectors to improve the social and economic welfare of individuals. This in turn would improve the adaptive capacity of individuals and communities. Furthermore, government and private sectors should support climate research financially and technically to improve adaptive capacity and resilience (Sojobi et al., 2016).

4.9. Adaptation in urban regions in Nigeria

People living in large, high-density cities and urban areas in Nigeria are exposed to climate impacts in one way or the other. To adapt to climate impacts on the environment, many of these urban areas have devised a variety of strategies to deal with these effects. These strategies in some cases, however, might not be able to stand the test of time. These include, but are not limited to, disaster planning to enable more effective evacuation, landfilling to raise elevations for new development against flood, and the use of proper designs in new constructions (Sanni et al., 2014, 2019).

In other cases, urban regions in Nigeria adapt through greening/planting trees, use of energy-efficient technologies, building resilient urban infrastructure, enforcement of building guidelines, and improving housing quality to make it more resistant to storm events (Akinola et al., 2020). Lagos, for instance, has developed a means of adapting to flooding through flood and drought warning systems, drainage networks, climate-proof infrastructures, provision of alternative energy sources, urban resettlement, and improving the resilience of vulnerable communities (LAS-CCAS, 2012; Leal Filho et al., 2018). The same scenario is true for most of the other urban regions along the Nigerian coast, though strategies vary with the inland urban areas. Moreover, a similar pattern of adaptation is obtained in other African urban regions. In Addis Ababa, early warning systems, drought control, energy-efficient transportations,

Table 8. Appropriate adaptation methods for identified CC impact for urban regions.

CC impact	Appropriate adaptation methods	References
Flooding	Construction of multi-purpose reservoir upstream, expansion of urban drainage systems, early flood forecasting and warning system, flood plain restoration, increased height of dikes, improvement of drainage systems, enlargement of tube wells and reservoirs, urban planning to avoid infrastructures in areas likely to be affected.	Pathak and Eastaff (2014); Devkota et al. (2017)
Drought	Early forecasting and warning system, water transfers, minimal water-intensive measures, construction, and expansion of water reservoirs.	Devkota et al. (2017)
Increased urban temperature	Changes in urban energy consumption to renewable options, promotion of household or neighbourhood-level greening, emission control and scaling up of low-carbon actions	Wilby (2008); Bouzarovski, and Haarstad (2019); Kondo et al. (2021)
Coastal inundation	Artificial sand dunes, construction of seawalls, sea dikes, and detached breakwaters, wetland restoration, enhanced drainage systems, and use of saline-resistant crops.	Zhu et al. (2010)
Reduced resilience of infrastructure	Adoption of improved building standards, adoption of building regulations following the International Building Code	OECD, 2021
Residence displacement	establishment of a long-term migration scheme across the country to take care of displaced residence	Constable (2017)

and buildings are employed (Bryan et al., 2009). In Douala, adaptive strategies include reducing greenhouse gas emissions, alternative energy sources, and poverty reduction to strengthen adaptive capacity (Wouapi et al., 2014). In Accra, residents adapt by building climate-resilient buildings and infrastructures (Ghana Ministry of Environment Science, 2013), which is similarly applied in urban regions in India, Indonesia, Thailand, and Vietnam (Jarvie et al., 2015).

In agriculture, some of the adaptation strategies employed specifically in urban regions include; the use of air ventilation, integrated farming, use of energy-efficient bulbs in farms, and regular dissemination of short-term weather forecasts to farmers (LAS-CCAS, 2012; Liverpool-Tasie et al., 2019). In other urban regions, most of the adaptation strategies highlighted in the result of this study are employed. On a more general note, these impacts affect both the urban poor and rich. However, the rich city-dwellers are better able to protect themselves from the impacts through the insurance of their lives and valuable property (Sanni et al., 2014). A list of appropriate adaptation methods for identified CC impact for urban regions is presented in Table 8.

4.10. Best practices for climate adaptation in selected developed/ developing countries

It is now a known fact that adaptation strategies are irreplaceable in CC mitigation and impact reduction (Sarkodie and Strezov, 2019). Many developed and developing countries have devised means of adapting to climate actions (Dinesh et al., 2017). Examples in developing countries include the improved cocoa farming and mass agroforestry in Ivory Coast, and smallholder aquaculture in Zambia, which utilizes 'relish' ponds to provide resilience to climate shock. In the Philippines, alternate wetting and drying in the Angat-Maasim River are practiced. Other good examples are the solar irrigation entrepreneurship in Chakhaji, India, and digital agriculture practices in Zimbabwe (Dinesh et al., 2017). These adaptation strategies are still employed among these countries with effective outcomes.

Likewise, developed countries like Norway, Switzerland, Spain, Canada, United Kingdom, France, China, Finland, and so on, have resorted to more ambitious adaptation plans and policies as part of their developmental plans. In the Netherlands, spatial planning 'climate proof' has been developed, while desalination and water reuse, and resilience agriculture are practiced in the US and China respectively (Dinesh et al., 2017; He, 2017). In the EU, best adaptation practices include integrated river basin management, drought management for vulnerable river basins, soil management and vegetation cover, sustainable (re-)use of water, residential water saving, vertical farming, etc (European Commission, 2021). These practices have been found effective over the years and worth being considered in the Nigerian framework.

4.11. Research gaps identified

This study identified some research gaps on CC impact research in Nigeria. Currently, there is no research that investigated the scale and magnitude of future impacts in the aquatic environment (RG1) and resources (including aquaculture). This is essential in providing better insights into effective planning, use, and protection of our aquatic environment and resources.

To date, some regions, particularly the Northern region are underrepresented in CC impact research (RG2). Although there is a significant amount of existing data in certain fields conducted in the South, such data may not be transferable considering the differences in environments.

Also, there is an absence of study investigating the effects of multiple variables of CC at the same time (RG3), for instance, on fish physiology and other important aquatic species. Such experimental research is required to provide clearer evidence of the impacts in the coming decades. Research direction for the identified research gap is presented in Figure 12.

4.12. Cogent measures to be taken by government, industry, and researchers

To prevent CC and improve on adaptation measures, the government, industry, and researchers have significant roles to play. There is a need for the Nigerian government to invest more in modern research facilities and equipment for researchers to utilize. The government needs to protect or restore key ecosystems such as mangroves, forests, oceans, wetlands, and rivers. These key ecosystems play vital roles as a barrier against tropical storms, and in absorbing large quantities of carbon, thus slowing warming.

Furthermore, the government should initiate programs that will increase awareness of the environmental specificity of CC adaptation strategies. Besides, more proactive approaches such as the development of a national climate and adaptation databases, are required to match up with adaptation results as obtained in other countries. Agricultural producers that employ sustainable practices with a respect for nature need to be supported. The government should also control short-lived climate pollutants such as hydrofluorocarbons, ozone, methane, and black carbon (soot) through national policies, regulations, and adequate monitoring. These strategies have been employed in Australia, Canada, China, India, Japan, Russia, Mexico, Brazil, the United States, and the EU (Government of the Netherlands, 2014; Miller et al., 2017).

At the industrial level, coal-fired electricity generation should be phased out or reduced to a minimum at the soonest possible period. Sustainable energy such as onshore wind power, offshore wind power, and solar energy should be promoted. Industries should fund innovations aimed at hydrogen and other sustainable fuels. A minimum CO_2 price for electricity production should also be introduced to encourage sustainable energy consumption. Incentives should be provided for climate-friendly

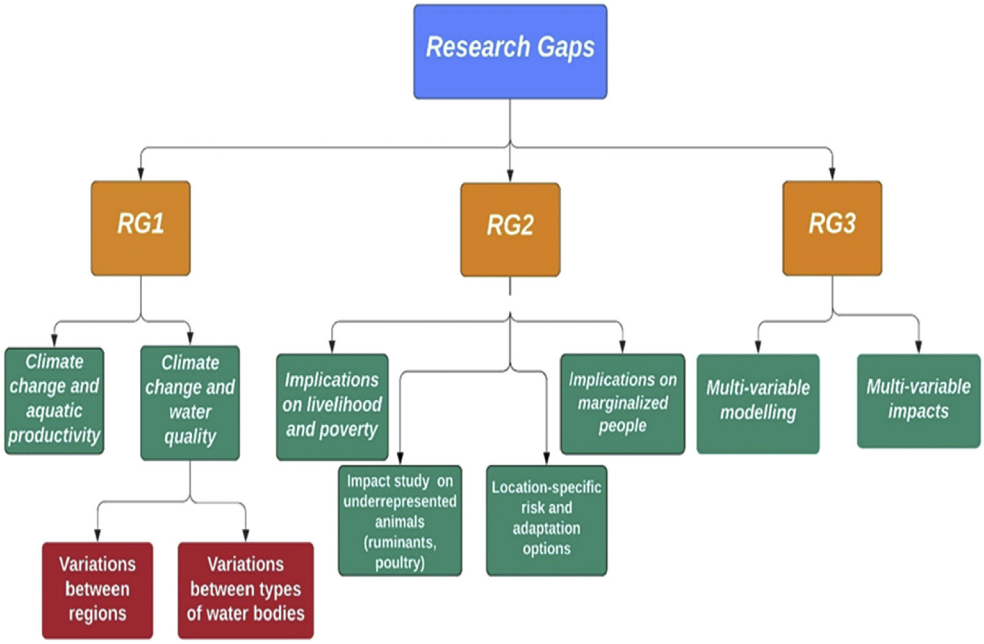

Figure 12. Research direction for each identified research gap on CC impact in Nigeria.

food products; thus, encouraging sustainable consumption and reducing food waste (Government of the Netherlands, 2014).

Additionally, researchers are required to engage in more real-life scenarios to better understand the mechanisms and processes underlying CC impacts. These might require collaboration with international researchers to facilitate knowledge transfer.

5. Conclusion

There have been significant inputs in CC impact research and publications in Nigeria. Available studies have investigated and reported diverse CC impacts on agriculture, the environment, and humans. However, the number of published articles on the study theme has been low and on the decline over the past years. The recent decline in research and publication efforts could be risky when compared with future research needs in the country. This is because there has been no current link to adequate implementation of past findings, programs, and strategies against present and future impacts. Furthermore, the research method employed in most of the studies is a questionnaire/interview approach which could be in a rather subjective manner (e.g., respondent's judgment); and may not reflect the magnitude of impacts. An underrepresentation of CC impact clearly makes it difficult to conduct spatial and temporal comparisons, which is useful for understanding the dynamics in ecosystems and their services, including agricultural products.

To this end, it is vital for developing nations such as Nigeria to leverage new technologies, strategies, and approaches that are being employed in advanced countries. Based on the relatively high vulnerability of the Northern region of Nigeria to CC, together with the low human capital development, there is a need for increased attention from research institutions, particularly those situated in the region.

In addition, a timely revision and adequate monitoring of adaptation/mitigation strategies across the various categories are imperative to assess their effectiveness in the country. These are necessary steps to ensure that the changing climate does not exacerbate the multidimensional pressure already on the food and environmental systems. Ultimately, if the government's strategies and plans towards human and economic development in Nigeria are to achieve needed results, it must include appropriate measures to CC impacts. This is only possible through a coordinated effort on climate research, facilitated through improved investment.

On a more general note, this study has also highlighted how CC impacts a typical tropical environment across three thematic areas – agriculture, environment, and humans. Thus, providing a baseline for comparative studies with other environments.

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