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BUILDING CLIMATE RESILIENCE IN NIGERIA: CLIMATE RISKS, ADAPTATION PATHWAYS, AND POLICY PRIORITIES — A SCOPING REVIEW

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Abstract
Climate change is intensifying the frequency, severity, and unpredictability of extreme weather events, threatening food security, water resources, ecosystems, public health, infrastructure, and socio-economic development, particularly in regions with limited adaptive capacity. Existing scholarship tends to examine climate hazards, vulnerability, adaptation, and governance separately, limiting understanding of how these dimensions interact to shape resilience outcomes. This paper is a scoping review that synthesizes recent scientific assessments, empirical studies, and national policy documents on climate change, extreme weather, and adaptation in Nigeria, situated within the wider African and global context. The review develops an Integrated Climate Resilience Framework linking climate drivers, hazards, exposure and vulnerability (including the differentiated vulnerability of women and girls), adaptive capacity, adaptation interventions, and resilience outcomes through explicit feedback relationships rather than a simple linear sequence. It identifies persistent gaps in Nigeria's adaptation response limited and inaccessible climate finance, weak inter-agency coordination, constrained local government capacity, underuse of indigenous knowledge, poor climate data systems, low public awareness, and vulnerable infrastructure and translates these into specific, institution-level policy recommendations. The paper argues that adaptation must be prioritized alongside mitigation, financed directly at the sub-national level, and built on the integration of scientific and indigenous knowledge systems. The review contributes a policy-relevant synthesis and an original conceptual framework to guide climate resilience planning in Nigeria and comparable developing-country contexts.

Keywords
Climate resilience; adaptation; extreme weather; vulnerability; Nigeria; scoping review

1. INTRODUCTION

Climate change is among the defining challenges of the twenty-first century, altering temperature and precipitation patterns through anthropogenic greenhouse gas emissions from fossil fuel combustion, deforestation, industrialization, and land-use change [1]. Global temperatures have already risen approximately 1.1–1.45°C above pre-industrial levels, with atmospheric CO_2 reaching roughly 420 ppm in 2023 the highest level in at least two million years [1], [3], [4]. This warming is manifesting as more frequent and intense extreme weather events: in 2023 alone, 399 major natural disasters affected over 93 million people and caused economic losses exceeding US$250 billion [5]. Africa contributes less than 4% of global greenhouse gas emissions yet remains disproportionately vulnerable because of high climate sensitivity, dependence on climate-sensitive livelihoods, poverty, infrastructure deficits, and limited adaptive capacity [1], [6]. Nigeria exemplifies this vulnerability: rising temperatures, rainfall variability, recurrent flooding, drought, coastal erosion, and desertification are converging with rapid population growth and heavy dependence on climate-sensitive livelihoods [7]. The 2022 floods alone affected over 4.4 million people and displaced more than 2.4 million [8]. Despite substantial research on individual hazards, existing literature remains fragmented: studies tend to examine physical climate trends, vulnerability, adaptation, or governance in isolation, with limited attention to how these dimensions interact [6]. This fragmentation limits understanding of how climate risks evolve and how context-specific adaptation strategies should be designed. This review addresses that gap by synthesizing climate trends, drivers, vulnerability (including its gender dimension), adaptation strategies, and governance within a single, integrated framework for Nigeria,

comparing global and African adaptation experience with Nigeria's own policy and institutional context to identify transferable lessons and implementation gaps.

This manuscript is a scoping review. It does not report a systematic effect-size synthesis; rather, it maps and synthesizes the breadth of existing scientific, empirical, and policy literature on climate risk and adaptation as it applies to Nigeria, in order to identify patterns, gaps, and an organizing conceptual framework a purpose for which the scoping review format is methodologically appropriate [36].

The paper's contribution is fourfold: (i) it integrates recent climate science with adaptation policy; (ii) it bridges global/African evidence with Nigeria-specific realities; (iii) it proposes a resilience framework built on feedback relationships rather than a linear hazard-to-outcome sequence; and (iv) it translates the literature into specific, institution-level adaptation and policy pathways.

2. METHODOLOGY

This review follows a scoping review approach, consistent with the Arksey and O'Malley framework as extended by PRISMA-ScR reporting guidance [36], given the objective of mapping a broad, heterogeneous evidence base rather than pooling effect estimates. Structured searches were conducted in the academic databases Scopus, Web of Science, and Google Scholar, supplemented by targeted searches of the institutional repositories of the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), and the World Bank, as well as the publication archives and websites of relevant Nigerian agencies, including the National Emergency Management Agency (NEMA), the Nigerian Meteorological Agency (NiMet), and the Federal Ministry of Environment. The search covered publications from 2013 to 2026, with priority given to sources published from 2020 onward; a small number of older foundational references were retained for historical and background context outside this window. Search terms combined "climate change," "extreme weather," "adaptation," "resilience," "vulnerability," and "governance" with "Nigeria" and/or "Africa," using Boolean operators (AND/OR) and, where supported by the database interface, truncation and phrase searching. Inclusion criteria: peer-reviewed articles, IPCC and UN-system assessment reports, and national/international policy documents addressing climate trends, drivers, vulnerability, adaptation, or governance with direct relevance to Nigeria, Africa, or comparable developing-country contexts. Exclusion criteria: sources without a discernible link to climate risk, adaptation, or governance; non-English sources without an available translation; and sources that could not be independently verified. Synthesis approach: sources were thematically organized around five domains climate trends and drivers, vulnerability and impacts, adaptation strategies, governance and policy gaps, and cross-cutting frameworks and synthesized narratively, with points of disagreement across sources noted explicitly rather than treated as uniform. As a scoping review, this paper does not formally appraise the methodological quality of every included source, and its search was not exhaustive; it is best read as a structured synthesis and conceptual contribution rather than a definitive systematic account.

3. CLIMATE CHANGE AND EXTREME WEATHER TRENDS

3.1 Global Trends

The IPCC's Sixth Assessment Report confirms that human influence on the climate system is unequivocal, with warming already affecting ecosystems, economies, and societies worldwide [1]. Rising temperatures have intensified the hydrological cycle, increasing heavy precipitation and flooding in some regions while worsening drought elsewhere; sea level has risen at approximately 3.7 mm per year between 2006 and 2018 through thermal expansion and ice loss [1], [13]. Weather- and climate-related disasters now account for the large majority of global hazard events, and floods and storms remain the most frequent disaster type worldwide [3].

3.2 African Context

Africa's climate risk is shaped less by its emissions contribution than by the interaction between exposure and socio-economic constraints: dependence on climate-sensitive livelihoods, widespread poverty, and limited adaptive capacity [1], [6]. Risks are regionally differentiated — intensified drought in Southern Africa, recurrent flooding in East Africa, and rising rainfall variability and heat stress in West Africa yet interconnected in their effects on food security, migration, and resource competition [1]. Recent extremes illustrate the scale of exposure: the 2020–2023 Horn of Africa drought disrupted livelihoods across Ethiopia, Kenya, and Somalia, while cyclones Idai (2019) and Freddy (2023) devastated Mozambique, Malawi, and Madagascar [14].

3.3 Nigerian Context

Nigeria's diverse ecological zones produce markedly different adaptation needs across the country, and the literature increasingly organizes discussion of climate risk around these zones rather than treating Nigeria as climatically uniform. Flooding is the most significant risk in the Niger and Benue river basins: the 2022 floods displaced over 1.4 million people, caused more than 600 deaths, and damaged infrastructure and

agriculture nationwide [15], [8]. Northern Nigeria and the Sahelian fringe face rising heat stress, desertification, and land degradation that threaten food security [7]. Coastal states Lagos, Bayelsa, and Rivers face sea-level rise, erosion, and storm surge, while rapidly urbanizing southwestern cities such as Lagos and Ibadan experience flooding intensified by inadequate drainage and unplanned expansion [7], [19]. Table 1 summarizes these hazard types, their climate linkages, and their consequences for Nigeria.

Table 1: Major Types of Extreme Weather Events and Their Implications

Extreme Weather Event	Climate Linkages	Environmental and Socio-economic Consequences	Nigeria Examples
Flooding	Increased extreme rainfall, poor drainage, sea-level rise, land-use change	Infrastructure damage, displacement, disease outbreaks, agricultural losses	2022 national flood disaster affecting communities across Nigeria
Drought	Rising temperatures, prolonged dry seasons, rainfall variability	Water scarcity, crop failure, livestock losses, food insecurity	Northern Nigeria and Sahel regions affected by prolonged dry spells
Heat waves	Increasing global temperatures from greenhouse gas accumulation	Heat stress, health risks, reduced labour productivity	Increasing heat stress in northern Nigeria
Storms and tropical cyclones	Warmer oceans and increased atmospheric moisture	Coastal destruction, displacement, economic losses	Cyclones affecting African coastal countries such as Mozambique and Madagascar
Wildfires	Higher temperatures and prolonged drought conditions	Vegetation loss, biodiversity decline, air pollution	Increasing wildfire risks in dry regions globally
Sea-level rise and coastal erosion	Ocean warming, thermal expansion, melting ice sheets	Coastal flooding, saltwater intrusion, livelihood disruption	Vulnerability of Lagos, Bayelsa, and Rivers coastal communities

Source: [1], [3].

4. DRIVERS OF CLIMATE CHANGE

Although natural factors solar variability, volcanic aerosols, and ocean-atmosphere interactions such as Atlantic and Gulf of Guinea sea-surface temperature variation continue to influence regional variability, they cannot account for the pace and magnitude of contemporary warming [1], [7]. The dominant driver is anthropogenic greenhouse gas emissions, and in Nigeria this is closely tied to dependence on oil and gas, fossil-fuel-based electricity and transport, and gas flaring, which contribute both to emissions and to local environmental and health harms near extraction and industrial sites [16]. Deforestation driven by agricultural expansion, fuel wood demand, and logging, concentrated in southern Nigeria and the Middle Belt reduces carbon sequestration capacity while accelerating biodiversity loss, erosion, and desertification risk [17], [18]. Urbanization and industrialization compound these pressures: expanding cities increase energy demand, transport emissions, and urban heat-island effects, while inadequate drainage in cities such as Lagos amplifies flood exposure; industrial emissions from cement, refining, and manufacturing add further pressure where pollution controls remain weak [1], [19], [16]. Agriculture is both a contributor (methane from livestock, nitrous oxide from fertilizer, emissions from bush burning) and a sector highly exposed to the resulting climatic instability [1], [7]. Table 2 summarizes these drivers and their Nigerian manifestations; collectively, they show that Nigeria's climate challenge stems from the interaction of several sectors rather than any single activity, requiring integrated not siloed mitigation responses.

5. IMPACTS AND VULNERABILITY

Extreme weather events in Nigeria are increasingly systemic rather than isolated, affecting agriculture, health, water resources, infrastructure, and the economy simultaneously [1]. The 2022 floods damaged farmland and reduced yields of rice, maize, cassava, and yam across Kogi, Benue, and Anambra, while prolonged dry spells in the north have undermined drought-sensitive crops such as millet and sorghum, with cascading effects on food prices and malnutrition [21], [22]. Flood-related contamination raises the risk of cholera, typhoid, and diarrheal disease, while heat extremes contribute to cardiovascular and respiratory stress; coastal flooding threatens Niger Delta mangroves and desertification degrades vegetation in the north [7], [1]. Economically, floods routinely damage roads, schools, health facilities, and power and water infrastructure in cities such as Lagos, Port Harcourt, and Ibadan, disrupting business and public services [7]. Water stress is spatially uneven declining river flow and groundwater recharge in the north versus flood-driven contamination elsewhere and resource competition over water, grazing land, and farmland has

contributed to farmer-herder conflict in northern and central Nigeria, with climate change functioning as a threat multiplier rather than a direct cause [1], [22]. Climate vulnerability in Nigeria is not gender-neutral. Women and girls, who make up a large share of the smallholder agricultural workforce and bear primary responsibility for water and fuel collection in many households, face compounded exposure when floods, drought, or displacement disrupt these roles; existing gender-based inequalities in land tenure, access to credit and agricultural extension services, and representation in local decision-making structures constrain women's capacity to adapt independently of household or community resources [37]. Climate-induced displacement and resource conflict also raise protection risks disproportionately affecting women and girls. Adaptation and resilience programming in Nigeria should therefore explicitly account for gender-differentiated exposure and build women's participation into planning and implementation rather than treating vulnerability as uniform across households.

Table 2: Major Climate Drivers and Their Contributions to Climate Change

Climate Driver	Mechanism of Influence	Major Impacts	Examples in Nigeria/Developing Countries
Greenhouse gas emissions	Increased atmospheric CO_2, CH_4, N_2O enhance the greenhouse effect	Global warming, changing rainfall, increased climate extremes	Fossil fuel combustion, gas flaring, transportation and industrial emissions
Deforestation and land-use change	Reduces carbon storage capacity; alters local climate regulation	Biodiversity loss, increased emissions, soil degradation, desertification	Forest loss in southern Nigeria and the Middle Belt (agriculture, fuel wood, logging)
Industrialization	Manufacturing and energy production release GHGs and pollutants	Atmospheric warming, air pollution, ecosystem degradation	Cement production, oil refining, industrial emissions in urban centers
Urbanization	Higher energy demand, construction, transport emissions, urban heat island	Higher urban temperatures, flooding risk, increased emissions	Rapid urban expansion and flood vulnerability in Lagos, Ibadan, Abuja, Port Harcourt
Agriculture and land management	Livestock emissions, fertilizer use, rice cultivation, bush burning	Food system vulnerability, ecosystem degradation, CH_4/N_2O emissions	Livestock production and agricultural expansion in northern Nigeria
Natural climate variability	Solar radiation, volcanic activity, ocean-atmosphere interactions	Short-term climatic variability and regional weather changes	Rainfall variability linked to Atlantic Ocean and Gulf of Guinea conditions

Source: Adapted from [1], [16], and [19].

6. ADAPTATION AND RESILIENCE STRATEGIES

Nigeria's adaptation response has moved from isolated interventions toward more integrated approaches spanning agriculture, infrastructure, community action, and policy [1]. Climate-smart agriculture agroforestry, conservation agriculture, drought-tolerant varieties, and improved soil and water management has shown productivity and income gains in northern Nigeria, reinforced by irrigation investment through River Basin Development Authorities and improved varieties from IITA and NASC [23], [24]. Infrastructure adaptation includes drainage and flood-control investment in Lagos, Ibadan, Port Harcourt, and Abuja, and coastal shoreline defence in Lagos [25]. Community-based adaptation combines NiMet's seasonal forecasts and early warning information with indigenous ecological knowledge, while NEMA and state emergency agencies build preparedness through awareness campaigns and response training [26]. These strategies differ substantially in cost, institutional demand, and scalability, and the literature does not treat them as interchangeable. Climate-smart agriculture and community-based adaptation are comparatively low-cost and locally scalable but depend on sustained extension support and secure land tenure to persist; resilient infrastructure (drainage, coastal defenses) delivers large risk reductions but requires substantial capital and long-term maintenance capacity that many state and local governments lack; early warning systems are among the most cost-effective interventions per life protected but require reliable last-mile communication to translate forecasts into household-level action [35]. Ecosystem-based approaches such as mangrove and forest restoration are comparatively affordable and deliver co-benefits for biodiversity, but their resilience payoff accrues over a longer time horizon than infrastructure investment. Evidence of measured resilience outcomes as opposed to adoption or implementation counts remains thinner across all categories, which is itself a gap this review identifies rather than resolves. Table 3 summarizes these strategies and their applications in Nigeria.

Table 3: Climate Adaptation Strategies and Resilience Outcomes

Adaptation Strategy	Key Actions	Resilience Outcomes	Relevant Application in Nigeria
Climate-smart agriculture	Drought-resistant crops, conservation agriculture, agroforestry	Increased productivity and reduced climate risk	Adoption of improved maize, rice, cassava, and cowpea varieties
Climate-resilient infrastructure	Flood control, improved drainage, coastal protection, resilient buildings	Reduced disaster losses, improved durability	Drainage improvement and coastal protection projects in urban areas
Community-based adaptation	Local participation, indigenous knowledge, preparedness	Increased local adaptive capacity and ownership	Community disaster preparedness and traditional environmental management
Early warning systems	Climate forecasting, risk communication, emergency preparedness	Improved preparedness, reduced mortality	Seasonal forecasts by Nigerian Meteorological Agency (NiMet)
Ecosystem-based adaptation	Forest restoration, wetland conservation, mangrove protection	Biodiversity conservation, ecosystem resilience	Mangrove restoration in coastal Nigeria and afforestation initiatives
Climate governance and policy integration	Climate legislation, institutional coordination, planning	Improved policy implementation and resource management	Climate Change Act (2021), National Adaptation Plan Framework
Climate finance mechanisms	Access to international and domestic adaptation funding	Increased implementation capacity	Support from Green Climate Fund, World Bank, and AfDB

Source: [1], [27].

Table 4: Key Policy Gaps Limiting Climate Adaptation in Nigeria and Developing Countries

Policy Gap	Underlying Challenge	Implications for Climate Resilience	Required Intervention
Limited adaptation financing	Insufficient domestic resources; difficulty accessing international funds	Delayed implementation of resilience programmes	Establish dedicated adaptation funding mechanisms, including local-government funds
Weak institutional coordination	Fragmented responsibilities among agencies and sectors	Inefficient climate planning and disaster response	Strengthen climate governance and inter-agency coordination
Limited local government capacity	Lack of technical expertise, funding, and climate information	Reduced ability to implement community-level adaptation	Decentralize adaptation planning; strengthen local institutions
Inadequate integration of indigenous knowledge	Limited recognition of traditional adaptation practices	Loss of context-specific resilience strategies	Institutionalize indigenous knowledge within national adaptation plans
Poor climate data and monitoring	Limited access to reliable climate information	Weak risk assessment and decision-making	Expand climate research, monitoring networks, and data sharing
Low public awareness and climate literacy	Limited understanding of climate risks and adaptation options	Low community participation in resilience initiatives	Strengthen climate education and public awareness programmes
Infrastructure vulnerability	Existing infrastructure not designed for changing climate conditions	Increased disaster losses and economic disruption	Promote climate-resilient infrastructure planning

Source: Literature synthesis (this review).

7. POLICY AND INSTITUTIONAL GAPS

Nigeria has established relevant policy architecture the National Climate Change Policy, National Adaptation Plan Framework, Climate Change Act (2021), and the National Council on Climate Change and engages international mechanisms including the Paris Agreement, UNFCCC, and partnerships with the

World Bank, African Development Bank, and Green Climate Fund [7]. Implementation, however, is constrained by several interlocking gaps: adaptation finance remains limited and difficult to access, particularly for sub-national actors [1]; institutional coordination across federal ministries, state governments, and agencies remains weak, limiting monitoring and response capacity [7]; local governments often first responders to climate disasters frequently lack the technical expertise and resources to implement adaptation directly [28]; indigenous knowledge remains under-integrated into formal planning; climate data and monitoring systems remain limited [31]; public climate literacy remains low, constraining community participation [30]; and much existing infrastructure was not designed for current climate conditions [28]. Insecurity and conflict further divert resources from long-term resilience-building toward humanitarian response [29]. Table 4 summarizes these gaps and the corresponding institutional interventions required.

8. INTEGRATED CLIMATE RESILIENCE FRAMEWORK

Building on the evidence synthesized above, this review proposes an Integrated Climate Resilience Framework linking climate drivers, hazards, exposure and vulnerability, adaptive capacity, adaptation interventions, and resilience outcomes (Figure 1).

8.1 Theoretical basis and relationships among components: The framework draws on the hazard–exposure–vulnerability logic underlying the IPCC's risk framework and the UNDRR/Sendai resilience concept, but departs from both in two respects. First, rather than presenting climate risk as a one-directional sequence from driver to outcome, the framework treats adaptive capacity and governance as feeding back upon exposure and vulnerability: investment in early warning systems, for example, directly reduces exposure to a subsequent hazard, and successful resilience outcomes (e.g., improved local financing) expand future adaptive capacity, rather than adaptation being a terminal stage reached only after impact. Second, the framework treats governance and indigenous knowledge as cross-cutting components shaping every stage driver mitigation, hazard forecasting, vulnerability reduction, and adaptation delivery rather than as inputs confined to the adaptation stage alone, consistent with the governance gaps identified in Section 7.

8.2 Originality relative to existing frameworks: The hazard-exposure-vulnerability structure is adopted from the IPCC AR6 risk framework [1], and the resilience-outcome orientation draws on World Bank resilience-integration guidance [10]. The framework's original contribution is (i) the explicit feedback loops connecting adaptation and governance back to exposure and vulnerability, rather than a linear pipeline, and (ii) its Nigeria-specific instantiation, which embeds the gender dimension of vulnerability (Section 5) and the institutional gaps identified in Section 7 directly into the framework's vulnerability and governance components, rather than treating them as external commentary on a generic model.

Figure 1: Integrated Climate Resilience Framework for Nigeria

CLIMATE DRIVERS (natural + anthropogenic — GHG emissions, deforestation, urbanization, industrialization)
↓
CLIMATE HAZARDS (floods, droughts, heat waves, storms, sea-level rise)
↓
EXPOSURE & VULNERABILITY (poverty, weak infrastructure, gender-differentiated exposure, climate-sensitive livelihoods, weak governance)
↓ ↑ (feedback)
ADAPTIVE CAPACITY & GOVERNANCE (institutions, finance, indigenous knowledge, early warning)
↓ ↑ (feedback)
ADAPTATION INTERVENTIONS (climate-smart agriculture, resilient infrastructure, ecosystem restoration, community-based adaptation)
↓
CLIMATE RESILIENCE OUTCOMES (reduced risk, food/water security, sustainable development) — feeds back to Adaptive Capacity & Exposure/Vulnerability above

Source: Author's conceptualization, adapting the risk logic of [1] and the resilience-integration approach of [10]

8.3 Position statement: Consistent with this framework, the paper argues that adaptation should be treated as an equally urgent pillar of climate action alongside mitigation, particularly for vulnerable, low-emitting countries such as Nigeria [1]. This requires three shifts: adaptation finance disbursed directly to sub-

national governments and communities, who are typically first responders but lack resources to act; infrastructure planned for future rather than historical climate conditions; and indigenous knowledge formally institutionalized within adaptation planning alongside not subordinate to scientific climate information, recognizing that such knowledge can complement but should not substitute for scientific data under rapidly changing conditions [1], [32].

9. POLICY RECOMMENDATIONS

Table 5 translates the review's findings into specific, actionable recommendations, identifying the responsible institution, implementation level, and expected resilience outcome for each priority area, consistent with the institutional gaps identified in Section 7.

Table 5: Policy Recommendations by Responsible Institution and Level

Recommendation	Responsible Institution	Level	Priority Action	Expected Resilience Outcome
Strengthen climate governance	National Council on Climate Change; sectoral ministries	Federal	Mainstream climate action across environment, agriculture, water, health, and energy ministries [1]	Coordinated, accountable policy implementation
Expand renewable energy	Federal Ministry of Power; private investors	Federal/private	Incentivize solar, wind, and hydro deployment [33]	Reduced emissions; improved energy security
Decentralize climate finance	Federal Ministry of Finance; state/local governments	Federal to local	Establish dedicated local-government adaptation funds [31]	Faster, locally appropriate adaptation delivery
Scale climate-smart agriculture	Federal/State Ministries of Agriculture; IITA; NASC	State/local	Expand drought-tolerant varieties and conservation agriculture [34]	Stabilized yields and farm incomes
Strengthen early warning systems	NiMet; NEMA; state emergency agencies	Federal/state	Invest in forecasting infrastructure and last-mile communication [35]	Reduced disaster mortality and losses
Expand public climate literacy	Educational institutions; media; civil society	All levels	Integrate climate education and community engagement	Increased community participation in adaptation

10. CONTRIBUTION TO KNOWLEDGE

This review contributes to climate resilience scholarship in three specific ways. First, it synthesizes global, African, and Nigerian evidence within a single framework rather than treating these scales separately. Second, it advances an Integrated Climate Resilience Framework built on explicit feedback relationships between adaptation, governance, and vulnerability rather than a linear hazard-to-outcome model and embeds Nigeria-specific gender and institutional dimensions directly into that structure. Third, it translates identified policy gaps into institution- and level-specific recommendations (Table 5), providing a more directly actionable output than a purely descriptive synthesis.

11. CONCLUSION

Climate change and extreme weather in Nigeria are interconnected challenges that existing fragmented, hazard-by-hazard responses are poorly suited to address. This review synthesizes climate trends, drivers, and vulnerability including its gender dimension adaptation strategies, and governance gaps into an Integrated Climate Resilience Framework built on feedback rather than linear logic, and translates that synthesis into institution-specific policy recommendations. The evidence indicates that adaptation must be prioritized alongside mitigation, financed directly at the sub-national level, and grounded in the integration of scientific and indigenous knowledge. Future research should prioritize context-specific resilience indicators, rigorous evaluation of adaptation interventions' measured outcomes (not only their adoption), and the role of local institutions and community-led financing in building adaptive capacity.

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