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Progress in Climate–Agricultural Vulnerability Assessment in Nigeria

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Abstract: An in-depth understanding of the impact of vulnerability on livelihoods and food security is important in deploying effective adaptation actions. The Nigerian agricultural sector is dominated by rainfed and non-homogenous smallholder farming systems. A number of climate change risk studies have emerged in the last decade. However, little attention has been given to vulnerability assessments and the operationalization of vulnerability. To highlight this shortcoming, this study systematically reviewed climate-change-focused vulnerability assessments in the agricultural sector by evaluating (1) variation in climate variables in Nigeria over time; (2) the state of climate change vulnerability assessment in Nigerian agriculture; (3) the theoretical foundations, operationalization approaches, and frameworks of vulnerability assessments in Nigeria; (4) the methods currently used in vulnerability assessments; and (5) lessons learned from the vulnerability studies. We used a linear trend of climatic data spanning over a period of 56 years (1961–2016) obtained from the Nigerian Meteorological Agency and the Climate Research Unit of the University of East Anglia, United Kingdom, along with a systematic review of literature to achieve the objectives. The analysis indicates a significant and positive correlation between temperature and time in all major agro-ecological zones. For precipitation, we found a non-significant correlation between precipitation in the Sahel, Sudan, and Guinea Savanna zones with time, while the other zones recorded positive but significant associations between precipitation and time. The systematic review findings indicate no clear progress in publications focused specifically on vulnerability assessments in the Nigerian agricultural sector. There has been progress recently in applying frameworks and methods. However, there are important issues that require addressing in vulnerability assessments, including low consideration for indigenous knowledge and experience, unclear operationalization of vulnerability, non-standardization of vulnerability measures, and inadequacy of current assessments supporting decision making.

Keywords: temperature; precipitation; trend analysis; vulnerability assessment; climate change; agriculture; Nigeria

1. Introduction

Climate change is one of the gravest problems faced by mankind. Climate-change-induced events include increased incidents of floods, droughts, irregular precipitation patterns, and other extreme events [1]. These climate-induced events pose serious risks to developing economies [2]. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) [3] notes that climate change, with its attendant consequences, may continue into the future, especially if swift global measures are not taken to address it [4]. These negative impacts are currently felt mostly in the agricultural sector, with projections indicating that the trend will continue to worsen for the sector, leading to increased vulnerability for the population segments whose livelihoods are largely dependent on agricultural subsistence [5].

Nigeria, similar to most sub-Saharan African (SSA) countries, is vulnerable to climate change due to increased variations in rainfall patterns [3], which has been documented in recent studies [6]. The country's economy is largely agricultural-based because the sector contributes about 30 percent of the gross domestic product (GDP) and provides about 70 percent of the employment for the labor force [7].

Climate-change-induced impacts adversely affect smallholder farmers disproportionately due to their heavy reliance on natural resources, which is worsened by high incidence of poverty, poor land tenure, high volatility of commodity prices, low productive capacity, and low adaptive capacity [1,8]. The combination of these characteristics and projected future climate vagaries indicates that climate change may stall resilience in the country. As such, there is a need for an understanding of the vulnerability of agricultural systems to climate change. The concept of vulnerability is widely used, for example in poverty and development, sustainability science, and climate studies [9]. There is increased interest in climate vulnerability assessment within the scientific community [10,11]. Preston [12] notes that the meaning of vulnerability could vary across studies.

There is a dearth of research on climate vulnerability in the Nigerian agricultural sector, despite renewed interest in this area [12]. Hence, reviewing the current literature will help to address the gap and to identify areas that require attention while fostering decision making at all levels within the country [13]. This paper aims to systematically review the existing literature on climate impacts and vulnerability in the Nigerian agricultural sector. The research questions are as follows:

1. What is the linear variation of climate variables in Nigeria?
2. What is the current state of climate impact and vulnerability assessments in Nigerian agricultural sector?
3. What are the theoretical foundations, operationalization approaches, and frameworks of vulnerability assessments in Nigeria?
4. Which methods are currently used in vulnerability assessments?
5. Which lessons are learnt from the vulnerability studies?

Answers to these questions will help fill the gap in vulnerability assessment studies in Nigeria, improve the existing knowledge of vulnerability in the agricultural sector, and inform decision making, aiming to foster adaptation planning and actions. The review proceeds as follows: Section 2 briefly presents a related literature on climate vulnerability. Section 3 presents the linear trend of weather and climate variables across Nigeria's major agro-ecological zones. Section 3 also provides details of the data extraction and screening methods used. Section 4 presents the results. In Section 5, we discuss our findings and conclude the review.

2. Vulnerability

Vulnerability entails the degree or extent to which a system or host is prone to harm due to exposure to a perturbation or stress, and the ability of the exposure unit to cope, recover, or fundamentally adapt [14,15]. Furthermore, vulnerability to climate constitutes adaptive capacity, sensitivity, and exposure [4]. There are different conceptual approaches and methodologies used in measuring climate change vulnerability. Here, we present a brief review of some relevant vulnerability studies, guided by the works of Hoddinott and Quisumbing [15] and Deressa et al. [14] on risks and vulnerability assessment.

2.1. Components of Climate Change Vulnerability

The identification of vulnerability drivers further helps in the identification of measures aimed at reducing such vulnerability. Following Deressa et al. [14] and Hoddinott and Quisumbing [15], vulnerability is composed of three component parts, namely exposure, sensitivity, and adaptive capacity. Exposure refers to the potential between an exposure unit (individuals, groups, economic sectors, places, and various parts of ecosystems) and a perturbation or stress factor. Our exposure unit of interest in this review is the agricultural sector. Sensitivity refers to the potential extent to which an exposure unit is likely to experience changes, harm, or stress due to an exposure to perturbations or stress. For our purpose, it is changes in rainfall and temperature patterns that expose the agricultural households to vulnerability. Adaptive capacity may be referred to as the ability of an exposure unit to adjust to stress or recover from shock, to manage the damages, and explore any beneficial opportunities the stress might bring.

2.2. Conceptual Approaches Used in Vulnerability Studies

Three major approaches constitute the major conceptual approaches using vulnerability analysis, namely socioeconomic, biophysical, and integrated assessment approaches [14]. The socioeconomic approach accounts for the changes in the individual or group's socioeconomic status [9,16]. Variations in human characteristics within a community often result in varying vulnerability levels. Generally, the socioeconomic approach tends to identify an individual or community's adaptive capacity based on own characteristics [16,17]. The socioeconomic approach is limited due to its sole focus on within-society variations. It also ignores the natural resource base's potential to withstand the adverse effects of environmental shocks. For example, places with accessible underground water may be better able to cope with drought by accessing this water [18].

The biophysical approach in vulnerability assessment assesses the damage to both social and biological systems resulting from environmental stress [18]. For example, the monetary impact of climate change on agriculture can be ascertained by analyzing the impact of climatic variables' on farm-level income [19,20]. Similarly, impacts of climate change on agricultural yield can be ascertained by modelling the relationships between crop yields and climatic variables [21]. Kelly and Adger [17] explain the biophysical approach as pertaining to research questions such as, "What is the extent of the climate change problem?".

The integrated assessment approach in vulnerability assessment aggregates the two previous approaches to determine climate vulnerability. Examples of integrated assessment approaches include the hazard-of-place model and vulnerability mapping approach [22]. Füssel and Klein [23] advocate for the use of the IPCC vulnerability definition, since they argue that it accommodates an integrated approach to vulnerability analysis. While the integrated assessment method advances the biophysical and socioeconomic methods, it has identified limitations. Chief among these short-comings is the lack of standardized methods of combining the biophysical and socioeconomic indicators. Despite this short-coming, the integrated assessment method better fosters informed decision making than the biophysical and socioeconomic methods taken individually [14].

3. Methods

3.1. Linear Variations in Climate Variables in Nigeria's Agro-Ecological Zones

We used precipitation data from the Nigerian Meteorological Agency (NIMET) from 1961 to 2016. The data from NIMET used for this study were point-based data. For each agro-ecological zone, data from one point (weather station) were used to represent the entire agro-ecological zone. Our temperature data came from the global gridded dataset (Climate Research Unit (CRU) Time-Series

(TS) v4.03) provided by the Climate Research Unit (CRU) at the University of East Anglia, United Kingdom [24]. Given the low spatial and temporal coverage of meteorological stations in Africa, the CRU dataset provides alternative data for climate analysis and has been used in previous studies focused on Nigeria, Africa, and global climate models [25–28]. In this study, we analyze the trend of rainfall and temperature during the 1961 to 2018 period.

We used the parametric method to check the trend of the climate data (temperature and precipitation) over a period of 55 years (1961–2016). We determined the coefficient of correlation of each climatic variable and time as a means of ascertaining the relationship between climate and time. Furthermore, the statistical significance ($p < 0.05$) of the correlation and trend coefficients were also determined.

3.2. Systematic Literature Review

We studied the progress in climate–agricultural vulnerability assessments carried out in Nigeria between 2010 and 2019 using a systematic literature review (SLR) method. As a review method, the SLR can be used to assess the state of knowledge regarding a thematic area, such as climate change, as in the current study [29]. This systematic review uses the SLR method because of the rigorous nature of the study, and the SLR method fosters the structuring of observations from recent literature studies [30]. Furthermore, the SLR helps in identifying gaps and by providing information obtained by summarizing evidence in literature databases using clear research methods and questions [31].

We conducted an online literature search of relevant open access, English language databases, including Google Scholar (GS), Nigerian higher education journals, government-owned repositories, and non-governmental organization publications. We restricted our study timeframe to the period spanning from 2010 to 2019 because this period accounted for the majority of the overall search results. We carried out the literature search using several keyword combinations as well as inclusion and exclusion criteria to select publications for the systematic review. These keywords included “climate change”, “vulnerability”, “climate risk or impact”, “agriculture”, and “Nigeria”. Furthermore, we accounted for various agricultural sectors, including crops, livestock, and fish farming. We report the inclusion and exclusion criteria used in the selection of relevant published studies in Table 1.

Table 1. Steps considered in the selection of vulnerability publications for review.

Search Stages	Inclusion Criteria	Exclusion Criteria
Initial search	Studies published in English Climate-change-related vulnerability in the agricultural sector Studies focused on Nigeria Distinct/single studies	Studies published in other languages Climate-change-related vulnerability in the non-agricultural sector Other countries Non-distinct/duplicates
Title and abstract screening	Strictly focused on agricultural systems (crop, livestock, poultry, and fish production) Focus on vulnerability associated with climate risks	Non-agricultural systems (crop, livestock, poultry. and fish production) Focus on vulnerability associated with non-climate risks
Final step for review	Non-systematic review studies Livelihoods for rural farmers households Vulnerability studies focused on agricultural systems/productivity	Systematic literature review or discourse analysis Livelihoods for non-farm households Vulnerability studies focused on non-agricultural systems/productivity

We identified 112 studies from the accessed databases during our initial search, consisting of peer-reviewed and gray literature (for example, working papers, project reports, theses, and conference proceedings). The selection process started by removing duplicate studies. Next, we excluded publications unrelated to the central theme of this review—climate change vulnerability—while the last step involved screening of abstracts and full texts. However, we note that while many studies exist on the climate change and Nigerian agricultural sector relationship, there are very few studies analyzing climate impact and vulnerability in Nigeria, which is the main focus of the current systematic review. Out of the 20 studies for review in this study, 15 (75%) were peer-reviewed publications and 5 (25%) were gray literature. According to [32], the value in reviewing relevant gray literature on climate change studies lies in their provision of useful area-specific information and policy-relevant responses, which can be ignored by peer-reviewed literature. Figure 1 presents a schematic of our literature search and selection procedure, which led to 20 studies. For the review analysis, this study uses thematic and descriptive statistics to analyze the questions in this review study; these studies are classified based on geographical location, primary focus, dimensions of vulnerability, analytical methods, agricultural sector, constraints to vulnerability response, and other factors. These classifications demonstrate the complexities associated with vulnerability assessments [1].

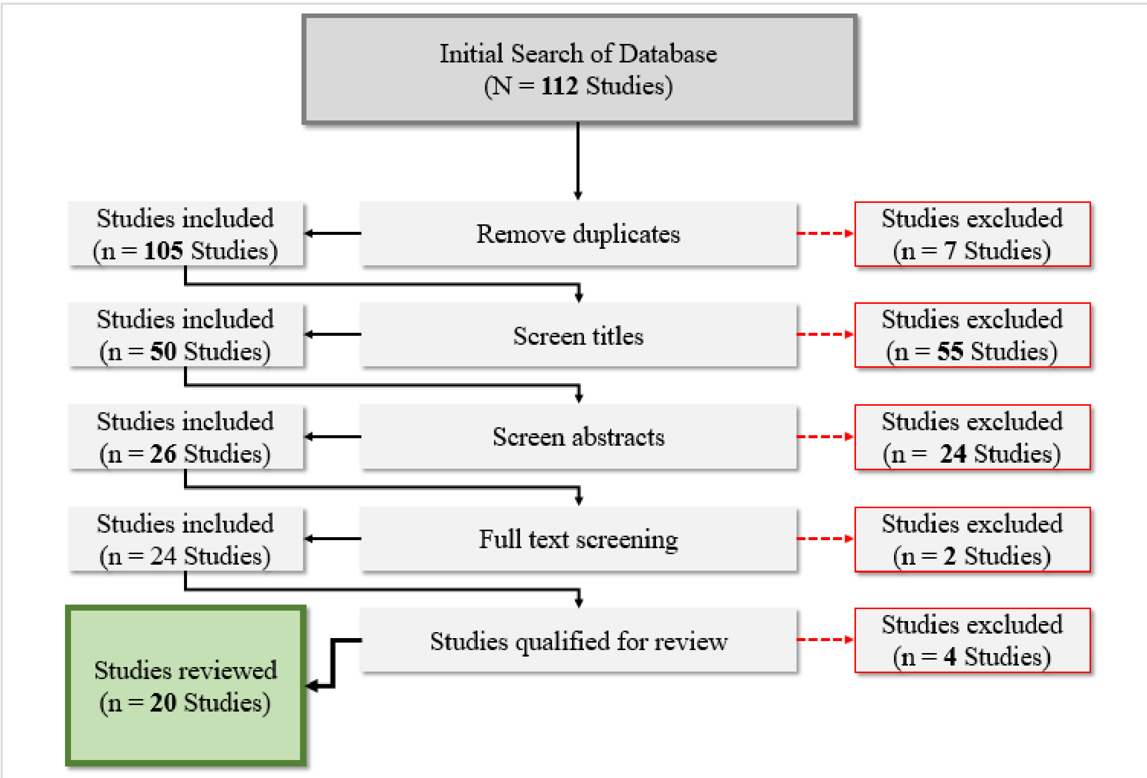


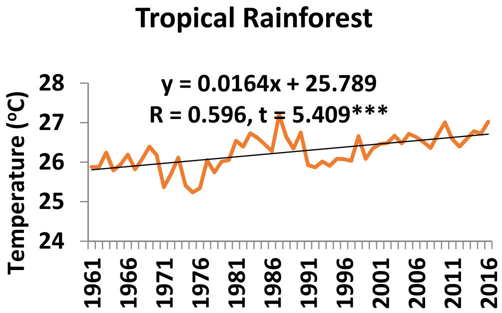
Figure 1. Schematic of literature search and screening process.

4. Results and Discussion

4.1. Linear Variation in Climate Variables in Nigeria's Agro-Ecological Zones

4.1.1. Variation of Annual Temperature

Figure 2 shows the variation of (annual) temperature across the major agro-ecological zones in Nigeria, while Table 2 reports the descriptive statistics of temperature and precipitation time series. The variations in annual means in all major agro-ecological zones revealed that temperature significantly increased over time across Nigeria. The correlation coefficients of temperature and time across the major agro-ecological zones exhibited strong and positive relationships, implying that the temperatures of the major agro-ecological zones of Nigeria significantly increased within the period under study. The strongest positive variation is seen in the Sudan Savanna zone, which had the highest correlation coefficient (0.735), followed by the Sahel zone (0.733), while temperature in the tropical rainforest zone yielded the lowest correlation coefficient.



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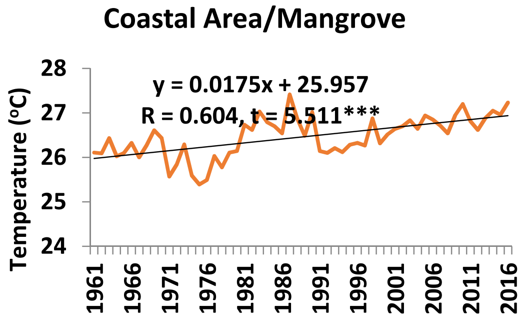

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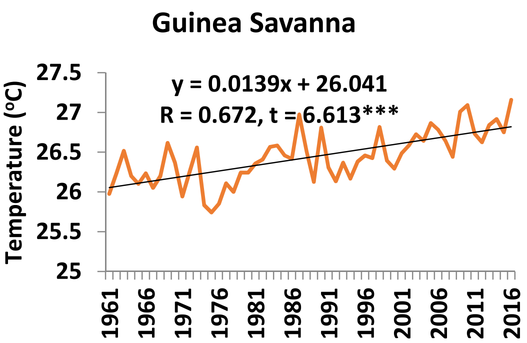

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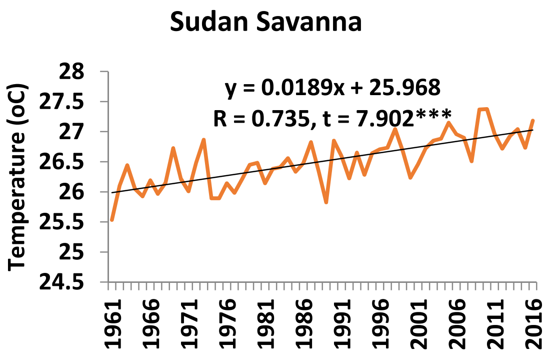

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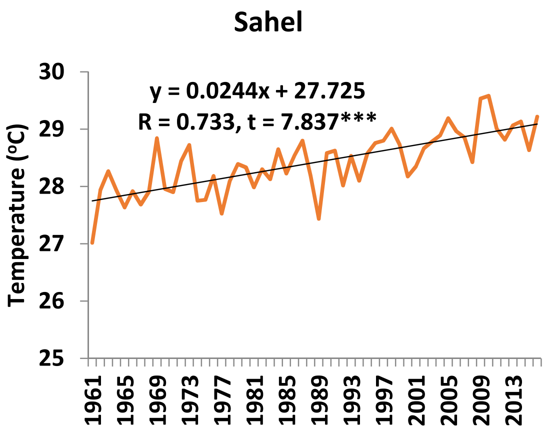

(**e**)

Figure 2. Variation in temperature in Nigeria's major agro-ecological zones between 1961 and 2016. Source: Climate Research Unit (CRU) Climate Dataset TS v4.03 [24]. (**a**) Variation in temperature in Nigeria's tropical rainforest between 1961 and 2016; (**b**) Variation in temperature in Nigeria's coastal zone between 1961 and 2016; (**c**) Variation in temperature in Nigeria's guinea savanna between 1961 and 2016; (**d**) Variation in temperature in Nigeria's sudan savanna between 1961 and 2016; (**e**) Variation in temperature in Nigeria's sahel between 1961 and 2016.

Table 2. Average values, standard deviations, and coefficients of variation of climatic variables across the major agro-ecological zones.

Agroecological Zone	Rainfall (mm)	Temperature (°C)
Coastal Area/Mangrove	2945.71 ± 408.29 (13.86%)	26.46 ± 0.46 (1.74%)
Rainforest	2164.96 ± 360.97 (16.67%)	26.26 ± 0.43 (1.64%)
Guinea Savanna	1204.14 ± 211.99 (17.61%)	26.44 ± 0.33 (1.25%)
Sudan Savanna	571.31 ± 144.94 (25.37%)	26.51 ± 0.41 (1.55%)
Sahel	440.46 ± 110.24 (25.03%)	28.42 ± 0.53 (1.86%)

Note: Values in parentheses are coefficient of variation values.

Similar findings from Freduah [33] show that temperature has been increasing in the Guinea and Sudan Savanna zones. The increase may be associated with lower grain yields in these agro-ecological zones. They also find evidence of increasing precipitation in these agro-ecological zones, which together with increasing temperature, reduce grain yield. Weather-related reduction in grain yield occurs through factors such as increased leaching, shortened grain-filling phase, and higher rate of senescence, which lowers the maize plant's ability to efficiently fill the grains [33].

4.1.2. Variation of Annual Precipitation

Figure 3 shows the variation of (annual) precipitation across the major agro-ecological zones in Nigeria. The variation in annual rainfall in all the major agro-ecological zones revealed varying results for precipitation. The rainfall point data for the rainforest and the mangrove/coastal areas had significant and positive correlations with time over the last 56 years. The Sahel, Sudan, and Guinea Savanna zones showed a negative correlation between precipitation and time over the last 56 years. However, Table 2 shows that the coefficients of variation of precipitation in the Sahel, Guinea, and Sudan Savanna zones were higher than the rainforest and coastal zones, indicating that the Savanna zones had high variation in rainfall. Agricultural systems are sensitive to climate changes and the high variability of precipitation predisposes agricultural production to climate risks.

Our precipitation results are similar to other studies conducted in Nigeria. Akinbile et al. [34] found that temperature increased in the major agro-ecological zones of Nigeria, while precipitation increased significantly from 1971 to 2010 (40 years) in the rainforest and coastal agro-ecological zones. Furthermore, similarly to our results, they found increasing trends in maximum rainfall across the major agro-ecological zones, except in the Sahel Savanna, where we found a significantly increasing trend in temperature. Similarly to our results, they found a non-significant trend for precipitation in the Guinea Savanna agro-ecological zone.

Our findings are also similar to Umar, Mashi, and Bako [35], who found an overall decreasing trend in rainfall during the 1971 to 2006 period in the Sudan Savanna zone, associated with shorter rainy seasons and occasional drought events. The implication of these climatic events, they argue, is changes in crop phenology resulting in longer time take to reach crop maturity and harvest in the absence of irrigation.

4.1.3. State of Climate Change Vulnerability Assessment in Nigerian Agriculture

Figure 4 shows the annual frequency of publications focused on agricultural vulnerability assessment in the region.

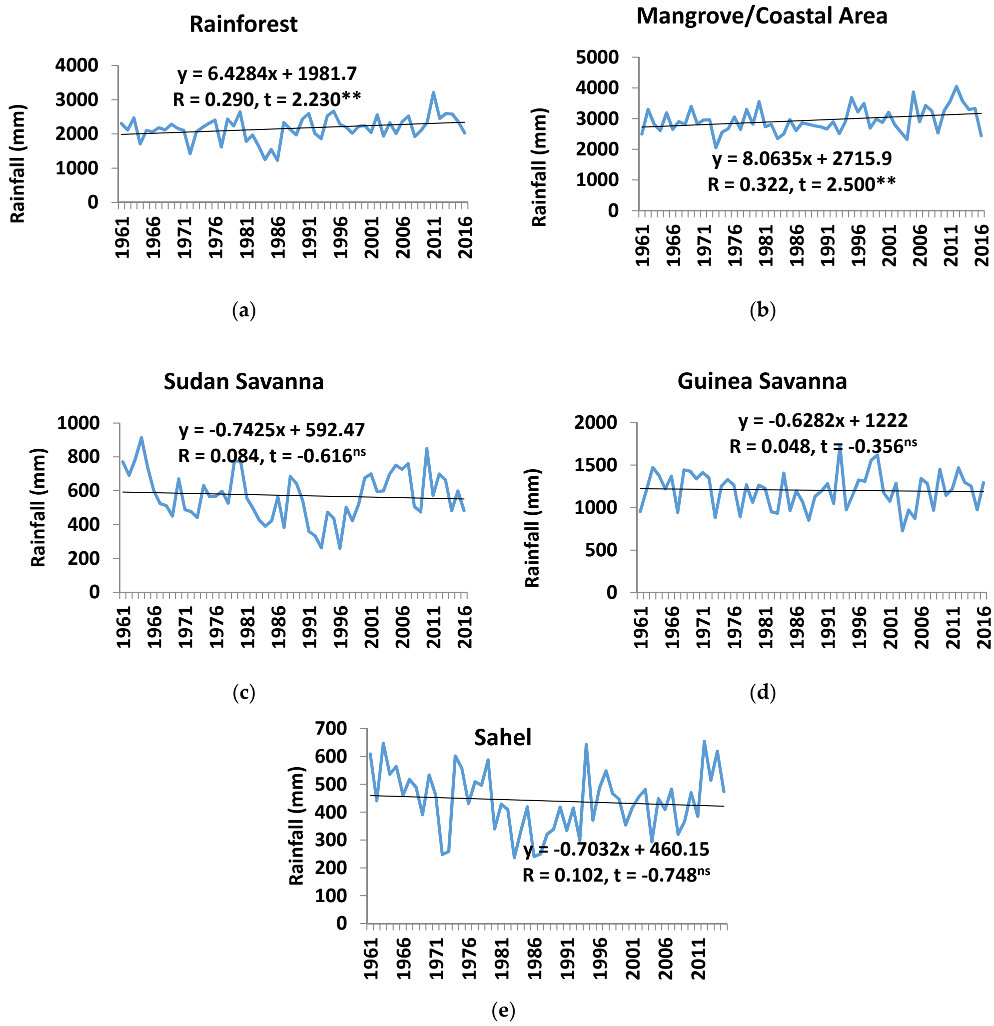

Figure 3. Variation in precipitation in Nigeria's major agro-ecological zones between 1961 and 2016. Source: Nigerian Meteorological Agency. (**a**) Variation in precipitation in Nigeria's tropical rainforest between 1961 and 2016; (**b**) Variation in precipitation in Nigeria's coastal zone between 1961 and 2016; (**c**) Variation in precipitation in Nigeria's guinea savanna between 1961 and 2016; (**d**) Variation in precipitation in Nigeria's sudan savanna between 1961 and 2016; (**e**) Variation in precipitation in Nigeria's sahel between 1961 and 2016.

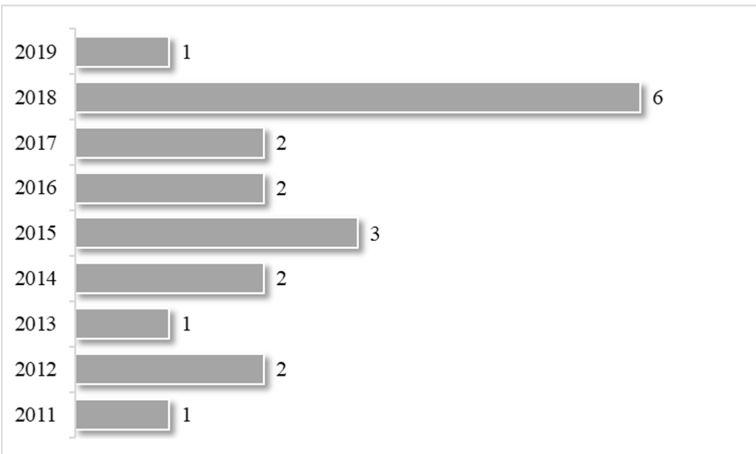

Figure 4. Reviewed assessments by year of publication.

In the above figure, we find no clear trend in the annual number of vulnerability assessment publications in Nigeria, with the highest number (6) published in 2018. The average number of publications per year is two.

Vulnerability assessments in the last decade in Nigeria's agricultural sector have focused mainly on the crop sub-sector (60%) (Figure 5). The literature search tried to account for other agricultural sub-sectors, however only about 20% and 10% of the studies focused on livestock and fish farming, respectively. Approximately 10% did not explicitly specify which sub-sector was under study (see [36,37]).

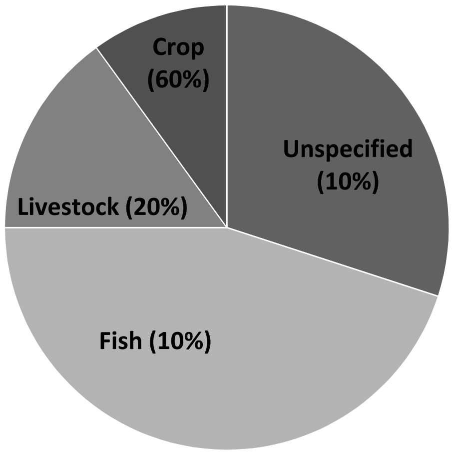

Figure 5. Agricultural sub-sectoral focus of vulnerability assessments.

Studies of agricultural vulnerability in Africa are mainly classified according to socioeconomic, biophysical, and integrated assessments, as reported in Table 3. Vulnerability assessments in the last decade in Nigeria's agricultural sector are distributed as follows. The Guinea Savanna had the highest number of climate vulnerability assessments in our sample, accounting for some 33.33%. Studies combining all the agro-ecological zones accounted for 22.22%, rainforest zones accounted for 18.52%, Sudan Savanna accounted for 11.11%, Sahel Savanna (7.41%), mangrove forest zones (3.70%), while the remaining 3.70% did not specify which zone was studied (Table 4). Vulnerability studies require incorporation of various dimensions, including environmental, socioeconomic, biophysical, and institutional dimensions, to address the difficulty of having a single representative measure of vulnerability to climate change [31].

Recently, there has been an upswing in vulnerability assessment research in Nigeria and other sub-Saharan African countries, especially in agriculture, since this sector represents the mainstay of the economy. However, despite this interest, there is no discernible trend in the yearly publication of assessment studies focused on the agricultural sector. Our study finds that most studies have been spread across major agro-ecological zones in the country. The crop sub-sector has the most assessment studies in our review; at the same time, most of these studies did not specify which specific crop systems they assessed. Furthermore, the vulnerability assessments considered mainly socioeconomic factors, followed by biophysical factors (see Table 3). We found 4 studies that integrated assessment methods and other subjective approaches to vulnerability research [13].

Table 3. Information on conceptual frameworks with representative studies.

Author (Year)	Agro-Eco Zone	Vulnerability Measure	Theory	Subjective	Socioeconomic	Biophysical	Integrated Assessment
Abaje et al. [38]	GS	CVI	✓		✓		
Adeoti et al. [39]	GS	CVI	✓		✓		
Adewuyi et al. [40]	TR, GS	CVI	✓		✓	✓	✓
Ajibola [18]	All	LnCLAH	✓		✓	✓	✓
Atedhor [36]	SdS	U		✓		✓	
Awolala and Ajibefun [41]	TR, GS	CVI	✓	✓	✓		
Awoyemi and Olajide [42]	All	CVI	✓		✓		
Ayanlade and Ojebisi [43]	GS	D, FS		✓	✓		
Aye and Ater [44]	All	CY	✓			✓	
Building Nigeria's Response to Climate Change (BNRCC) [6]	ShS, GS, TR, MF	V	✓	✓	✓	✓	✓
Cervigni et al. [45]	All	CY, LTHI, LGPP	✓	✓		✓	
Chikezie et al. [46]	TR	CVI	✓		✓		
Chukwuemeka et al. [47]	TR	CVI	✓		✓		
Eze et al. [48]	GS	CVI	✓		✓	✓	✓
Madu [37]	All	CVI	✓		✓	✓	✓
Madu [49]	All	CVI	✓		✓	✓	✓
Manu et al. [50]	GS, SdS	CVI	✓		✓		
Medugu and Majid [51]	U	CVI	✓		✓		
Ojo et al. [52]	GS	CY	✓			✓	
Umar et al. [35]	SdS, ShS	CY	✓			✓	

Note: All: All major agro-ecological zones; ShS: Sahel Savanna; SdS: Sudan Savanna, GS: Guinea Savanna; TR: tropical rainforest; MF: mangrove forest; D: drought; FS: fodder sufficiency; U: unspecified. CVI: composite vulnerability index, LnCLAH: log of consumption loss per agricultural household; CY: crop yield; V: various different measures. LTHI: temperature humidity index for livestock; LGPP: gross primary productivity for livestock; U: unspecified.

Table 4. Agro-ecological focus of vulnerability assessments.

Agro-Ecological Focus	Frequency	Percentage
All	6	22.22
Guinea Savanna	9	33.33
Sudan Savanna	3	11.11
Sahel	2	7.41
Tropical Rainforest	5	18.52
Unspecified	1	3.70
Mangrove Forest	1	3.70

4.1.4. Theoretical Foundations, Operationalization Approaches, and Frameworks of Vulnerability Assessments in Nigeria

The theoretical backgrounds typically provide a guide for the conceptual frameworks used to operationalize vulnerability assessments [12]. Table 3 further shows that studies applied different methods to construct a composite vulnerability index. All vulnerability measures (100%) of vulnerability operationalization stem from theory. One-quarter (25%) of the studies use subjective measures of vulnerability operationalization. Furthermore, there are differences in the vulnerability formulation in the assessments under review; there is currently increasing interest in the conceptualization and operationalization of vulnerability with the aim of fostering consensus [12,32]. We find that vulnerability studies in Nigeria have inconsistent frameworks in the assessment of vulnerability.

4.1.5. Methods Currently used in Vulnerability Assessments

Table A1 reports the different approaches used in vulnerability formulation in the studies under review in our study. We find that the indicator-based method was mostly used in the studies we reviewed, which aims to operationalize vulnerability. This method uses proxy indicators to construct vulnerability indices. The next most commonly used analytical methods are the statistical or econometric analysis methods, such as linear regression and principal component analysis. Only one study used geographic information system (GIS) spatial mapping methods to analyze vulnerability in the current review. Sourcing of data in the assessments includes both primary and secondary sources.

Different methods are used in all the vulnerability assessments, as is common with studies in other regions [12,31]. The primary sources include administering questionnaires, focus group discussions, and interviews. The secondary sources of data include accessing survey (National Bureau of Statistics (NBS), Central Bank of Nigeria (CBN), and Nigerian Meteorological Agency (NIMET)) databases. Data for spatial analysis include spatial indicators, such as land cover and use and crop yields, which are obtained from several organizations providing satellite data.

4.1.6. Lessons from the Vulnerability Studies

An in-depth understanding of climate-change-related vulnerabilities and their impacts on livelihoods and food security is important in deploying effective adaptation actions. Vulnerability assessments aim to identify the problem, establish a methodological basis, and foster decision making [12]. We follow in this manner by categorizing the main objectives and conclusions of the reviewed studies as follows:

1. Identification of Vulnerability according to various agricultural sub-sectors, agro-ecological zones, and geographical locations: The reviewed vulnerability assessment studies reported mainly on the determinants and vulnerability of agricultural sub-sectors, people, and places, as well as methodological contributions and decisions in the study areas.
2. Facilitation of vulnerability and adaptation decision making: The concluding sections of the reviewed assessments provided links to their findings on vulnerability and adaptation foci. This allows identification of the possible outcomes of improving adaptation practices, which is informed by the assessments carried out. The identified beneficiaries of these assessments are policy and decision makers and all relevant stakeholders.

The major contribution of the vulnerability assessments carried out on the Nigerian agricultural sector over the last decade has been the focus on the identification of vulnerability, as well as the focus on the vulnerability of agricultural sub-sectors, systems, people, and places.

In Figure 6, we find that only 2 (10%) of the studies provided prospects for future research based on their findings. About 12 (60%) of the reviewed studies identify vulnerability issues in the study areas, while 10 (50%) of the studies specifically reported on adaptation measures used in the study areas.

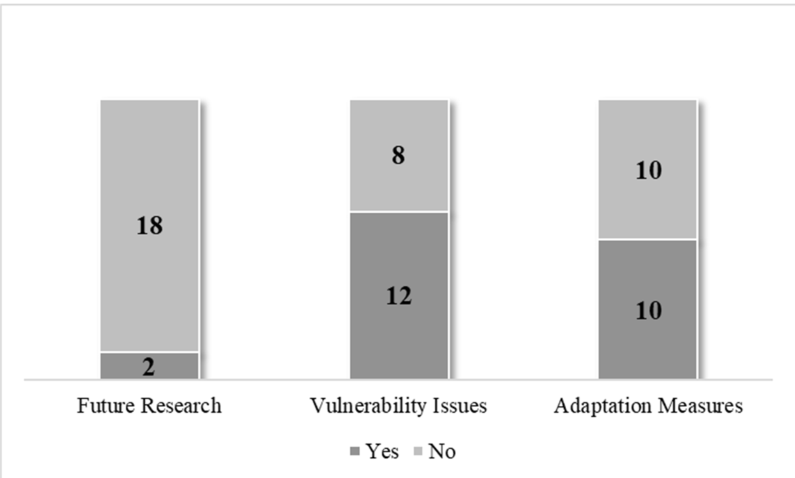

Figure 6. Number of assessments providing directions for further studies, identifying vulnerability issues and existing adaptation practices.

5. Conclusions

We have analyzed the linear rainfall and temperature using data from the Nigerian Meteorological Agency and the CRU for the period 1961 to 2018 in the Nigerian major agro-ecological zones. While station data is more appropriate for the analysis of climatic variables, there is, however, low spatial and temporal coverage of meteorological stations in Nigeria, and indeed Africa. The CRU dataset provides alternative data for climate analysis and has been widely used in previous studies focused on Nigeria, Africa, and global climate models. For temperature, we found evidence of significantly increasing trend in temperature in all the major agro-ecological zones. The highest positive trend was observed in the Sudan Savanna zone, followed by the Sahel Savanna, Guinea Savanna, mangrove forest zone, and rainforest zone. For precipitation, we found varying results that showed significant increasing precipitation trends for mangrove/coastal and rainforest zones and non-significant trends elsewhere.

For the systematic review, given the absence of binding principles in the operationalization of vulnerability, the studies under review mostly used concepts and frameworks rooted in theory. However, there are opportunities for improvement in future assessments, such as involvement of diverse stakeholders as participants in the assessment process to enhance inclusivity. Overall, comparing the studies reviewed on smallholder agricultural systems in Nigeria to current scientific knowledge on vulnerability research, which is argued to have a multidimensional nature, we suggest an integrated approach to the assessment process. At the conceptualization and methodological levels, strengths observed in the literature indicate that the future of vulnerability assessment in Nigeria requires a holistic and multidimensional approach. It needs to be integrative to avoid ambiguity in understanding the system assessed, as well as comprehensive enough to understand the human and environmental system relationship better.

Furthermore, best practice links vulnerability assessment outputs with adaptation policy and measures regarding the relevance of assessments to end users. The scarcity of evaluation of economic effectiveness of adaptation strategies as a critical aspect of vulnerability assessment literature in Nigeria requires improvement in future research. This would empower exposure units to address the causes of the hazards they are been exposed to, provide guidance and inform effective decision making for allocation of scarce resources, and help in understanding trade-offs between management and implementation to build understanding among stakeholders (farmers and policy makers) in order to pursue possible responses to reduce vulnerability. In order to produce knowledge needed to navigate projected changes in climate systems for agricultural economies and to ensure sustainable smallholder livelihoods, we suggest that future research efforts should be oriented towards providing more information to enlighten science, policy, and practice for informed decision making and evidenced-based policies.

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Appendix A

Table A1. Summary information of climate vulnerability assessment studies.

Serial/Number	Author(s)	Primary Data	Secondary Data	Data Collection Tool	Vulnerability Proxy	Main Analytical Approach
1	Abaje et al. [38]	✓		Household Survey	Composite Vulnerability Index	Statistical method (principal component analysis, index computation, and fixed effects regression)
2	Adeoti et al. [39]	✓	✓	Questionnaire, NIMET	Composite Vulnerability Index	Statistical method (descriptive, index computation, and multinomial logit regression)
3	Adewuyi et al. [40]	✓	✓	NIMET Database, Questionnaire	Composite Vulnerability Index	Statistical method (descriptive, trend, principal component analysis, index computation, and linear regression)
4	Ajibola [18]	✓	✓	*Fadama*-II Database, NIMET	Log of Consumption Loss Per Agricultural Household	Statistical method of vulnerability as exposure to uninsured risk (instrumental variable, logit regressions)
5	Atedhor [36]	✓	✓	Questionnaire, NIMET	Unspecified	Statistical method (descriptive statistics, trend analysis. and ordinary least squares (OLS) regression)
6	Awolala and Ajibefun [41]	✓		Questionnaire	Composite Vulnerability Index	Statistical method (descriptive and index computation)
7	Awoyemi and Olajide [42]		✓	Household Survey	Composite Vulnerability Index	Statistical method (principal component analysis, index computation, and fixed effects regression)
8	Ayanlade and Ojebisi [43]	✓	✓	Questionnaire	Drought and Fodder Sufficiency	Statistical method (descriptive statistics, trend analysis)

Table A1. *Cont.*

Serial/Number	Author(s)	Primary Data	Secondary Data	Data Collection Tool	Vulnerability Proxy	Main Analytical Approach
9	Aye and Ater [44]		✓	NBS, World Weather Records, Global Historical Climatology Network (GHCN) v.3 (2011) Database	Crop Yield	Statistical (multiple linear regression)
10	Building Nigeria's Response to Climate Change (BNRCC) [6]	✓	✓	Focus Group, Interviews, Questionnaire	Various	Indicator method, statistical method
11	Cervigni et al. [45]		✓	GIS, Expert Review of National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN)	Yield (t/ha) (Crop); Temperature Humidity Index (Livestock); Gross Primary Productivity (Livestock)	Spatial mapping (remote sensing and GIS techniques, re-scaling normalization technique)
12	Chikezie et al. [46]	✓		Questionnaire	Composite Vulnerability Index	Indicator method (principal component analysis), statistical method (ordinary least squares regression)
13	Chukwuemeka et al. [47]	✓		Questionnaire, Focus Group Discussions	Composite Vulnerability Index	Indicator method (index computation)
14	Eze et al. [48]	✓		Questionnaire	Composite Vulnerability Index	Indicator method (principal component analysis, correspondence analysis)
15	Madu [37]		✓	Nigerian Annual Abstract of Statistics 2009 Database; General Household Survey 2006 Database; Core Welfare indicator Questionnaire Survey (CWIQ) 2006 Database	Composite Vulnerability Index	Indicator/statistical method (descriptive analysis, principal component analysis, cluster analysis)

Table A1. *Cont.*

Serial/Number	Author(s)	Primary Data	Secondary Data	Data Collection Tool	Vulnerability Proxy	Main Analytical Approach
16	Madu [49]		✓	Nigerian Annual Abstract of Statistics 2009 and General Household Survey 2006	Composite Vulnerability Index	Indicator/statistical method (descriptive analysis, principal component analysis, index computation, Pearson's product correlation analysis)
17	Manu et al. [50]	✓	✓	Questionnaire, NIMET Database	Composite Vulnerability Index	Indicator/statistical method (descriptive analysis, principal component analysis)
18	Medugu and Majid [51]	✓		Questionnaire, Interviews, Focus Group Discussions	Composite Vulnerability Index	Indicator method (descriptive, weighting, and averaging indicators)
19	Ojo [52]		✓	GIS, NIMET; Federal Ministry of Agriculture	Crop Yield	Spatial mapping (GIS techniques and re-scaling normalization technique)
20	Umar et al. [35]		✓	NIMET	Crop Yield	Statistical method (descriptive statistics, trend analysis)

Note: NIMET: Nigerian Meteorological Agency; GIS: geographic information system; NBS: Nigerian National Bureau of Statistics.

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