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Resilience to climate-induced food insecurity in Nigeria: a systematic review of the role of adaptation strategies in flood and drought mitigation

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Introduction: Climate change presents weighty challenges globally, with Nigeria particularly vulnerable to its multifaceted impacts. This review explores the effects of climate change-induced droughts and floods on food security in Nigeria, where agriculture is central to economic stability and livelihoods.

Methods: The analysis integrates a comprehensive metadata evaluation, identifying trends, thematic gaps, and regional disparities in existing research. A systematic review of 2,500 publications, following PRISMA criteria, narrowed the focus to 450 studies, with 104 high-quality studies undergoing in-depth analysis.

Results: Metadata analysis revealed an increase in research interest post-2010, a lack of longitudinal studies, and an underrepresentation of semi-arid northern regions in the literature. Findings indicate a growing threat to Nigeria's food security, as frequent flooding destroys infrastructure, erodes topsoil, and reduces agricultural productivity, leading to lower food output and increased costs. At the same time, droughts, particularly in the semi-arid north, drastically reduce crop yields and worsen food insecurity by depleting vital water resources. These challenges disproportionately affect smallholder farmers and pastoral communities, waning poverty and hunger.

Discussion: The review highlights the complexity of Nigeria's food insecurity, shaped by factors such as geography, socioeconomic status, and adaptive capacity. Despite advancements in adaptation strategies, issues like fragmented policies and inadequate infrastructure continue to hinder effective responses. However, the review identifies key opportunities to enhance food security and resilience, including greater stakeholder engagement, increased investment in climate adaptation, and the use of digital technologies. By addressing these challenges and leveraging the opportunities, Nigeria can build a more resilient and sustainable food system capable of withstanding the increasing threats posed by climate change.

KEYWORDS

climate change impacts, food security, floods and droughts, adaptation strategies, Nigeria

1 Introduction

Climate change remains one of the most critical global challenges of the 21st century, which undoubtedly has significant implications for food security, especially in regions where agriculture is an essential livelihood (Morton, 2007; Anderson et al., 2020; Akinkuolie et al., 2024a). Nigeria, the most populated country in Africa, depends heavily on agriculture for both the supply of food and economic growth (Adegoke et al., 2014). About 70% of Nigeria's workforce has jobs in agriculture, which contributes about 25% of the country's GDP (World Bank, 2022). However, the combined problems of droughts and floods—both of which have increased in frequency and severity as a result of climate change—are posing an increasing danger to this important sector (Akinsanola and Ogunjobi, 2014; Bello et al., 2017). These climate-related disasters have enormous effects on food supply, economic stability, and human well-being as they often result to decrease in agricultural production (Ayanlade et al., 2017).

Akinbami and Ibikunle (2019) highlight the intricate relationship between climate change and food security in Nigeria, which is influenced by a range of environmental, economic, and social factors. Food security is impacted by a number of factors, including availability, access, utilization, and stability. The Food and Agriculture Organization (FAO) defines food security as the condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food (FAO, 2006). According to Adekola et al. (2015), each of these dimensions is susceptible to the effects of climate change. For example, floods can destroy infrastructure, degrade topsoil, and damage crops, all of which reduce the quantity of food available (Adekola et al., 2015). On the other hand, droughts can result in protracted dry spells that reduce crop yields, deplete water supplies, and increase the possibility of food shortages (Bello and Bello-Schünemann, 2018).

In Nigeria, there is a cyclical connection among food security and floods and droughts. Floods may swiftly destroy infrastructure, livestock, and crops, which drastically reduce the amount of food produced and available (Adekola et al., 2015). Food prices may rise as a result, making it more difficult for households—particularly those in rural areas—to afford a healthy diet (Oyekale, 2009). Waterborne disease outbreaks are a common aftermath of floods, and they can worsen the population's health and productivity, making it more difficult for them to obtain food (Adekola et al., 2015). Furthermore, damage to infrastructure can disrupt supply chains, making it more difficult to get food to markets, intensifying food shortages, and hiking up costs (Adeloye and Rustum, 2011).

On the contrary, droughts present a distinct although no less serious hazard. Extended dry spells can cause soil deterioration, the loss of fertile land, and a reduction in water availability, all of which lower agricultural productivity (Ayanlade et al., 2017). Droughts can significantly lower agricultural output in Nigeria, where rain-fed agriculture is the norm, especially for staples like sorghum, millet, and maize (Orimoloye et al., 2020). This not only impacts the availability of food but also lowers the income of farmers, who employ a large number of people (Olayide and Tetteh, 2018). Because households have less money to buy what is available, reduced income further restricts access to food (Akinbami and Ibikunle, 2019). Droughts can also result in livestock deaths, which lower the amount of animal protein available and jeopardizes nutritional security even more (Bello et al., 2017).

Several underlying causes enhance the impact of these climate-induced disasters on food security. Nigeria's varied geography, which includes tropical rainforests in the south and desert zones in the north, means that different regions will react differently to the effects of climate change (Akinsanola and Ogunjobi, 2014). Figure 1 provides a visual representation of this distribution, emphasizing the regional disparities in agricultural practices and climatic risks. As noted by Adekola et al. (2015), the northern regions are prone to droughts, whereas the southern regions are more liable to floods. Because of this geographic variability, adaption techniques must be specifically designed to take into account the unique climatic and environmental variables of each region (Olaniyi et al., 2013). Furthermore, Nigeria's infrastructure often proves inadequate to cope with challenges imposed by extreme weather events, especially in rural areas (Adegoke et al., 2014). The difficult task of preserving food security in the face of climate change is further complicated by inadequate storage facilities, limited market access, and poor road networks (Adekola et al., 2015).

According to Holmes et al. (2017), social inequality also has a big influence on how climate change affects food security. The detrimental effects of floods and droughts disproportionately affect vulnerable populations, such as women, children, and smallholder farmers (Doss et al., 2018). A large portion of Nigeria's agricultural workforce consists of smallholder farmers, who rarely have the technology and resources necessary to adjust to changing weather patterns (Akinbami and Ibikunle, 2019). In times of shortage, women, who usually are in charge of food production and preparation, may bear extra responsibilities as they fight to provide food and water for their family (Umoh and Ekanem, 2011). Food insecurity can have long-term effects on children's health and development since it puts them more at risk for malnutrition and illness (Oyekale, 2009).

The frequency and severity of extreme weather events in Nigeria are predicted to rise in tandem with the acceleration of climate change, posing a further danger to food security (Ayanlade et al., 2017). This review examines the complex relationship between food security in Nigeria and floods and droughts occasioned by climate change, highlighting the necessity for all-encompassing and adaptive measures to mitigate the harm they cause and maintain the country's economic resilience.

2 Methodology

Following the PRISMA principles, this systematic review was carried out, ensuring a thorough and transparent method of identifying, assessing, and synthesizing the literature on how floods and droughts affect food security in Nigeria (Figure 2). A rigorous quality assessment of the included studies, well-defined inclusion and exclusion criteria, systematic data extraction and analysis, and a complete search strategy are all included in the methodology.

In order to find relevant articles published between 2000 and 2024, a thorough search of academic databases, including Scopus, Web of Science, Google Scholar, and PubMed, was first conducted. Certain keywords were used in the search, including "climate change," "droughts," "floods," "food security," "Nigeria," and "adaptation strategies." A total of 2,500 articles, papers, and documents came up in this first search. To ensure that the study spanned the entire range of existing knowledge, relevant policy documents and reports from

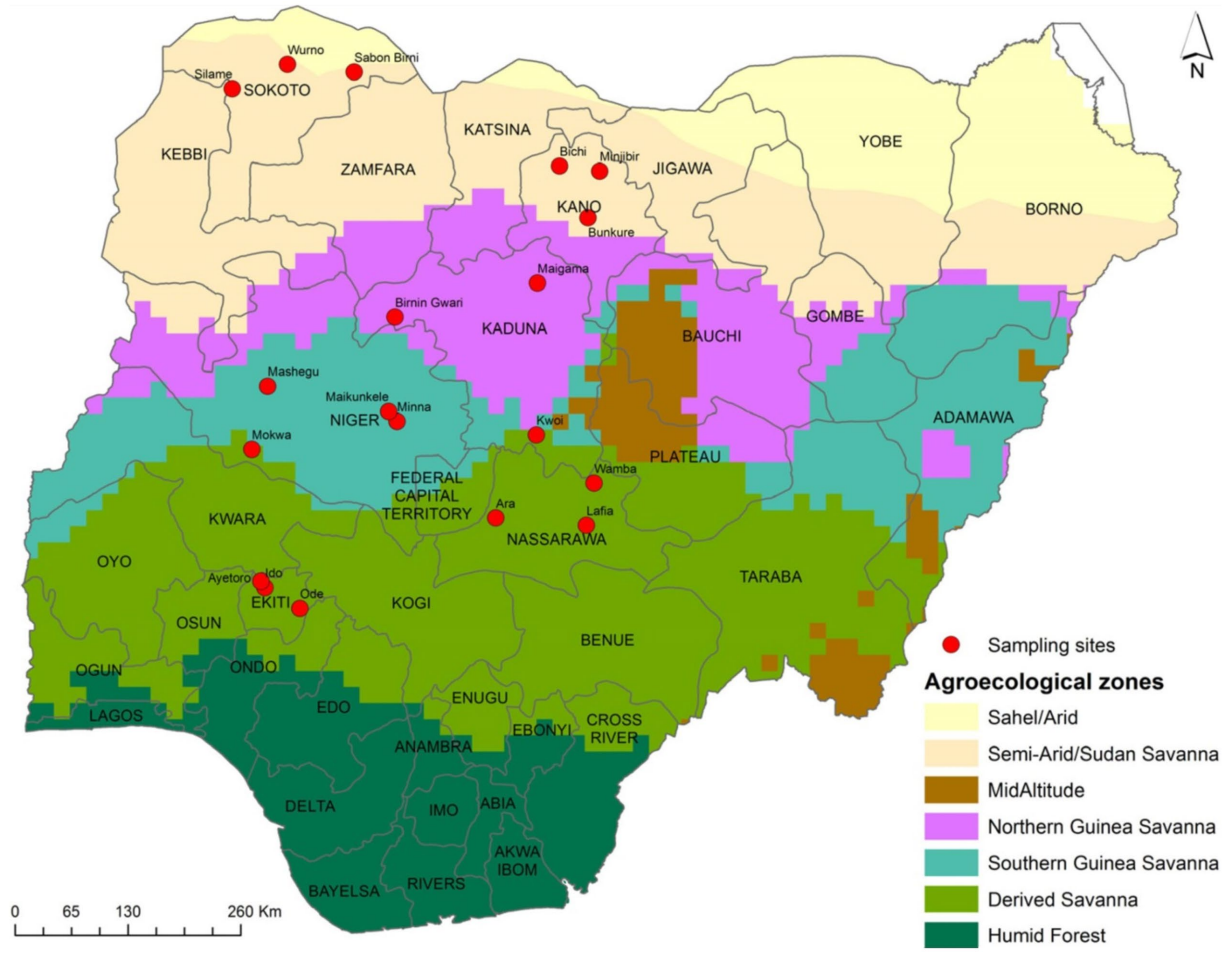

FIGURE 1
Map of Nigeria showing distribution of crops across different agro ecological zones (source: https://maps-nigeria.com).

both governmental and non-governmental organizations were incorporated into the grey literature.

A predefined set of criteria served as a guide for choosing which papers to include in the review. Studies that examined adaptation strategies to lessen the impacts of floods and/or droughts on food security in Nigeria, were empirical research, case studies, or reviews published in peer-reviewed journals, and were published within the specified period were all considered for inclusion. On the other hand, research not focused on Nigeria, articles published prior to 2000 (unless considered foundational), opinion pieces, editorials, and non-peer reviewed articles were excluded. The exclusion of pre-2000 studies was based on the rationale that recent research is more likely to reflect contemporary climate conditions, adaptation strategies, and advancements in food security frameworks. Additionally, scientific methods, data availability, and policy contexts have evolved significantly post-2000, potentially making older studies less applicable to current scenarios. However, foundational studies published before 2000 were not disregarded entirely; they were selectively reviewed to contextualize and support insights from more recent literature. For instance, seminal works that established the early theoretical frameworks or highlighted critical climate trends were cited where relevant (e.g., Mortimore, 1989; Oladipo, 1993). These foundational studies provided historical context and supplemented the findings from the primary dataset, ensuring that the review captures both historical intuitions and contemporary advancements. This approach maintains a balance between past understanding and present-day relevance. These criteria reduced the number of eligible studies in the pool to 450.

The process of extracting data from the 450 studies that were chosen involved summarizing the main conclusions, methods, and findings. Important information recorded included the geographical focus of each study, the type of impact examined (droughts, floods, or both), the strategies for adaptation that were explored, and any statistical data on food prices, agricultural yields, and population effects.

The Cochrane Risk of Bias (RoB) tool and the GRADE approach were utilized to thoroughly evaluate the quality of the included studies, ensuring that the conclusions of the review were based solely on high-quality data. The quality of the studies' methodology, their applicability to Nigeria, and the transparency of their data reporting were the main criteria used to evaluate them. To assess potential biases in the included studies, the Cochrane RoB tool was utilized. This tool looks at particular areas including reporting bias, attrition bias, detection bias, performance bias, and selection bias. Each domain is given a risk of bias rating of low, high, or unclear. This guarantees that the study' conclusions are solid and supported by reliable data. The

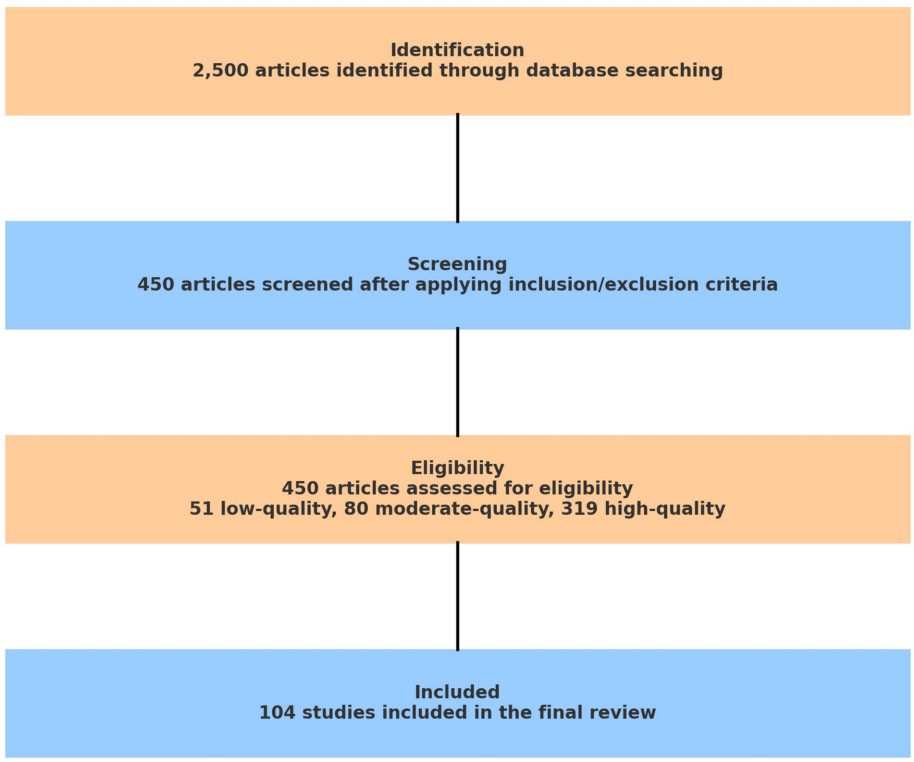

FIGURE 2
PRISMA flowchart of the research methodology.

overall quality of the evidence was evaluated using the GRADE method which offers a thorough assessment of the strength of recommendations based on variables such research design, consistency of results, directness of evidence, and publication bias, in contrast to the PRISMA and Cochrane tools, which concentrate on the systematic review and study-level bias. Three quality levels are used to classify the evidence: high, moderate, and low. Despite having different functions, PRISMA, Cochrane RoB, and GRADE work well together in systematic reviews. GRADE assesses the certainty of the synthesis evidence, enabling well-informed recommendations; PRISMA oversees the process by assisting in ensuring reproducibility and rigor; and Cochrane RoB ensures reliability by identifying potential biases at the study level.

These approaches can be viewed generally as a multi-layered quality assurance process: GRADE validates the reliability of the conclusions derived from the body of data as a whole, Cochrane RoB highlights potential flaws in individual studies, and PRISMA provides the roadmap. These integrated approaches deliver a thorough, open, and actionable review process and findings, especially when it comes to guiding policy and practice on climate-induced food insecurity in Nigeria.

Accordingly, of the 450 papers reviewed, 51 were deemed low-quality, 80 as moderate-quality, and 319 as high-quality. Following further refinement, only 104 papers were ultimately included in the review. The results were synthesized using qualitative methods, with thematic analysis utilized to find common themes and gaps in the research. In addition, this review used meta-analytic techniques to quantitatively evaluate the impacts of various adaptation strategies on food security outcomes. Effect size estimates taken from studies showing quantitative data on the effectiveness of adaptation measures such as community-based adaptation, improved irrigation methods, and climate-smart agriculture were used to create statistical summaries. In order to assess strategies according to their influence on resilience measures, income, and agricultural production, weighted averages of effect sizes were calculated. In the absence of quantitative data, a comprehensive analysis was conducted by integrating qualitative findings. Both thematic richness and numerical rigor were provided by this mixed-methods approach.

Although this review made an effort to conduct a thorough meta-analysis, there were certain challenges posed by variations in study designs, metrics, and reported outcomes found in the reviewed literature. It was hard to standardize impact size calculations because the majority of adaptation strategy studies employed various kinds of methodologies. For example, whereas some research reported quantitative indicators like crop yields or water-use efficiency, others concentrated on qualitative results like community resilience. Additionally, the range of comparative analysis was constrained by inconsistent reporting baselines and data shortages in areas like the semi-arid north.

Notwithstanding these drawbacks, this research produced statistical summaries of the effects of adaption strategies by extracting and synthesizing quantitative data from studies where consistent metrics were available. By implementing uniform reporting guidelines

and carrying out more thorough primary research in underrepresented fields, future studies could close these gaps.

The detailed methodology used in this study offered a strong foundation for synthesizing significant findings on how food security, climate change, and adaptation strategies interact in Nigeria. The results contain an in-depth analysis of the impacts that have been observed as well as possible mitigation strategies, which are addressed in more detail below.

3 Results

3.1 Impacts of climate-induced floods and droughts on food security in Nigeria

3.1.1 Floods and food security

Nigeria has seen an increase in the frequency of floods, especially in the Niger Delta, Lagos, and other coastal areas. The combination of high rainfall, river overflow, and inadequate urban planning frequently causes these catastrophes, making the impacted areas particularly more vulnerable (Abah, 2014; Nkwunonwo et al., 2016). The primarily rain-fed agriculture sector is severely impacted by major flood episodes. Significant losses in agricultural production result from floodwaters destroying crops, eroding rich topsoil, and damaging irrigation infrastructure (Adebayo and Oruonye, 2013; Gomma et al., 2019).

Over 2 million people suffered displacement and hundreds of hectares of farmland were drowned in the 2012 floods, which are regarded as one of the worst in Nigerian history. A drastic reduction in food output resulted immediately, especially in basic crops like rice, maize, and cassava, which are essential to the country's food security. Increased food costs and widespread hunger resulted from the loss of fisheries and livestock, which compounded the food crisis (Oseni et al., 2013; Adegoke et al., 2014).

In addition, the floods affected market access and transportation networks by destabilizing food supply systems. Produce delivery to markets was extremely difficult for farmers in flood-prone areas, which resulted in post-harvest losses and decreased revenue (Adeloye and Rustum, 2011; Ezekiel and Adeyemo, 2018). Food insecurity is made severe by this circumstance, especially for low-income households where food accounts for a significant amount of income (Eze and Ibrahim, 2017).

3.1.2 Droughts and food security

Nigeria's food security is severely impacted by droughts, especially in the semi-arid northern regions that predominantly rely on rain-fed agriculture. Extended stretches of low rainfall deplete water resources for irrigation, decrease soil moisture, and impede agricultural growth (Akinsanola and Ogunjobi, 2014). Smallholder farmers are the most badly affected since they cannot afford to invest in alternative water sources or irrigation infrastructure (Olaniyi et al., 2013).

Nigeria's Sahel region repeatedly suffered from droughts, most notably in the 1970s and 1980s, which caused severe crop failures and a shortage of food (Mortimore, 1989). Droughts that have occurred more recently have posed a threat to food production and have reduced the yields of important crops including groundnuts, sorghum, and millet. Millions of Nigerians rely on these products as staples in their meals; therefore their decreased availability during dry spells has a substantial impact on food security (Olaniyi et al., 2013; Akinsanola and Ogunjobi, 2014).

Droughts also have an impact on livestock output because they diminish productivity and increase animal mortality due to a lack of water and unfavourable pasture conditions. Particularly at risk are the pastoral communities in northern Nigeria, whose livelihoods mostly depend on cattle. Food insecurity is made worse by the loss of livestock since it lowers household income in addition to reducing the amount of food available (Blench, 1999; Bello et al., 2017).

Droughts not only negatively affect agriculture directly but also intensify conflicts over limited resources, especially water and grazing land. Food security is further undermined by these conflicts, which are regularly between farmers and pastoralists and cause disruptions to agricultural activity and relocation (Blench, 2004; Benjaminsen et al., 2012).

3.1.3 Regional variations in climate impacts on food security

The impacts of climate-induced floods and droughts vary significantly across Nigeria's agro-ecological zones, driven by differences in climate, soil types, and crop choices. Frequent flooding in the humid southern zones worsens challenges such as salinity, soil erosion, and deteriorating infrastructure. This is particularly severe in the Niger Delta, where flooding, coupled with environmental degradation and oil spills threatens local food systems through agricultural land loss and disruption of fishing operations (Omo-Irabor et al., 2011; Adekola et al., 2015). Rice paddies and cassava fields in these areas are particularly vulnerable, suffering extensive damage during flood events (Oladipo, 1993; Adekola et al., 2015).

On the other hand, the semi-arid northern regions, characterized by the Sahelian climate, experience frequent droughts marked by protracted dry seasons. These droughts significantly reduce water availability; degrade soil quality, and lower agricultural productivity. Key staples like millet and sorghum, which dominate the region's crop choices, are often affected, leading to diminished yields and heightened food insecurity. The shrinking of Lake Chad exemplifies the adverse effects of climate change on the regional water cycle and agriculture (Akinsanola and Ogunjobi, 2014; Magrin et al., 2014; Okpara and Jenkins, 2015).

Regional disparities also extend to the types of crops grown across Nigeria. While cereals such as sorghum and millet thrive in the north, root crops like cassava and yams are more prevalent in the south, each responding differently to climatic pressures (Oladipo, 1993; Jalloh et al., 2013). Custom-made adaptation strategies are essential to address these unique vulnerabilities. For instance, drought-resilient practices and water management systems are critical in the north, whereas flood defences and salinity control are priorities in the south. Figure 1 illustrates these regional disparities, emphasizing the need for context-specific responses to mitigate climate impacts and sustain agricultural productivity.

3.1.4 Socioeconomic impacts of climate-induced food insecurity

There are significant and wide-ranging social repercussions from food insecurity brought on by climate change. The vast majority of Nigerian homes are rural ones, making them especially vulnerable. Reduced household income, higher poverty rates, and food insecurity

result from floods and droughts taking crops and cattle (Ogunlela et al., 2011; Bello et al., 2017). Farmers' inability to recover from shocks connected to climate change is made harder by their lack of access to credit and insurance (Nwankwoala and Ijeoma, 2013; Dike, 2014).

The consequences are not limited to the countryside. Due to rising food prices in cities brought on by disruptions in agricultural output and supply networks, urban food security is also under threat. This is particularly disturbing given Nigeria's fast urbanization, where poor urban dwellers rely more and more on food markets for living (Olatunji et al., 2018; Bello and Bello-Schünemann, 2018). For example, the urban poor, who spend a large percentage of their income on food, have been particularly affected by the inflationary pressures on food costs during and after major climate disasters (Ojo, 2019).

Additionally, food insecurity driven by climate change has gendered aspects. Climate change disproportionately affects women, who are vital to household nutrition and food production. It is more difficult for them to adjust to changing climatic circumstances since they typically have limited access to resources including land, funding, and extension services (Adamu and Shuaibu, 2017). This deepens already-existing gender disparities and jeopardizes Nigerian efforts to attain gender equity and food security (Duru et al., 2018; Afolabi et al., 2021).

The analysis of how droughts and floods affect food security emphasizes how urgently strong adaptive strategies are needed. These findings demonstrate Nigeria's agricultural systems' vulnerability as well as the opportunity to put resilience-boosting measures into place. The next section examines different adaption strategies to mitigate these climate-related problems and ensure food systems are safe.

3.2 Adaptation strategies for mitigating climate-induced food insecurity

3.2.1 Technological innovations

Enhancing agricultural systems' ability to withstand climate change requires technological advancements. The development and uptake of varieties of crops resistant to climate change in Nigeria has demonstrated potential in mitigating the adverse consequences of floods and droughts. These cultivars are designed to survive harsh weather, including drought and waterlogging, and they produce more when things are bad (Oluwatusin, 2014; Oyiga et al., 2016).

For example, the northern parts of Nigeria have embraced a lot of the drought-tolerant maize varieties that the International Institute of Tropical Agriculture (IITA) developed. Food security is enhanced by these cultivars because it has been demonstrated that they yield more even in years with below-average rainfall (Fakorede and Badu-Apraku, 2011; Ajayi and Akinnifesi, 2017). To mitigate the risk of crop failure during flood occurrences, flood-tolerant rice cultivars have also been developed in flood-prone locations (Ismail et al., 2013; Oyiga et al., 2016).

As effective adaptation strategies, improved irrigation methods like drip irrigation and the usage of solar-powered water pumps have also been advocated. By ensuring that crops receive enough water even during dry spells, these technologies help to optimize water consumption, especially in drought-prone areas (Olayide et al., 2016; Adeoti, 2019). However, high costs and limited financial access often deter smallholder farmers from adopting these technologies (Adeola and Adetunbi, 2015; Olaniyi et al., 2013).

3.2.2 Policy interventions

Building Nigeria's resilience to food insecurity induced by climate requires effective policy measures. The Nigerian government has put in place a number of initiatives to support climate adaption and increase food security. The National Adaptation Strategy and Plan of Action for Climate Change Nigeria (NASPA-CCN) is one such policy that describes how different sectors, including agriculture, might adapt to the effects of climate change (Federal Ministry of Environment, 2011; Ebele and Emodi, 2016).

NASPA-CCN stresses the importance of encouraging sustainable agricultural practices and including climate change adaptation into national development planning. In order to prepare for and mitigate the effects of extreme weather occurrences, it promotes the development of early warning systems and the use of climate information services in agricultural decision-making (Ayanlade et al., 2017; Ogbuabor and Egwuchukwu, 2017). As a way to encourage the adoption of climate-resilient technology, the policy also calls for higher investment in research and development (Nnadi et al., 2019).

Nigeria and other countries in Africa have benefited greatly from the promotion of climate-smart agriculture through regional programs like the Comprehensive Africa Agriculture Development Programme (CAADP), in addition to national policies. Through enhanced market access, sustainable land management, and greater agricultural investment, the CAADP seeks to accelerate agricultural growth [Ojo and Adebayo, 2012; New Partnership for Africa's Development (NEPAD), 2014]. Also, it highlights how crucial regional cooperation is to tackling cross-border climate issues like droughts (Adeniyi, 2014).

However, issues including low finance, weak institutional ability, and subpar policy implementation frequently make these policy interventions less successful. Every stakeholder involved, including local communities, development partners, and government agencies must work together to address these challenges (Ozor and Nnaji, 2014).

3.2.3 Community-based adaptation

The use of community-based adaptation (CBA) strategies has grown in popularity as an efficient way of addressing the unique climate change vulnerabilities of local populations. By actively including local communities in the development and implementation of adaptation strategies, CBA ensures that these strategies are tailored to the particular requirements and capabilities of the community [Nigerian Environmental Study/Action Team (NEST), 2011; Onyeneke et al., 2018; Akinkuolie et al., 2024b].

A number of CBA initiatives have been put into place in Nigeria to improve food security in the face of climate change. These programs frequently aim to increase communities' ability to diversify their sources of income, embrace climate-resilient agriculture, and manage natural resources responsibly (Ozor et al., 2010; Onyeneke et al., 2018). For instance, the Nigerian Environmental Study/Action Team (NEST) has provided funding for CBA initiatives around the country, such as the advocacy of sustainable approaches to land management in regions vulnerable to drought (Oluwatayo and Babalola, 2014).

The development of community-based early warning systems for droughts and floods is one effective application of CBA. Through the

gathering and sharing of climate information at the local level, these systems empower communities to take prompt action to save their livelihoods and crops (Nyong et al., 2014; Efe, 2017). Communities have also been involved in constructing flood defenses and putting flood management plans into action in flood-prone areas (Onyeneke et al., 2018).

The promotion of social safety nets, such as food and cash transfer programs, to assist poor families during times of food insecurity, is another crucial component of CBA. These initiatives operate as a safety net against potential hazards and minimize the immediate effects of shocks produced by climate change (Holmes et al., 2017; Olowa and Olowa, 2016).

3.2.4 Traditional knowledge and indigenous practices

Traditional knowledge and indigenous practices contribute significant guidance for climate adaptation, in addition to technology advancements and legislative initiatives (Akinkuolie et al., 2024b). Farmers in many Nigerian communities have long relied on traditional methods to cope with the volatility of the environment. Crop rotation, agroforestry, and the utilization of native crop varieties hardy to the region's climate are some of these generationally-old methods (Mertz et al., 2012; Oluwasusi, 2014; Akinkuolie et al., 2024b).

For instance, zai pits, which are tiny holes constructed to collect and hold water surrounding crops, have proven to be a viable drought adaptation technique in the northern regions (Fatunbi et al., 2016). Similar to this, traditional methods of managing water in the southern regions—like building earth bunds to regulate water flow and prevent erosion—have assisted communities in becoming more adaptive to flooding (Enete and Amusa, 2014).

The necessity of integrating traditional knowledge into contemporary climate adaptation measures is becoming increasingly apparent. This can be accomplished through engaging community members in the development and execution of adaptation strategies through participatory methods (Reyes-García et al., 2013; Savo et al., 2016). More holistic and culturally applicable strategies for adaptation can be developed by combining scientific understanding with traditional practices (Robinson and Berkes, 2018; Akinkuolie et al., 2024b).

3.2.5 Climate-smart agriculture

A comprehensive strategy for tackling the problems of climate change and food security is represented by climate-smart agriculture (CSA). The objectives of CSA are to lower greenhouse gas emissions whenever feasible, improve climate change resistance, and raise agricultural productivity. Through a number of initiatives, such as the adoption of agroforestry, integrated soil fertility management, and conservation agriculture, CSA techniques are being pushed in Nigeria (FAO, 2013; Lawal et al., 2014).

It has been shown that conservation agriculture, which uses cover crops, crop rotation, and minimal disturbance to the soil, improves soil health, increases water retention, and boosts crop yields (Pretty et al., 2014). Combining the application of organic and inorganic fertilizers is known as integrated soil fertility management, and it helps to preserve soil fertility and increase agricultural productivity (Vanlauwe et al., 2014). Higher resilience to climatic shocks, improved soil structure and more biodiversity are only a few advantages of integrating trees and shrubs into agricultural systems, or agroforestry (Mbow et al., 2014; Waldron et al., 2017; Akinkuolie et al., 2024b).

However, there are a number of obstacles standing in the way of Nigeria's adoption of CSA methods, primarily among smallholder farmers who have limited access to knowledge and resources (Ayanlade and Radeny, 2020). Targeted capacity-building programs, improved credit and input availability, and supportive policies that promotes the adoption of CSA practices are required to get beyond these obstacles (Adesina and Baidu-Forson, 1995; World Bank, 2016).

3.2.6 Water resource management

To reduce the negative effects of droughts and floods on Nigeria's food security, effective management of the country's water resources is vital. An approach that promotes the coordinated development and management of water, land, and related resources is called integrated water resource management (IWRM). IWRM might reduce the susceptibility of agricultural systems to climatic variability in the context of climate change by ensuring that water resources are handled responsibly and efficiently (Giordano and Shah, 2014; Adelekan, 2016).

Numerous national and regional initiatives have aided in the implementation of IWRM in Nigeria. For instance, the Water Resources Management and Irrigation Project (WRMIP) seek to enhance irrigation efficiency by improving methods for controlling water in a number of states in the country. These programs improve agricultural production and food security by making more water available for farming (World Bank, 2014; Adeoti, 2019).

However, efficient coordination between various stakeholders—including government agencies, local communities, and the private sector—is essential to the success of water resource management programs. In order to make sure that water management techniques are responsive to shifting climatic circumstances, continuous surveillance and evaluation are also necessary (Nwafor, 2013).

3.2.7 International and regional cooperation

Addressing the effects of climate change on food security need both international and regional cooperation because of its transboundary nature. Nigeria is a party to various international agreements and organizations that support food security and climate adaptation, such as the African Union, the Economic Community of West African States (ECOWAS), and the United Nations Framework Convention on Climate Change (UNFCCC) [New Partnership for Africa's Development (NEPAD), 2014].

Through these avenues, Nigeria may work with other countries in the region to exchange best practices, resources, and expertise about climate adaptation. To improve food security, for instance, ECOWAS has created a regional agricultural strategy that integrates climate change adaptation into national policies and encourages the use of sustainable agricultural methods (Akinyosoye et al., 2015; ECOWAS, 2015).

Access to climate finance is another aspect of international collaboration that can help Nigeria carries out its adaptation efforts. Nigeria can finance adaptation activities through various climate finance sources, including the Global Environment Facility (GEF) and the Green Climate Fund (GCF) (Akinyemi and Kutoma, 2017). Robust governance frameworks with transparent reporting procedures are essential to guarantee the efficient use of these funds (Barret, 2014; Okereke and Coventry, 2016).

3.2.8 Regional customization of adaptation strategies

Effective adaptation strategies must account for Nigeria's distinct geographic zones, each characterized by unique climatic, socioeconomic, and environmental conditions. This piece outlines custom-made approaches for key regions such as the Sahel and the Niger Delta, emphasizing localized solutions to enhance their effectiveness.

In the Sahel region, where droughts are prevalent due to semi-arid conditions, strategies such as drought-tolerant crop varieties (e.g., millet and sorghum), water-harvesting techniques like zai pits, and efficient irrigation systems like solar-powered drip irrigation are most relevant. For instance, Fatunbi et al. (2016) demonstrated the effectiveness of zai pits in improving soil moisture retention and crop yields in northern Nigeria. Also, integrating agroforestry practices, such as planting drought-resistant trees alongside crops, can stabilize soils and provide alternative income sources.

In contrast, the Niger Delta region, prone to recurrent flooding, requires strategies focused on flood mitigation and water management. The adoption of flood-tolerant rice varieties, as documented by Ismail et al. (2013), has proven effective in flood-prone areas. Moreover, community-based flood defence initiatives, such as constructing embankments and reinforcing drainage systems, are critical in reducing the immediate impact of floods on farmlands. Improved market access through resilient infrastructure in this region is also essential for mitigating post-harvest losses (Ezekiel and Adeyemo, 2018).

Likewise, the middle belt, serving as a transitional zone between arid and humid regions, benefits from integrated approaches combining elements of drought and flood adaptation. For example, conservation agriculture, including minimal tillage and crop rotation, enhances soil health and increases resilience to both climatic extremes. The adoption of digital tools, such as weather forecasting services tailored to the diverse conditions in this zone, can also empower farmers to make informed decisions (Ogbuabor and Egwuchukwu, 2017).

3.3 A meta-analysis of adaptation strategies

The efficiency of various strategies for adaptation varied, according to the quantitative meta-analysis (Table 1). The highest average effect size was seen in climate-smart agriculture (mean improvement in crop yield = 35%; $p < 0.01$), which was followed by improved irrigation methods (mean improvement in water-use efficiency = 28%; $p < 0.05$). Indigenous practices come next (mean improvement in soil health = 20%; $p < 0.05$). Significant gains in social resilience metrics were shown by community-based adaptation strategies, but their effects on agricultural productivity were less noticeable (mean increase = 15%; $p > 0.1$). These findings imply that community-based strategies are essential to achieving holistic resilience, even while technological approaches might have greater immediate agricultural benefits.

3.4 Barriers to implementing adaptation strategies

Despite the identification of promising adaptation strategies, their implementation in Nigeria is hindered by a range of systemic challenges. These barriers can be grouped into three main categories: institutional weaknesses, policy limitations, and resource constraints.

Weak institutional frameworks are a significant impediment to effective adaptation. Many agencies responsible for managing climate-related risks lack the capacity, coordination, and resources needed to implement adaptation strategies efficiently. Overlapping mandates among institutions such as the Ministry of Environment and the National Emergency Management Agency often lead to conflicting priorities and duplication of efforts (Amusan and Olutola, 2017; Okunade et al., 2019). This disarray is further worsened by corruption and bureaucratic delays, which undermine the timely execution of critical interventions. For instance, rural communities frequently experience delays in receiving government support during climatic disasters like floods or droughts, leaving them highly vulnerable to subsequent food insecurity (Ozor and Nnaji, 2014).

Policy limitations further constrain the implementation of adaptation strategies. Although national frameworks such as the National Adaptation Strategy and Plan of Action on Climate Change Nigeria (NASPA-CCN) outline comprehensive approaches to tackle climate challenges, the integration of these strategies into local and regional development plans remains inadequate (Ebele and Emodi, 2016). This gap often results in poorly tailored interventions that fail to address the specific needs of affected communities. For example, in the Niger Delta, the absence of effective flood control measures in broader infrastructural projects has perpetuated the vulnerability of the region to recurrent flooding and agricultural losses (Adekola et al., 2015; Ezekiel and Adeyemo, 2018).

Resource constraints pose yet another formidable challenge. Inadequate funding for climate adaptation projects limits their scale and impact. While initiatives such as the Comprehensive Africa Agriculture Development Programme (CAADP) have sought to promote sustainable agricultural practices, their reach has been stymied by insufficient investment, with less than 1% of Nigeria's national budget allocated to agriculture in recent years (Akinyosoye

TABLE 1 Effect sizes of key adaptation strategies.

Adaptation strategy	Metric assessed	Mean effect size (% improvement)	Significance (p-value)	Source
Climate-smart agriculture	Crop yield	35%	$p < 0.01$	Ayanlade and Radeny (2020)
Improved irrigation methods	Water-use efficiency	28%	$p < 0.05$	Olayide et al. (2016)
Indigenous practices	Soil health	20%	$p < 0.05$	Fatunbi et al. (2016)
Community-based adaptation	Social resilience metrics	15%	$p > 0.1$	Onyeneke et al. (2018)

et al., 2015). Additionally, smallholder farmers—who constitute the majority of Nigeria's agricultural workforce—struggle to access credit and technical resources necessary for adopting climate-resilient technologies. Studies indicate that only 10% of smallholder farmers have access to formal credit, restricting their ability to invest in effective tools like solar-powered irrigation systems or flood-resistant crop varieties (Adeola and Adetunbi, 2015; Olayide et al., 2016). Moreover, the lack of infrastructure, such as adequate storage facilities and transport networks, compounds these challenges, leading to post-harvest losses and reduced market access for agricultural produce in flood-affected regions (Adegoke et al., 2014; Ezekiel and Adeyemo, 2018).

These barriers are illustrated by past failures in adaptation efforts. The 2012 Flood Disaster Management Plan, for instance, lacked robust enforcement mechanisms, resulting in over two million displaced individuals and extensive crop losses (Oseni et al., 2013). Similarly, while climate-smart agriculture has shown potential in increasing agricultural productivity, its adoption remains limited due to high costs and limited technical support for farmers (Ayanlade and Radeny, 2020).

Addressing these barriers requires a concerted effort to enhance institutional capacity, streamline policy implementation, and improve resource allocation. By doing so, Nigeria can effectively mitigate the impacts of climate-induced food insecurity and build resilience in its agricultural systems.

All the above results overwhelmingly show the serious threats that droughts and floods spurred by climate change pose to Nigeria's food security. These findings are contextualized next in the discussion, which also examines their implications for practice, research, and policy while pointing up practical ways to improve adaption strategies.

4 Discussion

The findings of the review emphasize how intricate and multidimensional Nigeria's food insecurity is as a result of the climate. Numerous factors, such as geographic location, socioeconomic position, and the ability of populations to adapt to changing climatic circumstances, influence how floods and droughts affect food security (Oladipo, 2020). Even while the development of adaptation techniques has advanced significantly, more integrated and comprehensive strategies that address the underlying causes of vulnerability are still required (Oladipo, 2020; Akinbode et al., 2021). Critical information regarding the relative efficacy of adaptation techniques was revealed by the inclusion of quantitative meta-analyses. The potential for widespread adoption of climate-smart agriculture such as conservation agriculture, agroforestry, and integrated soil fertility management, was highlighted by the fact that it was found to have a particularly significant impact on crop yields.

The analysis stresses the necessity of regional customization in adaptation strategies to address Nigeria's geographic diversity. While drought-oriented solutions like zai pits and agroforestry excel in the Sahel, flood-resilient crops and community-driven water management systems are critical in the Niger Delta. These tailored interventions not only maximize the efficiency of resources but also align with local socioeconomic and environmental contexts. By incorporating regional priorities, policymakers and practitioners can design more effective and sustainable adaptation frameworks.

Systemic barriers, such as limited access to finance and education, significantly hinder the ability of women and smallholder farmers to adopt effective adaptation strategies. For instance, women often lack ownership rights over land, which restricts their ability to secure credit needed to invest in climate-resilient technologies (Doss et al., 2018). Also, financial institutions are less likely to lend to smallholder farmers due to the perceived risks of agricultural activities in the face of climate change. According to a report by Adeola and Adetunbi (2015), only 10% of Nigerian smallholder farmers have access to formal credit, severely limiting their capacity to implement advanced irrigation or adopt drought-tolerant crops.

The education gap further compounds these challenges. Many smallholder farmers, particularly women, lack access to agricultural extension services and climate information, which are critical for informed decision-making. A study by Holmes et al. (2017) highlighted that 67% of female farmers in rural Nigeria rely solely on traditional knowledge, which may not always align with modern climate realities. Expanding access to education and training programs tailored to smallholder farmers can bridge this gap, empowering communities to effectively respond to climatic shocks.

Data-driven interventions demonstrate the potential to address these barriers. For example, initiatives like the Nigerian Incentive-Based Risk Sharing System for Agricultural Lending (NIRSAL) have improved access to credit for smallholder farmers, with early reports indicating a 20% increase in adoption of climate-resilient practices (World Bank, 2020). Similarly, the integration of mobile platforms for disseminating weather forecasts and market information has shown promise in enhancing decision-making among marginalized groups (Ogbuabor and Egwuchukwu, 2017).

A primary obstacle in mitigating climate-related food insecurity is the need for enhanced collaboration among stakeholders at every tier. Governmental bodies, international organizations, academic and research institutions, along with local communities must work together to adapt effectively (Akinbode et al., 2021). Adewale et al. (2019) suggest that a well-defined policy framework which fosters sustainable farming practices, facilitates the adoption of climate-resilient technology, and guarantees the inclusivity and equity of adaptation measures should serve as the foundation for this collaboration.

Furthermore, more funding is required for climate change adaptation, especially in the fields of infrastructure development, capacity building, and research and development (Fadama III, 2017). To ensure that people have all the resources and knowledge necessary to adapt to the impacts of climate change, this investment should be directed toward the regions and communities who are most at risk (Fadama III, 2017; Adewale et al., 2019). For the best results, technology and participatory methods must be combined, as evidenced by the comparatively smaller impact sizes for community-based approaches. The import of using both quantitative and qualitative methods to create context-specific solutions for complex climate issues is made clear by these findings.

It is impossible to overestimate the importance of international cooperation and support, especially when it comes to strengthening

local communities' ability to adapt to climate change. This support can come in the form of funds, technical expertise, and the exchange of best practices from other countries dealing with similar challenges [International Institute of Tropical Agriculture (IITA), 2018].

4.1 Challenges in implementing adaptation strategies

Although many adaptation options have been identified and put into practice, their efficacy is hampered by a number of issues. These difficulties include weak institutional capability, insufficient funding, and inadequate infrastructure (Amusan and Olutola, 2017; Akintoye and Akinola, 2020). Furthermore, overlaps and inconsistencies caused by Nigeria's fragmented policy implementation process usually compromise the effectiveness and coherence of adaptation efforts (Amusan and Olutola, 2017; Okunade et al., 2019).

The mismatch between national policies and regional realities must also be addressed. There is a disconnect between policy objectives and local needs as a result of the national design of many adaption programs with very little input from local communities [Intergovernmental Panel on Climate Change (IPCC), 2014; Oladipo, 2020]. In order to make adaptation measures more relevant and effective, it can be helpful to increase the involvement of communities in their design and implementation (Akintoye and Akinola, 2020; Oladipo, 2020). The challenges faced in carrying out a comprehensive meta-analysis underline the necessity of longitudinal and standardized research. The ability to perform solid quantitative assessments in the future would be substantially improved by standardizing the reporting of adaptation outcomes, including effect sizes for economic, environmental, and social measures.

4.2 Opportunities for scaling up adaptation initiatives

Notwithstanding challenges, there are numerous opportunities to expand effective adaptation initiatives. Adoption of stronger and more long-lasting adaptation strategies is made possible by the increased public understanding of climate change and its effects on food security [International Institute of Tropical Agriculture (IITA), 2018]. This can be accomplished by promoting public-private partnerships, boosting investment in climate-resilient infrastructure, and mainstreaming climate adaptation into national development planning [International Institute of Tropical Agriculture (IITA), 2018; United Nations Development Programme (UNDP), 2019].

Using digital technologies to improve climate adaptation is another possibility. For example, farmers can make informed choices and apply best practices through the utilization of mobile apps and internet platforms for exchanging agricultural advice and climatic information (World Bank, 2020). Likewise, monitoring and management of climate risks can be strengthened by the use of remote sensing and geographic information systems (GIS), enabling more focused and timely actions (World Bank, 2020). In addition, a greater comprehension of the impacts of adaptation will be possible by focusing more study on underrepresented regions and using gender-disaggregated data. Such improvements in research design and reporting will be crucial in influencing policy and practice as climate risks continue to grow.

4.3 Research gaps and future research directions

Despite the substantial understandings provided by the current body of research on climate-induced food insecurity and adaptation strategies in Nigeria, several critical knowledge gaps remain unaddressed:

- Limited regional analysis: while studies have investigated climate impacts broadly, there is insufficient understanding of region-specific vulnerabilities and adaptive capacities. Future research should focus on detailed sub-regional assessments, especially in underrepresented areas such as the semi-arid zones in northern Nigeria. In addition, more regional research is required, with an emphasis on the unique socioeconomic, cultural, and climatic conditions of Nigeria's various regions (Oladipo, 2020). These kinds of studies can provide helpful details about specific challenges and opportunities associated with local climate adaptation.
- Lack of longitudinal studies: the reviewed literature predominantly relies on cross-sectional data, which fails to capture the long-term dynamics of climate impacts. Longitudinal studies are needed to assess the temporal evolution of climate change impacts and the effectiveness of adaptation measures over time. This entails looking into how diverse agricultural systems may be affected by climate change in the long run, evaluating the effectiveness of different adaptation strategies, and researching how novel technologies might improve resilience (Fadama III, 2017; Akinbode et al., 2021).
- Inadequate integration of socioeconomic and gender dimensions: although some studies touch on socioeconomic and gender disparities, a comprehensive analysis integrating these factors with climate adaptation is rare. Further research should examine how gender and socioeconomic inequities influence adaptive capacities, particularly among marginalized groups.
- Insufficient focus on indigenous knowledge systems: while traditional and indigenous practices are briefly mentioned, their full potential remains underexplored. Future studies should systematically document and evaluate the efficacy of indigenous knowledge in mitigating climate impacts on food systems. Furthermore, the development of more robust and integrated adaptation strategies can be aided by multidisciplinary research that brings together ideas from the social sciences, economics, agriculture, and climate science (Adewale et al., 2019; Akintoye and Akinola, 2020).
- Limited evaluation of policy implementation: although numerous policies and strategies have been proposed, there is a lack of empirical evidence on their implementation and impact. Research should critically evaluate the effectiveness of existing policies and identify barriers to their successful execution.
- Underutilization of technology: there is a growing interest in climate-smart technologies, but their adoption remains low, particularly among smallholder farmers. Investigating the barriers to technology adoption and the role of digital tools in enhancing resilience warrants further study.

Addressing these research gaps will not only deepen our understanding of the challenges posed by climate-induced food insecurity but also inform the development of more targeted and effective adaptation strategies. Based on the systematic review findings, we propose the following hypotheses for empirical testing:

- Integrated technological and community-based adaptation strategies will result in greater resilience to floods and droughts compared to strategies focused solely on one pathway.
- Addressing gender disparities in access to resources will significantly improve the adoption of climate-resilient practices among smallholder farmers.
- Policy interventions that incorporate traditional practices will yield more culturally acceptable and sustainable outcomes in mitigating climate-induced food insecurity.

5 Conclusion and policy recommendations

Climate change makes floods and droughts more frequent and dangerous for Nigeria's food security. While many different adaptation strategies have been put into practice, continuous innovation is important for scaling up successful programs and guaranteeing their long-term efficacy. Building resilience requires promoting methods of sustainable agriculture and including climate change adaptation into national development planning.

Climate change's impact on Nigeria's food security necessitates focused adaptation strategies. Promoting climate-smart agriculture practices, such as agroforestry and conservation agriculture, alongside investments in drought-resilient maize and flood-tolerant rice, can significantly mitigate food insecurity risks. Establishing a National Climate Adaptation Fund will ensure financial accessibility for smallholder farmers to adopt these sustainable practices. Furthermore, integrating traditional methods like zai pits and earth bunds with modern technologies offers a comprehensive approach to resilience-building.

The necessity of improved collaboration between government agencies, development partners, and local communities is emphasized by this review. To mitigate the impacts of climate change on Nigeria's food systems, increased funds must be committed to climate-smart agriculture, water resource management, and other adaptation measures.

Indeed, Nigeria has a lot of opportunities to build a more resilient and sustainable food system, even if it also faces a lot of challenges in adapting to climate-induced food insecurity. The country can more effectively ensure food security and improve the standard of living for millions of its people by utilizing the synergies between traditional and modern adaptation strategies, promoting regional and international cooperation, and focusing on these areas in future research and policy initiatives.

To strengthen Nigeria's climate adaptation capacity and address food insecurity, this paper proposes actionable policy recommendations focused on funding mechanisms, institutional reforms, and inclusive stakeholder engagement.

A key recommendation is establishing a National Climate Adaptation Fund (NCAF), supported by green bonds, international climate finance mechanisms like the Green Climate Fund (GCF), and public-private partnerships (PPPs). This decentralized fund would direct resources to regions most affected by floods and droughts, such as the Niger Delta and Sahel. Nigeria can also draw lessons from Ethiopia's Climate-Resilient Green Economy (CRGE) strategy, which integrates climate resilience into national development through sustainable agriculture, renewable energy, and efficient water management. Ethiopia's success, bolstered by international collaboration, could serve as a model for Nigeria to adopt an integrated national strategy combining climate-smart agriculture (CSA) with broader development goals.

Institutional reforms are also essential to improve coordination. A Unified Climate Adaptation Agency should consolidate existing bodies like the Ministry of Environment and the National Emergency Management Agency. Local governments should be empowered with resources to implement strategies, and capacity-building programs for local officials are vital. Additionally, a robust monitoring and evaluation (M&E) framework should ensure transparency and accountability in fund use. Kenya's Drought Management Policy, which focuses on improving water storage and establishing community-based early warning systems, offers valuable lessons. Nigeria could replicate this participatory approach, particularly in rural areas, where smallholder farmers are most vulnerable. Engaging local communities in decision-making would improve the effectiveness of adaptation measures, as seen in Kenya.

Scaling up climate-smart agriculture (CSA) is crucial. Government at all levels should subsidize climate-resilient inputs like drought-tolerant seeds and solar irrigation systems. Expanding agricultural extension services and creating digital platforms for weather forecasts and market trends will benefit farmers. Bangladesh's flood management strategies, including investments in embankments, polder systems, and coastal defences, provide a model for Nigeria to strengthen its flood resilience, especially in the Niger Delta.

By adopting these comparative intuitions, Nigeria can develop an Integrated National Adaptation Strategy, create community-level committees, prioritize investments in flood protection infrastructure, and engage with international funding mechanisms like the Green Climate Fund (GCF) to support large-scale adaptation projects. These targeted actions, tailored to Nigeria's unique challenges, can significantly enhance the country's climate resilience and food security.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

TA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. TO: Conceptualization, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AA: Formal analysis, Writing – review & editing.

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