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RESEARCH ARTICLE

Climate Resilience, Adaptation, Hazard Prediction, Disaster Risk Reduction, and Early Warning Systems in Northern Nigeria: A Systematic Review

[*]Aramgo Joshua Akaito[1], Enanoshe Joshua Akaito[2], & [1]Shem Andrew Bahago

[1]Department of Geography, Kaduna State College of Education, Gidan Waya, Nigeria
[2]Department of Geoinformatics and Surveying, University of Nigeria, Enugu Campus, Nigeria
*Corresponding Author's Email: aramgoakaito4life@gmail.com

ABSTRACT

Climate variability and extreme weather events are intensifying across Northern Nigeria, posing significant threats to agricultural productivity, livelihoods, and socio-economic stability. This study presents a systematic review of literature on climate hazards, adaptation strategies, hazard prediction systems, disaster risk reduction (DRR), and early warning systems (EWS) in the region. Guided by the PRISMA framework, peer-reviewed articles and institutional reports published between 2015 and 2025 were analyzed to synthesize current knowledge on the drivers of vulnerability and resilience. The findings reveal that droughts, floods, desertification, and heatwaves are the dominant climate hazards, with impacts amplified by structural factors such as poverty, weak governance, and limited infrastructure. While local adaptation strategies, particularly in agriculture, are widespread, they remain largely incremental and constrained by unequal access to resources, technology, and climate information. Hazard prediction systems and early warning mechanisms have improved in technical capacity; however, their effectiveness is undermined by data limitations, poor dissemination, and the persistent last-mile communication gap. Similarly, DRR efforts are often reactive and insufficiently integrated into broader development planning. The review identifies critical gaps, including the underrepresentation of heatwave impacts, weak institutional coordination, and limited integration of indigenous and scientific knowledge systems. It argues that climate resilience in Northern Nigeria is shaped by the interaction of environmental, socio-economic, and institutional factors, requiring more than isolated sectoral interventions. The study concludes that enhancing resilience demands coordinated, multi-level, and transformative strategies that combine scientific innovation, institutional strengthening, and community-based approaches to address both climate risks and their underlying drivers.

Keywords: *Climate resilience; Adaptation; DRR; EWS; Northern Nigeria; Climate change*

1. INTRODUCTION

Climate change has increasingly been conceptualized not merely as an environmental phenomenon but as a systemic risk multiplier that amplifies existing socio-economic vulnerabilities and development inequalities, particularly in regions such as Sub-Saharan Africa. According to the Intergovernmental Panel on Climate Change Sixth Assessment Report, Africa is among the most climate-vulnerable regions globally due to the convergence of high exposure to climatic hazards, elevated sensitivity of livelihoods, especially in agriculture, and limited adaptive capacity driven by structural constraints (IPCC, 2022). This framing is critical because it shifts the discourse from climate change as an isolated biophysical process to one embedded within broader socio-economic and political systems.

In Northern Nigeria, this vulnerability is especially pronounced due to its location within the Sahel and Sudan savanna ecological zones, which are inherently characterized by high climatic variability, recurrent drought cycles, and fragile ecosystems. Recent climatological studies indicate that the region is experiencing accelerated warming trends, delayed rainfall onset, shortened growing seasons, and increased rainfall variability, all of which disrupt agricultural calendars and reduce crop yields (Abiodun et al., 2023; Sultan et al., 2020; Ayanlade et al., 2022). Empirical evidence further suggests that these climatic changes are no longer episodic but represent a structural shift in regional climate dynamics, thereby increasing the frequency and intensity of extreme events such as droughts and floods (Ishaku et al., 2024; Nkwunonwo et al., 2020).

However, a purely climatic explanation of vulnerability in Northern Nigeria is insufficient. A growing body of literature emphasizes that climate risks are socially differentiated and unevenly distributed, shaped by factors such as poverty, governance quality, infrastructure deficits, and access to resources (Serdeczny et al., 2017; World Bank, 2021; Fadairo et al., 2020). For instance, communities with similar exposure to drought or flooding often exhibit markedly different outcomes depending on their access to irrigation, markets, education, and institutional support. This underscores the argument that vulnerability is not only a function of environmental exposure but also of structural inequalities and development deficits, reinforcing the need for a more integrated analytical approach.

Agriculture remains the backbone of Northern Nigeria's economy, employing a significant proportion of the population and contributing substantially to food security. Yet, this sector is highly climate-sensitive due to its dependence on rain-fed systems and limited technological inputs. Climate variability has already resulted in declining agricultural productivity, increased crop failure, and heightened food insecurity, with cascading effects on livelihoods and rural economies (Ayanlade et al., 2022; FAO, 2021). Moreover, the interaction between climate stress and socio-political factors such as resource competition and land-use conflicts has further intensified vulnerability, particularly in regions affected by farmer–herder conflicts (Ide et al., 2020).

Within this context, the concept of climate resilience has gained prominence as a central framework for understanding and addressing climate risks. Traditionally, resilience has been defined as the capacity of systems to absorb shocks and recover to their original state. However, this "bounce-back" perspective has been increasingly criticized for its failure to address underlying structural drivers of vulnerability (Eriksen et al., 2021; Siders et al., 2023). Contemporary scholarship advocates for a shift toward transformative resilience, which emphasizes systemic change, institutional reform, and the reconfiguration of socio-economic systems to reduce long-term vulnerability. This shift is particularly relevant in Northern Nigeria, where

resilience cannot be achieved without addressing entrenched issues such as poverty, weak governance, and infrastructural deficits.

At the same time, there is growing recognition that resilience is a multi-scalar and multi-dimensional concept, shaped by interactions between environmental processes, socio-economic conditions, and institutional frameworks. For example, while local communities may demonstrate significant adaptive capacity through indigenous knowledge and coping strategies, their efforts are often constrained by broader systemic factors such as inadequate policy support, limited access to climate information, and weak institutional coordination (Hiwasaki et al., 2019; Makate et al., 2019). This highlights a critical gap between local adaptation practices and national-level policy frameworks, which often operate in isolation rather than in synergy.

In addition, the increasing frequency of climate-related hazards has brought renewed attention to the role of hazard prediction systems, disaster risk reduction (DRR), and early warning systems (EWS) as essential components of resilience-building. Advances in climate science and forecasting technologies have improved the ability to predict extreme events; however, the effectiveness of these systems in Northern Nigeria remains limited by challenges related to data availability, technical capacity, and communication infrastructure (Odekunle et al., 2019; WMO, 2022). More importantly, the persistence of the "last-mile problem" where critical information fails to reach vulnerable populations in a timely and actionable form underscores the need for more inclusive and people-centered approaches to climate information dissemination (Tall et al., 2020).

Despite increasing scholarly and policy attention to climate resilience in Nigeria, the existing literature remains fragmented, with limited integration across key domains such as adaptation, hazard prediction, DRR, and EWS. Many studies adopt a sector-specific focus, particularly on agriculture, without adequately considering the interconnected nature of climate risks and responses. Furthermore, significant research gaps persist, including the underrepresentation of emerging hazards such as heatwaves, limited attention to governance dynamics, and insufficient exploration of the integration between indigenous and scientific knowledge systems (Mora et al., 2023; Rohat et al., 2019).

Against this backdrop, this study provides a comprehensive and critical systematic review of climate resilience in Northern Nigeria, focusing on five key dimensions: climate hazards, adaptation strategies, hazard prediction systems, disaster risk reduction, and early warning systems. By synthesizing recent empirical and theoretical studies, the review aims to move beyond descriptive analysis and offer a more integrated and critical understanding of the drivers of vulnerability and resilience in the region. In doing so, it contributes to the growing body of literature calling for holistic, multi-level, and transformative approaches to climate resilience that address both environmental risks and the structural conditions that underpin them.

To contextualize the issues discussed above, it is important to understand the geographical, ecological, and socio-economic characteristics of Northern Nigeria, where the interaction between climatic variability and structural vulnerabilities provides the basis for this systematic review. The following section therefore presents the study area and highlights the environmental and socio-economic conditions that shape climate resilience in the region.

Study Area

Northern Nigeria occupies a substantial portion of the country's landmass, extending between latitudes 6°N and 14°N and longitudes 3°E and 15°E. It comprises the North-West, North-East, and North-Central geopolitical zones and shares international boundaries with Niger, Chad, and Cameroon. The region includes key states such as Kano, Kaduna, Katsina, Sokoto, Borno, Niger, Plateau, Benue, and the Federal Capital Territory (FCT), making it central to Nigeria's agricultural production and population dynamics, as shown in Figure 1.

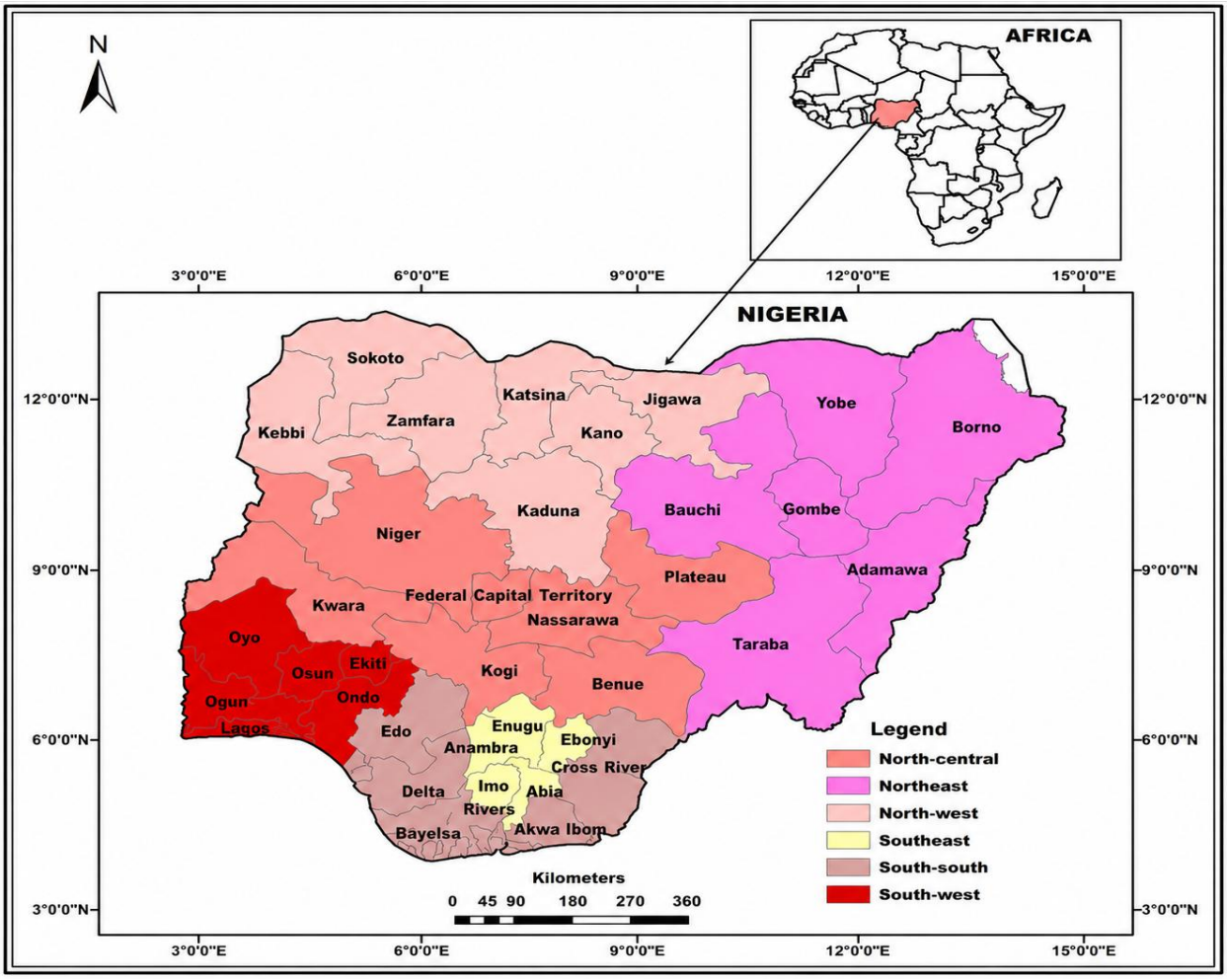

Figure 1. Administrative and Geopolitical Structure of Nigeria (Source: National Bureau of Statistics (NBS), Nigeria; 2022).

Physically, the region is dominated by extensive plains interspersed with uplands such as the Jos Plateau and Mambilla Plateau. Its drainage system is structured around the River Niger and River Benue, which converge at Lokoja and form extensive floodplains that are both agriculturally productive and highly flood-prone. In the northeast, Lake Chad has experienced significant shrinkage, largely due to climate variability and anthropogenic pressures, with profound implications for water resources and livelihoods (IPCC, 2022).

Ecologically, Northern Nigeria spans three major zones: the Sahel Savanna**,** Sudan Savanna, and Guinea Savanna, reflecting a strong north–south gradient in vegetation and moisture availability. Rainfall ranges from less than 300–600 mm annually in the Sahel to about 1,000–1,200 mm in the Guinea Savanna, while temperatures are generally high and may exceed 40°C during the dry season (Abdullahi, 2021). The climate is characterized by distinct wet and dry seasons driven by the movement of the Inter-Tropical Convergence Zone (ITCZ).

Recent studies indicate increasing climate variability in the region, including delayed rainfall onset, shorter growing seasons, and rising temperatures (Ishaku et al., 2024). These changes have intensified the frequency and severity of climate hazards such as droughts, floods, and heatwaves. Flooding is particularly pronounced along the Niger–Benue trough, while desertification is advancing in the Sahelian belt, reducing arable land and increasing vulnerability (Okafor et al., 2024).

Socio-economically, Northern Nigeria is predominantly agrarian, with livelihoods heavily dependent on rain-fed agriculture and pastoralism. However, high poverty levels, limited infrastructure, and weak institutional capacity constrain adaptive responses to climate change (Farauta, 2012). As emphasized by the Intergovernmental Panel on Climate Change (2022), such socio-economic factors significantly influence climate vulnerability and resilience. On the whole, the region represents a critical climate hotspot where environmental stressors intersect with socio-economic fragility, making it highly suitable for examining climate resilience, adaptation, hazard prediction, disaster risk reduction, and early warning systems.

While the study area provides the environmental and socio-economic context of Northern Nigeria, understanding climate resilience requires an appropriate conceptual approach through which the complex interactions among hazards, vulnerability, adaptation, and institutional responses can be interpreted. Accordingly, the next section presents the conceptual framework underpinning this review.

2. LITERATURE REVIEW

Conceptual Framework

The conceptual framing of this study is anchored in an integrative approach that draws from three dominant yet complementary traditions in climate research: the vulnerability framework advanced by the Intergovernmental Panel on Climate Change, the Sustainable Livelihoods Framework (SLF), and contemporary Disaster Risk Reduction (DRR) theory as institutionalized through global policy instruments. This triangulation is necessary because no single framework sufficiently captures the multi-dimensional, cross-scalar, and politically embedded nature of climate resilience in contexts such as Northern Nigeria. Rather than treating these frameworks as discrete analytical tools, this study synthesizes them to develop a more robust lens capable of interrogating both the biophysical drivers and structural determinants of vulnerability and resilience.

At its core, the IPCC vulnerability framework conceptualizes climate risk as a function of hazard, exposure, and vulnerability, with vulnerability further decomposed into sensitivity and adaptive capacity (IPCC, 2022). This framework has been widely adopted due to its clarity and applicability across scales; however, it has also been critiqued for its technocratic orientation, which tends to prioritize measurable indicators while underemphasizing the socio-political processes that produce vulnerability (Eriksen et al., 2021). In the context of Northern Nigeria, such limitations are particularly salient, as vulnerability is not merely a product of climatic exposure but is deeply shaped by governance deficits, unequal resource distribution, and historical patterns of marginalization. For example, two communities exposed to the same drought conditions may exhibit vastly different outcomes depending on their access to irrigation infrastructure, institutional support, and social networks. Thus, while the IPCC framework provides a useful starting point, its explanatory power is significantly enhanced when complemented by frameworks that foreground socio-economic complexity.

The Sustainable Livelihoods Framework offers such a perspective by emphasizing the role of asset portfolios as natural, human, financial, physical, and social capital in shaping adaptive capacity (Scoones, 2015). Within this framework, resilience is understood not simply as the ability to withstand shocks but as the capacity to sustain and improve livelihoods under changing environmental conditions. This is particularly relevant in Northern Nigeria, where livelihoods are predominantly agrarian and highly sensitive to climatic variability. However, despite its strengths, the SLF has been criticized for its relative neglect of power relations and macro-level political economy dynamics that influence access to these assets (Tschakert et al., 2019). For instance, while the framework recognizes financial capital as a key determinant of resilience, it often does not fully interrogate the structural barriers such as unequal market access or policy biases that limit resource distribution.

Consequently, this study adopts a critical livelihoods perspective, which situates asset access within broader systems of governance and inequality.

Complementing these approaches is Disaster Risk Reduction (DRR) theory, particularly as articulated through the United Nations Office for Disaster Risk Reduction Sendai Framework, which shifts the focus from reactive disaster response to proactive risk management (UNDRR, 2019). DRR emphasizes key pillars such as risk identification, prevention, preparedness, and mitigation, aligning closely with resilience thinking. However, empirical evidence from developing contexts including Nigeria suggests that DRR implementation often remains fragmented and reactive, with limited integration into broader development planning processes (Adelekan et al., 2020; Kelman, 2020). This disconnect highlights a fundamental challenge: while DRR frameworks are conceptually robust, their effectiveness is contingent upon institutional capacity, governance quality, and stakeholder coordination, all of which are often constrained in Northern Nigeria.

A critical dimension that emerges from integrating these frameworks is the recognition that climate resilience is inherently multi-scalar, operating at household, community, institutional, and national levels simultaneously. At the household level, resilience is shaped by access to assets and livelihood diversification strategies; at the community level, it is influenced by social networks and collective action; at the institutional level, it depends on governance structures, policy frameworks, and service delivery systems. Importantly, these scales are not independent but are deeply interconnected, with processes at one level shaping outcomes at others (Eriksen et al., 2021; Siders et al., 2023). For example, national climate policies may promote climate-smart agriculture, but their effectiveness at the local level depends on extension services, infrastructure, and farmer access to information and resources.

Another key insight from this integrated conceptualization is the need to move beyond static notions of resilience toward a more dynamic and transformative understanding. Traditional approaches often conceptualize resilience as the ability to return to a pre-shock state; however, in contexts characterized by chronic vulnerability such as Northern Nigeria, returning to the status quo may simply reproduce existing inequalities and risks. Transformative resilience, by contrast, emphasizes structural change, including institutional reform, improved governance, and the reconfiguration of socio-economic systems to reduce long-term vulnerability (Eriksen et al., 2021). This perspective is particularly important for addressing systemic challenges such as poverty, inadequate infrastructure, and limited access to climate information, which cannot be resolved through incremental adaptation alone.

Furthermore, the integration of these frameworks underscores the importance of knowledge systems and information flows in shaping resilience outcomes. While scientific climate data and forecasting models play a critical role in hazard prediction, local and indigenous knowledge systems provide context-specific insights that are essential for effective adaptation (Hiwasaki et al., 2019). However, the literature reveals a persistent disconnect between these knowledge systems, with limited efforts to integrate them in a complementary manner. Bridging this gap is crucial for enhancing the relevance, accessibility, and uptake of climate information, particularly in rural communities where formal communication channels may be limited.

In synthesizing these perspectives, this study advances a conceptual framework that views climate resilience in Northern Nigeria as the product of interacting environmental, socio-economic, and institutional processes. Climate hazards such as droughts, floods, and heatwaves interact with exposure patterns and sensitivity factors to produce varying levels of risk. Adaptive capacity, in turn, is shaped by access to livelihood assets, governance structures, and the effectiveness of DRR and early warning systems. Crucially, these elements are embedded within broader political and economic contexts that influence resource distribution, policy priorities, and institutional performance.

Overall, this integrated conceptual framework provides a more comprehensive and critical lens for analyzing climate resilience, moving beyond reductionist approaches to capture the complexity and dynamism of real-world systems. It not only facilitates a deeper understanding of the drivers of vulnerability but also highlights the pathways through which resilience can be enhanced, particularly through institutional strengthening, knowledge integration, and transformative adaptation strategies.

Guided by the integrated conceptual framework presented above, the subsequent sections critically examine the major thematic dimensions of climate resilience in Northern Nigeria. The discussion begins with climate hazards, which constitute the primary drivers of vulnerability and the foundation upon which adaptation and resilience strategies are developed.

Climate Hazards

Climate hazards in Northern Nigeria are multifaceted, intensifying in both frequency and severity, and are best understood as the outcome of complex interactions between climatic processes and human activities. The region's location within the Sahel and Sudan savanna belts exposes it to pronounced climatic variability, making it highly susceptible to a range of hazards including drought, desertification, flooding, and increasingly, heatwaves. According to the Intergovernmental Panel on Climate Change, West Africa has experienced significant warming trends alongside increased rainfall variability, both of which contribute to the amplification of climate-related risks (IPCC, 2022). However, a critical examination of the literature reveals that these hazards cannot be interpreted solely as natural phenomena; rather, they are co-produced by environmental change and socio-economic processes such as land-use practices, urbanization, and governance failures.

Drought remains the most persistent and spatially extensive climate hazard affecting Northern Nigeria. Characterized by prolonged periods of below-average rainfall, drought has profound implications for water availability, agricultural productivity, and food security. Recent studies indicate that drought frequency and intensity have increased due to shifts in the West African monsoon system and rising temperatures, which accelerate evapotranspiration and soil moisture loss (Abiodun et al., 2023; Sultan et al., 2020). However, attributing drought solely to climatic factors obscures the role of anthropogenic drivers such as deforestation, overgrazing, and unsustainable agricultural practices, all of which contribute to land degradation and reduced ecosystem resilience (Mirzabaev et al., 2019). This highlights the need to conceptualize drought as a socio-ecological hazard, where human actions both exacerbate and mediate climatic impacts.

Closely linked to drought is the process of desertification, which has led to the progressive degradation of arable land in the northernmost parts of Nigeria. The expansion of desert-like conditions into previously productive areas has significant implications for livelihoods, particularly for pastoral and farming communities that depend on land and water resources. While climate change plays a critical role in driving desertification through reduced precipitation and increased temperatures, the literature increasingly emphasizes the importance of human-induced factors, including population pressure, fuelwood extraction, and inappropriate land management practices (Mirzabaev et al., 2019; Okafor et al., 2024). Importantly, desertification is not merely an environmental issue but also a socio-economic one, as it intensifies resource scarcity, contributes to migration, and can exacerbate conflicts over land and water.

Flooding represents another major and increasingly visible climate hazard in Northern Nigeria, particularly in the Niger–Benue basin and other low-lying areas. Unlike drought, which develops gradually, floods often occur suddenly and have immediate and devastating impacts, including loss of life, displacement, destruction of infrastructure, and disruption of economic activities. Major flood events, such as those recorded in 2012 and 2022, have been linked to a combination of extreme rainfall, river overflow, and dam releases (Adelekan et al., 2020; Nkwunonwo et al., 2020). However, a critical perspective reveals that flood risk is significantly shaped by governance and planning failures, including inadequate drainage

systems, unregulated urban expansion, and weak enforcement of environmental regulations. Thus, flooding in Northern Nigeria can be more accurately described as a risk constructed through the interaction of natural hazards and human vulnerability, rather than a purely climatic event.

In recent years, heatwaves have emerged as a critical but under-researched climate hazard in Northern Nigeria. Rising temperatures, often exceeding 40°C during the dry season, pose significant risks to human health, agricultural productivity, and water resources. Global and regional studies indicate that extreme heat events are becoming more frequent and intense due to climate change, with serious implications for labour productivity, particularly in agriculture and informal sectors (Rohat et al., 2019; Mora et al., 2023). Despite these risks, the literature on heatwaves in Nigeria remains limited, reflecting a broader tendency to prioritize more immediate and visible hazards such as floods and droughts. This gap is particularly concerning given that heat stress is often a "silent hazard," with cumulative impacts that may not be immediately apparent but can significantly undermine long-term resilience.

Beyond these primary hazards, there is increasing recognition of the compound and cascading nature of climate risks in Northern Nigeria. For instance, drought conditions can reduce vegetation cover, increasing susceptibility to desertification, which in turn may intensify flooding by reducing soil infiltration capacity during rainfall events. Similarly, flooding can damage agricultural land and infrastructure, thereby exacerbating food insecurity and economic vulnerability. This interconnectedness suggests that climate hazards should not be analyzed in isolation but as part of a broader system of interacting risks (IPCC, 2022; Siders et al., 2023).

Another critical dimension often overlooked in the literature is the temporal and spatial variability of hazards. Climate risks are not uniformly distributed across Northern Nigeria; rather, they vary significantly across ecological zones, with drought and desertification more prevalent in the Sahelian north, while flooding is more common in the Guinea savanna and riverine areas. Additionally, the timing and duration of hazards such as delayed rainfall onset or prolonged dry spells can have significant implications for agricultural planning and livelihood strategies (Ishaku et al., 2024). This variability underscores the importance of localized and context-specific approaches to hazard assessment and management.

By and large, the evidence suggests that climate hazards in Northern Nigeria are becoming more complex, interconnected, and difficult to manage. While climatic factors such as rising temperatures and rainfall variability play a central role, the severity of impacts is largely determined by socio-economic conditions, governance structures, and human activities. This reinforces the argument that effective climate risk management must move beyond hazard identification to address the underlying drivers of vulnerability, including land-use practices, infrastructure deficits, and institutional weaknesses. In this sense, understanding climate hazards in Northern Nigeria requires a shift from a hazard-centric perspective to a systems-based approach that integrates environmental, social, and institutional dimensions.

The increasing frequency and intensity of these climate hazards have compelled households, institutions, and governments to adopt a range of responses aimed at reducing vulnerability and enhancing resilience. The following section therefore reviews the principal adaptation strategies reported in the literature and evaluates their effectiveness within the context of Northern Nigeria.

Adaptation Strategies

Adaptation strategies in Northern Nigeria are predominantly autonomous, livelihood-driven, and heavily concentrated in the agricultural sector, reflecting the region's dependence on rain-fed farming systems. Farmers commonly adopt measures such as crop diversification, staggered planting, the use of drought-resistant crop varieties, and small-scale irrigation to cope with increasing climatic variability. Empirical evidence suggests that these strategies can reduce vulnerability and stabilize

yields under moderate climate stress; however, their effectiveness remains uneven due to constraints in access to credit, inputs, extension services, and climate information (Aryal et al., 2020; FAO, 2021). This uneven access highlights a critical issue: adaptation is not only about the availability of strategies but also about who has the capacity to implement them**.**

Beyond technical adjustments, indigenous knowledge systems continue to play a significant role in shaping local adaptation practices. Communities rely on traditional indicators such as wind patterns, vegetation changes, and animal behavior to anticipate seasonal changes. While such knowledge is context-specific and culturally embedded, its reliability is increasingly challenged by shifting climate patterns, raising concerns about its long-term applicability (Hiwasaki et al., 2019). Recent scholarship therefore advocates for a more integrated approach that combines indigenous knowledge with scientific climate information to enhance adaptive decision-making (Makate et al., 2019).

At the institutional level, government and development partners have promoted climate-smart agriculture and resilience-building programs aimed at strengthening adaptive capacity. However, these interventions are frequently undermined by weak governance, fragmented implementation, and limited local participation, resulting in a persistent gap between policy design and on-the-ground outcomes (World Bank, 2021). Overall, adaptation in Northern Nigeria remains incremental rather than transformative, addressing immediate climate impacts without sufficiently tackling the structural drivers of vulnerability such as poverty, inequality, and infrastructural deficits. This suggests that enhancing adaptation effectiveness requires not only technological innovation but also institutional reform and inclusive governance frameworks.

Although adaptation plays a critical role in reducing climate vulnerability, proactive resilience also depends on the capacity to anticipate hazards before they occur. Consequently, the next section examines hazard prediction systems and their contribution to climate risk management in Northern Nigeria.

Hazard Prediction Systems

Hazard prediction systems in Northern Nigeria are primarily anchored in meteorological and hydrological monitoring, with agencies such as the Nigerian Meteorological Agency and the Nigerian Hydrological Services Agency responsible for generating seasonal climate forecasts, flood outlooks, and early advisories. While advances in climate science, satellite observation, and remote sensing have improved the technical capacity for forecasting globally, their effectiveness in the Nigerian context remains constrained by limited observational networks, data gaps, and weak technical infrastructure (Odekunle et al., 2019; WMO, 2022). In many parts of Northern Nigeria, sparse weather stations and inconsistent data collection reduce the spatial accuracy of forecasts, thereby limiting their usefulness for localized decision-making.

Beyond technical limitations, a critical challenge lies in the translation of forecasts into actionable, user-relevant information. Existing systems often produce generalized seasonal predictions that are not sufficiently tailored to the needs of farmers, pastoralists, and local planners. Recent literature emphasizes the importance of impact-based forecasting, which links climatic variables to specific sectoral outcomes such as crop performance, flood risk zones, or water availability (Tall et al., 2020). However, such approaches remain underdeveloped and poorly institutionalized in Nigeria, creating a disconnect between scientific output and practical application.

Equally important is the issue of accessibility and dissemination. Even when forecasts are available, they are frequently not communicated effectively to end-users due to language barriers, limited extension services, and weak communication channels. This results in a persistent gap between hazard prediction and adaptive response, particularly in rural communities. Consequently, strengthening hazard prediction systems in Northern Nigeria requires not only technological improvements but also a shift toward user-centered, participatory forecasting systems that integrate scientific data with local knowledge and ensure that information is timely, accessible, and actionable.

Effective hazard prediction provides valuable information for decision-making; however, forecasting alone cannot reduce disaster impacts without comprehensive risk management strategies. This underscores the importance of disaster risk reduction, which is examined in the following section.

Disaster Risk Reduction (DRR)

Disaster Risk Reduction (DRR) in Nigeria is formally aligned with global frameworks such as the United Nations Office for Disaster Risk Reduction Sendai Framework, which emphasizes proactive risk management through prevention, preparedness, mitigation, and recovery (UNDRR, 2019). Nationally, institutions like the National Emergency Management Agency (NEMA) and related state agencies are mandated to coordinate disaster response and risk reduction efforts. However, despite this institutional architecture, the implementation of DRR in Northern Nigeria remains largely reactive, with greater emphasis placed on post-disaster relief than on anticipatory planning and long-term risk reduction (Adelekan et al., 2020).

A critical weakness in current DRR practice is the limited integration of risk reduction strategies into broader development planning. Sectors such as agriculture, urban development, and infrastructure often operate independently of DRR considerations, resulting in policies that inadvertently increase vulnerability, for example, through unregulated urban expansion into flood-prone areas or inadequate land-use planning. This fragmentation reflects deeper governance challenges, including weak inter-agency coordination, insufficient funding, and limited technical capacity at local levels (Kelman, 2020). Furthermore, DRR initiatives frequently adopt a top-down approach, with minimal engagement of local communities, despite their central role in both experiencing and managing risks. This disconnect reduces the effectiveness and sustainability of interventions, as local knowledge and context-specific needs are often overlooked. Recent scholarship therefore advocates for mainstreaming DRR into development policy and adopting more participatory, community-based approaches that enhance local ownership and resilience. Ultimately, strengthening DRR in Northern Nigeria requires a shift from short-term emergency response toward institutionally embedded, prevention-oriented strategies that address the structural drivers of vulnerability.

Disaster risk reduction strategies are most effective when supported by efficient mechanisms for communicating risks and facilitating timely responses. Accordingly, the next section reviews the role of early warning systems as a critical link between hazard prediction and community preparedness.

Early Warning Systems (EWS)

Early Warning Systems (EWS) are widely recognized as a cornerstone of disaster risk management, providing the critical interface between hazard prediction and timely, informed action. In principle, an effective EWS integrates four key components: risk knowledge, monitoring and forecasting, dissemination and communication, and response capability. In Nigeria, these functions are supported by agencies such as the Nigerian Meteorological Agency and the Nigerian Hydrological Services Agency, which generate seasonal rainfall predictions, flood outlooks, and weather advisories. However, despite these institutional arrangements, the effectiveness of early warning systems in Northern Nigeria remains uneven and often limited by structural, technical, and socio-cultural constraints (WMO, 2022).

One of the most persistent challenges is the disconnect between the production of early warning information and its practical usability at the community level. Forecasts are frequently disseminated in technical formats that are not easily interpretable by local users, particularly rural farmers and pastoralists who have limited access to formal education or scientific training. As a result, even when early warnings are available, they may not translate into meaningful action. This highlights the

importance of impact-based and user-centered warning systems, which translate climate data into locally relevant advisories, such as planting dates, flood risk zones, or livestock management strategies (Tall et al., 2020). However, such approaches remain insufficiently developed and institutionalized in Northern Nigeria.

A critical issue underpinning the limited effectiveness of EWS is the so-called "last-mile problem," which refers to the failure of warning information to reach the most vulnerable populations in a timely and actionable form. Communication channels in many parts of Northern Nigeria are constrained by poor infrastructure, limited access to digital technologies, and language diversity. In addition, reliance on centralized dissemination mechanisms such as radio broadcasts or official bulletins often excludes marginalized groups who may lack access to these platforms. Studies have shown that the effectiveness of EWS is significantly enhanced when communication strategies are localized, multilingual, and tailored to specific community contexts (WMO, 2022; Lauta et al., 2018).

Trust also plays a crucial role in shaping the uptake of early warning information. In many cases, communities exhibit low levels of confidence in official forecasts, particularly when past predictions have been inaccurate or poorly communicated. This lack of trust can lead to the disregard of warnings, even when they are accurate, thereby increasing vulnerability to climate hazards. Conversely, indigenous knowledge systems based on local environmental indicators often enjoy higher levels of trust but may lack reliability under changing climatic conditions (Hiwasaki et al., 2019). This tension underscores the need for hybrid knowledge systems that integrate scientific forecasts with locally trusted forms of knowledge, thereby enhancing both credibility and usability.

Institutional and governance challenges further constrain the effectiveness of EWS in Northern Nigeria. Coordination among agencies responsible for data generation, communication, and emergency response is often weak, leading to delays, inconsistencies, and gaps in information flow. Moreover, limited funding and technical capacity hinder the development and maintenance of robust early warning infrastructure, including observation networks and communication systems. While national frameworks for disaster management exist, their implementation at state and local levels is frequently inconsistent, reflecting broader issues of governance and institutional capacity (UNDRR, 2019).

Another critical limitation is the inadequate linkage between early warning and early action. An effective EWS does not end with the dissemination of information; it must also enable timely and appropriate responses. In Northern Nigeria, however, response capacity is often constrained by limited resources, lack of contingency planning, and insufficient institutional support. For example, even when flood warnings are issued, communities may lack the means to evacuate, protect assets, or implement preventive measures. This gap highlights the need for integrating EWS with broader resilience-building strategies, including livelihood diversification, infrastructure development, and social protection systems.

Emerging global frameworks emphasize the transition toward people-centered early warning systems, which prioritize inclusivity, accessibility, and community engagement (WMO, 2022). Such systems recognize that effective early warning is not solely a technological challenge but also a social and institutional one. In the context of Northern Nigeria, this implies strengthening local communication networks, enhancing community participation in the design and implementation of EWS, and building trust through consistent and reliable information delivery. Moreover, advances in mobile technology and digital platforms present new opportunities for improving information dissemination, although their effectiveness depends on addressing issues of digital access and literacy.

In summary, while early warning systems in Northern Nigeria have made notable progress in terms of hazard monitoring and forecasting, their overall effectiveness is undermined by challenges related to communication, trust, institutional coordination, and response capacity. Addressing these challenges requires a shift from technology-centered approaches to

integrated, people-centered systems that bridge the gap between knowledge and action. Such a transformation is essential for ensuring that early warnings not only inform but also empower communities to anticipate, prepare for, and respond effectively to climate hazards.

Having critically examined the major thematic dimensions of climate resilience in Northern Nigeria, it is equally important to outline the methodological procedures that guided the identification, selection, and synthesis of the literature reviewed in this study. The following section therefore describes the systematic review methodology adopted to ensure transparency, rigor, and reproducibility.

3. MATERIALS AND METHODS

This study adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to ensure transparency, rigor, and reproducibility throughout the review process. The methodology was designed to systematically identify, screen, evaluate, and synthesize scholarly literature on climate resilience, adaptation, hazard prediction, disaster risk reduction (DRR), and early warning systems (EWS) in Northern Nigeria. The review focused on peer-reviewed journal articles, institutional reports, policy documents, and selected grey literature published between 2015 and 2025.

Research Design

The study employed a qualitative systematic review approach because the research aimed not only to summarize existing knowledge but also to critically synthesize conceptual, empirical, and policy-oriented evidence relating to climate resilience in Northern Nigeria. Unlike traditional narrative reviews, the systematic review approach follows a structured and transparent process that minimizes selection bias and enhances methodological reliability (Page et al., 2021). The PRISMA framework was therefore considered appropriate because it provides internationally recognized standards for literature identification, screening, eligibility assessment, and synthesis.

Literature Search

A comprehensive literature search was conducted between January and March 2026 using multiple electronic databases and institutional repositories. The databases consulted included Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, JSTOR, and the Directory of Open Access Journals (DOAJ). To complement peer-reviewed literature, institutional and policy documents were also retrieved from major international organizations and climate agencies, including the Intergovernmental Panel on Climate Change (IPCC), World Bank Climate Knowledge Portal, Food and Agriculture Organization (FAO), United Nations Office for Disaster Risk Reduction (UNDRR), and World Meteorological Organization (WMO).

The search process utilized combinations of keywords, Boolean operators such as "AND" and "OR," and truncation techniques to capture a broad range of interdisciplinary studies. Key search terms included "climate resilience," "climate adaptation," "hazard prediction," "disaster risk reduction," "early warning systems," "drought," "flooding," "heatwaves," "desertification," "livelihoods," and "climate-smart agriculture," combined with geographic identifiers such as "Northern Nigeria," "Nigeria," and "Sahel." The broad search strategy was necessary to capture studies from geography, climate science, agriculture, disaster management, environmental studies, and development studies.

Selection Criteria and Screening

To ensure consistency, relevance, and methodological rigor, studies were screened using predefined inclusion and exclusion criteria. Studies were included if they focused on climate resilience, adaptation, hazard prediction, disaster risk reduction, or

early warning systems and if they examined Northern Nigeria directly or included the region within broader Nigerian or West African studies. Only studies published between 2015 and 2025 were considered to ensure contemporary relevance, although a few foundational studies were retained where necessary for conceptual clarification. Eligible materials included peer-reviewed journal articles, conference papers, institutional reports, and credible grey literature published in the English language. In addition, studies were required to provide empirical, theoretical, or policy-relevant insights into climate risks and resilience. Conversely, studies were excluded if they focused exclusively on Southern Nigeria without relevance to Northern Nigeria, lacked direct connection to climate resilience themes, or consisted primarily of opinion-based discussions without analytical or empirical grounding. Duplicate studies identified across databases were removed, while publications with inaccessible full texts or insufficient methodological detail were also excluded from the review process.

Data Extraction, Quality Assessment and Methodological Limitations

The screening and selection process followed the four key stages recommended by the PRISMA 2020 guidelines, namely identification, screening, eligibility assessment, and final inclusion. The initial database and institutional search produced a total of 327 records. Following the removal of 78 duplicate studies, 249 records remained for title and abstract screening. During this phase, 161 studies were excluded because they were either outside the thematic scope of the review, geographically irrelevant, or lacked sufficient analytical depth.

Subsequently, 88 full-text articles were assessed for eligibility. At this stage, studies were critically examined for methodological quality, thematic relevance, and analytical contribution to climate resilience discourse in Northern Nigeria. A total of 46 studies were excluded due to insufficient relevance, poor methodological quality, duplication of findings, or inaccessible full-text content. Ultimately, 42 studies met the inclusion criteria and were synthesized in the final review as summarized in Table 1.

Table 1. Summarized PRISMA Screening Process

Stage	Number of Records
Records identified through database searching	327
Duplicate records removed	78
Records screened	249
Records excluded after title and abstract screening	161
Full-text articles assessed for eligibility	88
Full-text articles excluded	46
Final studies included in review	42

Relevant information from the selected studies was systematically extracted using a thematic data extraction matrix developed specifically for the review. Information extracted from each study included the author(s), year of publication, study location, research objectives, climate hazards examined, adaptation strategies identified, methodological approaches, major findings, and policy implications. This process enabled consistency in data organization and facilitated comparative analysis across studies.

The extracted information was analyzed using qualitative thematic content analysis. Studies were grouped into major thematic categories corresponding to the core focus areas of the review, namely climate hazards, adaptation strategies, hazard prediction systems, disaster risk reduction, and early warning systems. Through this analytical approach, recurring patterns, conceptual debates, emerging trends, and research gaps were identified and synthesized into broader thematic narratives.

To strengthen the credibility and reliability of the review findings, the methodological quality of the selected studies was critically evaluated. Particular attention was given to the clarity of research objectives, appropriateness of methodological design, reliability of data sources, analytical depth, and relevance to climate resilience issues in Northern Nigeria. Studies

with weak analytical grounding, unclear methodology, or insufficient thematic relevance were excluded during the eligibility assessment stage. This quality assessment process enhanced the robustness of the synthesis and minimized the inclusion of low-quality evidence.

Despite the structured and systematic approach adopted in this review, certain limitations should be acknowledged. First, the review relied primarily on English-language publications, which may have excluded relevant studies published in other languages. Second, although grey literature and institutional reports were included, some locally grounded community reports and unpublished materials may not have been accessible through the selected databases and repositories. Third, climate resilience research in Northern Nigeria remains relatively limited, resulting in uneven coverage across thematic areas, particularly regarding heatwaves, urban climate risks, and technological innovations in adaptation.

Nevertheless, the application of the PRISMA framework significantly enhanced the transparency, consistency, and reproducibility of the review process, thereby improving the overall validity and reliability of the study findings.

The methodological procedures described above resulted in the selection of studies that formed the evidence base for this review. The following section synthesizes the principal findings, discusses their implications for climate resilience in Northern Nigeria, and highlights key policy considerations emerging from the reviewed literature.

4. RESULTS AND DISCUSSION

The findings presented in this section are organized around the principal thematic areas identified during the systematic review process. This structure facilitates an integrated interpretation of the evidence and highlights the interrelationships among climate hazards, adaptation strategies, hazard prediction, disaster risk reduction, and early warning systems within the broader context of climate resilience in Northern Nigeria.

Synthesis of Findings

Drawing on the 42 studies included through the PRISMA review process, the findings are synthesized around five interrelated dimensions of climate resilience in Northern Nigeria: climate hazards, adaptation strategies, hazard prediction systems, disaster risk reduction, and early warning systems. Together, these themes provide an integrated understanding of the drivers of vulnerability, resilience, and policy responses in the region.

The synthesis of reviewed literature reveals a complex and interconnected set of challenges shaping climate resilience in Northern Nigeria. While there is broad consensus that climate hazards are intensifying and adaptation efforts are widespread, the effectiveness of these efforts is uneven and often limited by structural constraints. Institutional weaknesses, including poor governance, inadequate infrastructure, and limited coordination, emerge as critical barriers to resilience.

At the same time, significant debates persist regarding the role of indigenous knowledge and the effectiveness of early warning systems, reflecting broader tensions between traditional and scientific approaches. Notably, the literature exhibits clear gaps in areas such as heatwave impacts, governance dynamics, and technological innovation, indicating the need for more comprehensive and interdisciplinary research.

Discussion of findings

The findings of this review underscore that climate resilience in Northern Nigeria is shaped by a complex interplay of environmental, socio-economic, and institutional factors, rather than by climatic variables alone. While the region is undeniably exposed to increasing hazards such as droughts, floods, and heatwaves, the severity of their impacts is largely mediated by structural conditions including poverty, limited infrastructure, and weak governance systems (IPCC, 2022; World Bank, 2021). This reinforces the broader argument in climate literature that vulnerability is not simply a product of

exposure but is socially constructed and unevenly distributed, leading to differentiated resilience outcomes across communities facing similar climatic conditions.

A key insight emerging from the analysis is the persistent disconnect between knowledge generation and practical response**.** Although hazard prediction systems and early warning mechanisms have improved in technical capacity, their effectiveness remains constrained by communication gaps, limited accessibility, and low levels of trust among end-users. This gap reflects a broader systemic issue in which scientific information is insufficiently translated into actionable knowledge, particularly for rural populations. At the same time, local adaptation strategies, while widespread, remain largely incremental and reactive, addressing immediate risks without transforming the underlying drivers of vulnerability such as limited access to resources, institutional inefficiencies, and socio-economic inequalities (Eriksen et al., 2021; Siders et al., 2023).

Additionally, the review highlights a significant lack of integration across key domains of climate resilience, including adaptation, disaster risk reduction, and early warning systems. These components often operate in silos, resulting in fragmented interventions that limit overall effectiveness. The absence of strong institutional coordination and the limited incorporation of indigenous knowledge into formal systems further exacerbate this fragmentation. Consequently, advancing climate resilience in Northern Nigeria requires a shift toward holistic and integrated approaches that align policy, technology, and community-based strategies, while also addressing the deeper structural and governance challenges that underpin vulnerability.

Policy Implications

Policy responses must move beyond rhetorical commitments to resilience and focus on practical, context-specific interventions. Strengthening institutional coordination, improving climate data infrastructure, and investing in community-based adaptation are critical priorities. Additionally, integrating indigenous and scientific knowledge systems can enhance the relevance and effectiveness of resilience strategies. Importantly, policies must also address underlying socio-economic inequalities that shape vulnerability, ensuring that resilience-building efforts are inclusive and equitable.

The foregoing discussion highlights both the progress achieved and the persistent challenges associated with climate resilience in Northern Nigeria. Building on these findings, the concluding section summarizes the major insights of the review and outlines the broader implications for policy, practice, and future research.

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5. CONCLUSION

This systematic review demonstrates that climate resilience in Northern Nigeria remains constrained despite growing awareness of climate risks and the widespread adoption of local adaptation practices. The evidence shows that while communities are actively responding to climate variability, particularly within the agricultural sector, these efforts remain largely incremental and insufficient to address the scale and complexity of emerging hazards such as droughts, floods, desertification, and heatwaves. A central finding is that vulnerability in the region is not driven by climatic exposure alone but is deeply rooted in structural challenges, including poverty, weak institutional capacity, inadequate infrastructure, and limited access to climate information. In addition, persistent gaps in hazard prediction systems, disaster risk reduction frameworks, and early warning systems, particularly in terms of last-mile communication and actionable response, continue to undermine resilience-building efforts.

Addressing these challenges requires a shift from fragmented and reactive approaches toward integrated, multi-level, and transformative strategies that link scientific innovation with institutional strengthening and community engagement. This includes improving climate data infrastructure, enhancing people-centered early warning systems, mainstreaming disaster

risk reduction into development planning, and fostering the integration of indigenous and scientific knowledge systems. Equally important is the need to address the underlying socio-economic and governance constraints that shape vulnerability, ensuring that resilience-building efforts are inclusive, context-specific, and sustainable. Ultimately, building climate resilience in Northern Nigeria demands not only technological and policy advancements but also a commitment to structural transformation that enables communities to anticipate, adapt to, and thrive in the face of a changing climate. Future research should prioritize longitudinal assessments of climate resilience, the integration of emerging technologies into early warning systems, and empirical evaluations of governance reforms to support evidence-based climate adaptation in Northern Nigeria.

6. COMPETING INTEREST

None to declare

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