CLIMATE CHANGE ADAPTATION AND ENVIRONMENTAL HAZARD MANAGEMENT IN NIGERIA: INTEGRATING INDIGENOUS KNOWLEDGE SYSTEMS AND ENVIRONMENTAL EDUCATION FOR RESILIENCE

AKAEZE, Chukwufumnaya Cynthia
EMEDEM, Cecilia Ukaemeke
EGBULE, Philip Onyekachukwu
Department of Arts and Social Science Education,
University of Delta, Agbor, Delta State, Nigeria.
akaezecynthia503@gmail.com

Abstract
Significant influence exists between man, climate, and the environment. Recent happenings have emphatically demonstrated humanity's growing vulnerability to climate change and its threats to human survival, calling for a proactive approach to halt the envisaged ruin. Man's environment is dependent on climatic and environmental conditions, which either ease or complicate human existence. This paper examined how vulnerability to climate change and environmental hazards in Nigeria could be reduced by drawing jointly on indigenous knowledge systems (IKS) and formal climate science, with a particular interest in the complementary role that IKS can play alongside environmental education. The paper is aimed at creating awareness and educating Nigerians on environmental issues and empowering them to protect the environment, since national development cannot be achieved without the environmental protection that environmental education fosters. Given increasing climatic instability, the study synthesizes awareness-raising and mitigation and adaptation solutions to aid and reinforce resilience in Nigerian cities and rural communities. The paper demonstrated that climate-change-induced displacement is a determinant of conflict and a major threat to security in Nigeria, and that such conflicts have become a yardstick for internal migration in the country. This study adopted a qualitative documentary research design. The design was considered appropriate because the study seeks to critically examine the relationship between climate change adaptation, environmental hazard management, indigenous knowledge systems (IKS), and environmental education in Nigeria through the synthesis and analysis of existing literature and documented evidence. The approach enabled the study to draw together findings from previous scholarly studies, policy documents, institutional reports, and other relevant secondary sources to develop an integrated understanding of climate vulnerability and resilience in Nigeria. The paper concludes with recommendations on how indigenous knowledge and scientific-educational approaches can be woven together to strengthen coping capacity in Nigeria.

Keywords: Climate, Climate change, Environmental hazards, Environmental education, Indigenous knowledge systems

Introduction
Climate and environment are not peripheral to human affairs; they are the very stage upon which human existence unfolds. Farming, water supply, health, and where people settle are all shaped by what is happening in the atmosphere and on the land. When that stage becomes unsteady, as it increasingly is worldwide, the effects spread into every corner of society. Nigeria, whose economy and cultural life remain closely tied to land, rainfall, and natural resources, is among the countries most exposed. Its ecological range, from the Sahelian fringe in the far north to the mangrove coastline of the Niger Delta, means there is no single story to tell about climate impact here: desertification, drought, and shrinking grazing land dominate the north; flooding, coastal erosion,

and rising seas dominate the south; and gully erosion tears through the south-east (Okon et al., 2021).

The science on a warming, destabilising climate is no longer seriously disputed. The Intergovernmental Panel on Climate Change have bluntly stated that human activity has warmed the atmosphere, ocean, and land, and that the resulting extremes have already caused widespread, sometimes irreversible harm (IPCC, 2023). For Nigeria, this plays out as recurrent floods, rainfall that no longer follows its old patterns, longer dry spells, and desert-like conditions creeping further south, all chipping away at agricultural output, water and food security, and livelihoods (Akatah et al., 2025; Okon et al., 2021).

The central claim of this paper is that Nigeria cannot cope with climate change and environmental hazards through climate science and formal education alone, nor can it rely purely on inherited practices. Resilience is most achievable where the two traditions reinforce each other: where indigenous early-warning cues are strengthened by satellite forecasting, traditional land management is backed by climate-smart agronomy, and oral wisdom is amplified through environmental education curricula and public campaigns. This departs from treating indigenous knowledge as folklore, or scientific knowledge as the only legitimate basis for policy. National development depends on the kind of environmental protection environmental education fosters, and such education works best when it takes seriously the knowledge communities already hold.

The urgency here is sharpened by Nigeria's demographics. With a population above two hundred million, a large share of whom rely directly on rain-fed farming, artisanal fishing, or herding, climate variability translates almost immediately into pressure on human welfare. Agriculture still employs much of Nigeria's rural workforce and remains a significant part of GDP, so disruptions to rainfall timing, soil fertility, and water availability are direct threats to income and food security, not abstract environmental worries (Okon et al., 2021). At the same time, rapid, often unplanned urban growth has pushed more people into flood-prone lowlands and erosion-prone slopes, adding to the human cost of extreme weather that climate change is expected to make more frequent (IPCC, 2023).

Conceptual Clarifications

Climate and Climate Change

Climate is the long-term pattern of weather, temperature, precipitation, humidity, wind, which defines a region over an extended stretch, usually thirty years or more. It differs from weather, which is what is happening at a given place and moment; an unusually cool morning is weather, while a decades-long shift in when the rains typically begin is climate. Climate change is a statistically significant, lasting shift in these patterns, whether from natural causes like volcanic activity or solar cycles, or, as is now overwhelmingly the case, from human activity, chiefly greenhouse gas emissions from burning fossil fuels, deforestation, and land-use change (IPCC, 2023).

The IPCC's Sixth Assessment Report (2023) states that human influence has warmed the climate system at a pace unmatched in at least two thousand years, bringing more frequent heat waves, heavier rainfall punctuated by longer dry spells, and faster sea-level rise. In Nigeria, this shows up less as a distant statistic and more as lived disruption: planting seasons that no longer follow the old calendar, flood levels no one has seen before, and dry land pushing further south (Okon et al., 2021). Getting the concepts straight matters, because without a shared sense of what separates ordinary weather fluctuation from a genuine climatic shift, public conversation risks either dismissing long-term trends as passing anomalies or blaming every bad-weather day on climate change without

evidence.

Environmental Hazards

Environmental hazards are natural or anthropogenic events or conditions that can cause damage to life, property, or the functioning of an ecosystem. A hazard could usefully be considered as the latent or underlying risk and a disaster as that risk manifesting in a form that overwhelms local coping mechanisms, and that is why a hazard transforming into a disaster comes down so much to adaptive capacity, and includes indigenous knowledge. The major hazards in Nigeria which include flooding, gully and coastal erosion, desertification, drought, deforestation, and land degradation are all being exacerbated by the dual threat of climate change and poor land management (Okon et al., 2021; Osakwe et al., 2025). These hazards can hardly remain isolated: long-term drought in the north, for that matter, tends to trigger desertification, farmer–herder conflict, and distress migration in its wake (Osakwe et al., 2025) which explains why any mitigation that addresses a single hazard in isolation from its cascade effects likewise tends to provide incomplete, temporary relief.

Indigenous Knowledge Systems

Indigenous knowledge systems are the cumulative body of knowledge, practices, and beliefs that evolves through adaptive processes and passes across generations by cultural means, concerning how living beings, humans included, relate to one another and to their environment (Berkes et al., 2000). This knowledge is holistic rather than divided into disciplines, rooted in local cosmology, oral tradition, and communal governance, and tested through lived experience rather than controlled experiment (Berkes, 1999). In Nigeria, it includes traditional weather forecasting based on animal and plant behaviour, indigenous soil and water conservation techniques, communal land-tenure arrangements, and taboos protecting sacred groves and water catchments (Ajibade & Eche, 2017). It typically travels through oral narratives, proverbs, rituals, and apprenticeship within family and age-grade structures rather than classroom-based transmission, a distinction that matters for how it might be respectfully folded into formal environmental education without stripping away the relational qualities that give it meaning within the community.

Theoretical Framework

This paper leans on two complementary theories: Traditional Ecological Knowledge (TEK) theory, associated with Berkes, Colding, and Folke (2000), and Vulnerability Theory, associated with Adger (2006).

Traditional Ecological Knowledge Theory

Berkes et al. (2000) describe traditional ecological knowledge as a cumulative body of knowledge, practices, and beliefs that evolves through adaptive processes and passes down through generations by cultural transmission. Central to their argument is that indigenous management systems work much like formal adaptive management: both rely on continuous feedback from the environment, both tolerate and respond to uncertainty, and both embed learning within institutions that regulate resource use over time. Berkes (1999) breaks TEK into four connected levels: local knowledge of species and landscapes; resource-management practices; social institutions of governance; and worldviews encoding ethics about the human–nature relationship. Applied to Nigeria, this gives conceptual grounding for treating practices like reading cloud patterns or timing planting to a tree's flowering not as superstition but as an empirically grounded understanding capable of working alongside formal climate science.

A further point that matters here is that the social mechanisms through which indigenous knowledge is generated and passed on, local leadership, customary rules of access, embedded worldviews, are themselves part of what makes the knowledge work (Berkes et al., 2000). It cannot simply be

extracted as a stock of discrete facts to slot into scientific frameworks; the institutional and cultural context surrounding it is essential to its reliability and needs to be respected, not bypassed.

Vulnerability Theory

Adger (2006) defines vulnerability as susceptibility to harm from exposure to environmental and social stress combined with a lack of capacity to adapt. It is not just a matter of physical exposure to hazards; it is produced jointly by social, economic, and institutional conditions that determine who can anticipate, cope with, resist, and recover from hazard impacts. Adger draws attention to differential vulnerability: the same flood or drought can devastate one community while leaving a better-resourced or better-informed one relatively unscathed. This lens is essential for understanding Nigeria's experience, because it pulls attention away from the hazard alone and toward the social and institutional factors that determine harm, including whether communities can draw on inherited ecological knowledge as part of their adaptive capacity. This is especially useful for a country as regionally varied as Nigeria, where the north's exposure to desertification, the south's exposure to flooding and erosion, and the Middle Belt's exposure to farmer–herder conflict each call for context-specific responses rather than a single national template.

Taken together, these two theories suggest indigenous knowledge functions as a latent adaptive resource whose value is only realised when it is recognised, supported, and, where appropriate, integrated with scientific knowledge and formal education rather than displaced by them. This directly feeds into the conceptual framework below.

Environmental Education and Climate Change Awareness in Nigeria

A related strand of research looks at the state of environmental and climate change education in Nigeria, generally reporting a troubling gap between the scale of the threat and the level of public awareness. Oruonye et al. (2023), reviewing Nigeria's basic education system, argue that a dedicated climate change and environmental education curriculum would strengthen the system's resilience while empowering youth to lead environmental action, and recommend translating such a curriculum into Nigerian local languages. Eneji et al. (2021), studying rural farmers in Northern Cross River State, found that environmental education significantly shaped farmers' climate change awareness and capacity to adopt sound coping strategies, though this relationship was mediated by gender, with women carrying disproportionate adaptive burdens despite often having less access to formal education.

Mailumo et al. (2018), reviewing climate change education for sustainable development in Nigeria, similarly conclude that although the country has made policy commitments in this area, implementation stays fragmented across ministries and educational levels, with weak teacher training undermining classroom delivery. Together, this literature suggests Nigeria's environmental education deficit is less about missing policy and more about weak translation into classroom practice and language-appropriate materials, a gap into which indigenous knowledge, already trusted and locally understood, could usefully be inserted.

Broader awareness surveys corroborate these curriculum-focused findings. National surveys cited in the Nigerian climate education literature report that most Nigerians remain largely unaware of the technical dimensions of climate change even as they experience its effects directly through altered rainfall, flooding, and rising temperatures, a disconnect that suggests the barrier to climate literacy is not a lack of relevant experience to build from, but an absence of structured educational engagement connecting that experience to broader conceptual frameworks, scientific and, this paper argues, indigenous alike. Evidences from tertiary institutions adds nuance: surveys of

university, polytechnic, and college of education students and staff show general, if uneven, awareness of climate change terminology, but persistent gaps in deeper engagement and practical application outside environmental science departments narrowly defined. Climate and environmental literacy in Nigeria, in other words, remains largely confined to specialist audiences rather than diffused across the wider educated population, let alone the rural and peri-urban communities most exposed to climate hazards.

Socio-Economic Impacts of Climate Change and Environmental Hazards

Empirical assessments of climate impacts in Nigeria consistently document extensive socio-economic disruption. Okon et al. (2021), reviewing climate change impact research across the country, catalogue desert encroachment, wetland loss, declining surface water, soil degradation, flooding, and coastal erosion across Nigeria's geopolitical zones, with the south-east experiencing particularly severe flooding and gully erosion alongside falling crop yields. Akatah et al. (2025) document intensifying heatwaves nationwide, with risks to health, labour productivity, and energy demand, calling for coordinated strategies spanning urban planning, public health, and early-warning systems. Aborode et al. (2025), focusing on flooding in Borno State, report that climate-induced floods have been accompanied by water-related disease outbreaks and worsening malnutrition, showing how environmental hazards compound existing humanitarian vulnerability in conflict-affected regions.

Osakwe et al. (2025) extend this picture by linking climate-induced environmental degradation directly to natural resource conflict, arguing that intensifying desertification in the north, coastal erosion and flooding in the south, and erratic rainfall nationwide function not merely as environmental problems but as real drivers of conflict, displacement, and livelihood insecurity. Together, this evidence shows the socio-economic consequences of climate change in Nigeria are neither hypothetical nor confined to the future; they are already visible in reduced agricultural output, worsening public health, and heightened social tension.

The agricultural dimension deserves particular attention given how central farming is to Nigerian livelihoods. Reviews of climate impacts on Nigerian agriculture consistently report that erratic rainfall, rising temperatures, and greater pest and disease pressure have cut yields of staple crops such as maize, cassava, and rice, while livestock producers face growing heat stress and feed scarcity, and fisheries face shrinking, increasingly contaminated water. These reviews note that farmers already combine coping strategies, crop diversification, adjusted planting calendars, and indigenous knowledge, alongside externally introduced measures such as improved irrigation, showing that formal adaptation programmes tend to operate alongside indigenous coping mechanisms rather than replacing them.

Beyond agriculture, the built environment and urban infrastructure carry substantial and growing costs. Recurrent flooding in Nigerian cities, driven by heavier rainfall meeting inadequate drainage, has repeatedly damaged roads, housing, and public utilities, while coastal erosion along the Atlantic seaboard threatens infrastructure and settlements in low-lying parts of the Niger Delta and Lagos. These impacts compound the agricultural and health effects already documented, producing a cumulative burden that falls hardest on lower-income households with little capacity to relocate or rebuild after a hazard event (Okon et al., 2021).

Climate-Induced Displacement, Migration and Conflict

A distinct but closely related literature addresses the security implications of climate-induced

displacement in Nigeria. Studies of the Lake Chad Basin and the wider Sahelian north document how desertification and shrinking water resources have forced large-scale pastoral and agrarian migration, intensifying competition between farmers and herders over dwindling land and water and, in several documented cases, sparking violent confrontation (Osakwe et al., 2025). Research on the Niger Delta similarly reports that flooding-induced displacement generates resource competition among host and displaced populations, with disputes over fishing grounds and farmland compounding pre-existing tensions (Osakwe et al., 2025).

In north-eastern Nigeria, the interaction between climate stress and the Boko Haram insurgency has produced a particularly severe humanitarian and security crisis: recurrent drought and resource scarcity have combined with conflict-driven displacement to leave millions in protracted vulnerability, with weakened state presence creating conditions insurgent groups have exploited for recruitment (Osakwe et al., 2025). This literature backs the claim that climate-induced displacement functions as a determinant of conflict in Nigeria, and that such conflict in turn becomes a further driver of internal migration, a cyclical dynamic that compounds rather than resolves vulnerability.

Displacement-focused studies further show that congested camps and informal settlements hosting climate-displaced populations often experience secondary public health crises, heightened tension between host and displaced communities, and reduced access to education and healthcare for displaced children, effects that persist well beyond the hazard event that triggered displacement. Governance responses have generally been described as fragmented, reactive, and under-resourced, with security-oriented interventions frequently pursued apart from the environmental and livelihood interventions that would address the underlying drivers of displacement, a disconnect this paper's proposed framework is meant to help bridge.
In fairness, not all scholars treat the relationship between climate stress and conflict in Nigeria as direct or deterministic. Several studies reviewed here caution that climate-induced migration functions as a threat multiplier rather than a sole cause of conflict, with weak governance, poverty, and pre-existing ethnic or religious tension mediating whether resource competition escalates into violence. This cautious framing matters because it implies that strengthening governance and community-level adaptive capacity, including through the kind of indigenous knowledge integration this paper advocates, may do more to prevent conflict than security-focused interventions addressing displacement alone.

Although **the herdsmen-farmers crisis** is a problem that dates back to the pre-colonial period, the frequency of farmers/herdsmen conflicts appears to be on the increase in recent times. There also seem to be no clear consensus among scholars to show time-series evidence and the factor(s) responsible for this rise in violent conflicts between the farmers and the herdsmen (Egbule & Okonta, 2024 in Adigun, 2019). Recently, several claims have been made as to the factors that have given rise to the seeming rising incidence of violent attacks between the herders and the farmers in Nigeria with serious national security implications. The herdsmen-farmers crisis has deep historical roots, but recent shifts in climate patterns have amplified the competition for dwindling natural resources, particularly arable land and water.

Research Gap

Although the literature reviewed here offers considerable insight into indigenous knowledge, climate impacts, environmental education, and climate-induced displacement in Nigeria as separate lines of inquiry, three related gaps remain. First, studies on indigenous knowledge systems tend to document their existence and continuing use but rarely examine how such knowledge might be

deliberately built into environmental education curricula and public climate communication, rather than sitting alongside formal systems on parallel, largely unconnected tracks (Ajibade & Eche, 2017; Oruonye et al., 2023). Second, the literature on environmental education and the literature on climate-induced displacement and conflict have developed largely independently of each other, with little attention paid to whether stronger environmental education, especially education grounded in locally trusted indigenous knowledge, could reduce the vulnerability that turns environmental hazard into displacement and conflict. Third, existing studies rarely frame indigenous knowledge and scientific climate information as complementary rather than competing, leaving a gap around how the two might actually be operationalised together in policy and practice within Nigerian. This paper addresses that composite gap by positioning indigenous knowledge not as an alternative to climate science and environmental education but as a necessary complement for building coping capacity in Nigeria.

There is also a methodological dimension to this gap. Much of the Nigerian literature on indigenous knowledge and climate adaptation is descriptive, documenting the existence of indigenous practices without systematically assessing their comparative effectiveness against, or in combination with, scientific alternatives. Similarly, most environmental education research in Nigeria measures awareness levels or curriculum content rather than testing whether interventions that explicitly incorporate indigenous knowledge produce measurably different adaptive outcomes than conventional, science-only instruction. This paper does not resolve that methodological gap through primary research, which lies beyond its scope as a literature-based synthesis; it simply names the gap and argues that future Nigerian research should prioritise comparative, integrative study designs capable of testing the complementary model advanced here.

Critical Synthesis: The Complementary Role of Indigenous Knowledge Systems

Read through TEK theory and vulnerability theory, the evidence reviewed above supports a central argument: indigenous knowledge systems can meaningfully strengthen Nigeria's capacity to cope with climate change and environmental hazards, but only where they are deliberately woven into, rather than left parallel to, formal climate science and environmental education.

First, indigenous knowledge carries legitimacy and interpretive accessibility that purely technical climate information often lacks. A satellite-derived seasonal forecast may land with rural communities as an abstract, externally imposed pronouncement, whereas a forecast cross-validated against locally recognised indicators, the flowering of familiar trees, the behaviour of local birds, is more likely to be trusted and acted upon (Ajibade & Eche, 2017; Basdew et al., 2017). Environmental education programmes stand to gain by training teachers and extension workers not simply to transmit scientific climate information but to draw out and incorporate the indigenous ecological indicators already familiar to their communities, increasing both credibility and retention.

Second, indigenous knowledge systems encode place-specific adaptive practices, fallowing, agroforestry, communal water governance, that address the same vulnerabilities documented by Okon et al. (2021) and Osakwe et al. (2025): soil degradation, water scarcity, resource competition. These practices are frequently under-resourced in formal policy, yet Adger's (2006) framework suggests that strengthening this kind of locally embedded adaptive capacity offers a more durable route to reducing harm than relying solely on externally designed interventions. Extension and education services could usefully shift from simply supplying new techniques toward validating and reinforcing indigenous ones that already work, supplementing them with scientific inputs such

as soil testing and climate-smart agronomic advice.

Third, the literature on climate-induced displacement and conflict shows that where adaptive capacity, including indigenous knowledge, breaks down under unprecedented climatic stress, communities are pushed toward migration and, often, conflict (Osakwe et al., 2025). Environmental education that strengthens indigenous adaptive capacity, particularly around early warning, water and land management, and dispute-resolution mechanisms embedded in indigenous governance, may function not only as an environmental intervention but as an indirect contribution to conflict prevention in vulnerable regions such as the Lake Chad Basin, the Niger Delta, and the Middle Belt, an under-examined pathway and one of the more significant implications of treating indigenous knowledge as complementary rather than peripheral.

Fourth, and more cautiously, the evidence indicates indigenous knowledge alone cannot carry the full weight of adaptation, given that climate change now increasingly exceeds the range of historical variability upon which indigenous forecasting was built (Ajibade & Eche, 2017). The complementary framing advanced here is not a romanticisation of indigenous knowledge as sufficient in itself, but a recognition, consistent with Berkes et al.'s (2000) theorisation of TEK as an adaptive management system, that it works best as one input within a broader knowledge ecosystem that also includes scientific forecasting and structured environmental education.
Fifth, the regional variety in Nigeria's climate and hazard profile reinforces the case for a complementary rather than uniform national approach. The specific indigenous practices, hazard patterns, and educational needs of the arid north differ substantially from the humid south and the erosion-prone south-east, so any programme integrating indigenous knowledge with formal environmental education needs to be regionally differentiated rather than applied as a single template.

Challenges to Integrating Indigenous Knowledge with Science and Education
Despite its evident promise, integrating indigenous knowledge with climate science and environmental education in Nigeria faces real obstacles. Institutionally, climate and education policy has historically favoured scientific and technical framings, with indigenous knowledge given, at best, marginal acknowledgement rather than systematic incorporation into curricula, extension services, or early-warning systems (Oruonye et al., 2023; Mailumo et al., 2018). Epistemologically, it is often dismissed in formal educational settings as unscientific or superstitious, a bias that discourages both its serious documentation and its classroom use, notwithstanding the theoretical case, made by Berkes et al. (2000), that indigenous ecological knowledge is an empirically grounded body of understanding in its own right.

Generationally, rapid urbanisation, formal schooling that displaces traditional apprenticeship, and the erosion of oral transmission structures, age-grade systems and extended family networks, through which indigenous knowledge historically passed from elder to youth, threaten its continuity independent of any policy barrier (Ajibade & Eche, 2017). Practically, indigenous knowledge is highly localised and varies across Nigeria's ecological zones and ethnic groups, complicating efforts to standardise it in a national curriculum without diluting its specificity or excluding unrepresented communities. Finally, resource constraints, inadequate funding for teacher training, materials, and documentation, continue to hamper the translation of policy commitments into consistent practice (Mailumo et al., 2018; Oruonye et al., 2023).

There is also a risk of superficial or tokenistic integration, where indigenous knowledge is referenced in curricula or policy documents without genuine engagement with knowledge-holders, producing integration in name only. Guarding against this requires that integration efforts be participatory from the start, involving traditional rulers, elders, and community knowledge-holders as active partners in curriculum design rather than as passive sources consulted after key decisions have already been made. Without that grounding, well-intentioned efforts risk reproducing the very marginalisation of indigenous knowledge this paper argues against, while still claiming the language of complementarity.

Strategies for Coping/Recommendations

Building on the synthesis above, this paper proposes the following strategies for strengthening Nigeria's capacity to cope with climate change and environmental hazards through the complementary use of indigenous knowledge, climate science, and environmental education. First, environmental education curricula at the basic and tertiary levels should be redesigned to incorporate documented indigenous ecological knowledge alongside scientific climate content, translated into major Nigerian languages to widen accessibility, as recommended by Oruonye et al. (2023). Again, meteorological and extension services should establish routine arrangements–e.g., community climate forums–through which indigenous forecasting indicators can be cross-validated and communicated with scientific seasonal forecasts within the integrative framework akin to Basdew et al. (2017) Third, teacher education programmes in the Colleges and Faculties of Education need to have modules that focus on How to elicit and respectfully engage with local ecological knowledges in ways that teachers do not have to choose between or displace one knower within the other but can act as bridges between indigenous and scientific ways of knowing. Fourth, climate-related displacement and conflict in particular in the Lake Chad Basin, the Niger Delta and the Middle Belt require policy attention that focuses on building the capacity of indigenous institutions for land, water, and dispute resolution as a means of preventing conflict, rather than adopting the bifurcated approach of treating security response and environmental adaptation as divergent pathways (Osakwe et al., 2026). Fifth, comprehensive and community-based documentation of indigenous knowledges should be considered as an investment in research and policy formulation for its own sake for conserving knowledge at risk from discontinuities across generations and building the evidence base necessary for sound incorporation into the national planning. Finally, public awareness campaigns utilizing radio, community theatre, religious institutions and social media should be developed jointly with community elders to ensure delivery of climate messaging in idioms with which these communities already trust.

Conclusion

This paper investigates the contribution of indigenous knowledge to enhancing the capacity of Nigeria to adapt to climate change and environmental threats. Drawing upon traditional ecological knowledge and theories of vulnerability, it makes the case that indigenous knowledge, formal climate science, and environmental education are required to respond to the challenges of climate that Nigeria is facing. Indigenous knowledge offers locally trusted, place-based approaches that have sustained communities for generations and yet are being challenged by the accelerating pace of climate change. In contrast, climate science and environmental education provide comprehensive and scalable answers, but are frequently met with resistance when perceived as being at odds with local culture. It also shows that climate-related displacement causes conflict, yet conflict also causes displacement, a common cycle in places like the Lake Chad Basin and Niger Delta. Addressing these interrelated challenges will require advancing indigenous knowledge in environmental education within the context of Nigeria's overarching climate, security, and development framework. The integration provides a viable and culturally relevant means of

developing resilience.

References

Aborode, A. T., Otorkpa, O. J., Abdullateef, A. O., et al. (2025). Impact of climate change-induced flooding water related diseases and malnutrition in Borno State, Nigeria: A public health crisis. Environmental *Health Insights*, 19. https://doi.org/10.1177/11786302251321683

Adger, W. N. (2006). Vulnerability. *Global Environmental Change,* 16(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Akatah, B. M., Onyeaka, H., Onungwe, I., et al. (2025). Climate change-induced heatwaves in Nigeria: Causes, challenges, and adaptive strategies. *Journal of Environmental Management*, 394, Article 127433. https://doi.org/10.1016/j.jenvman.2025.127433

Egbule, P.O. & Okonta, E.C. (2024). How climate change induced land conflicts and food insecurity in Africa: A case of herdsmen-farmers crisis in Nigeria. *African Journal on Land Policy and Geospatial Sciences, 7*(1), 251–265.

Eneji, C. O., Onnoghen, N. U., Acha, J. O., & Diwa, J. B. (2021). Climate change awareness, environmental education and gender role burdens among rural farmers of Northern Cross River State, Nigeria. *International Journal of Climate Change Strategies and Management*, 13(4–5), 397–415. https://doi.org/10.1108/IJCCSM-06-2020-0070

Intergovernmental Panel on Climate Change. (2023). Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, H. Lee & J. Romero, Eds.). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

Kanu, I. A. (2022). *African Indigenous Ecological Knowledge Systems: Religion, Philosophy and the Environment. UK: AuthorHouse*

Kanu, I. A. (2022). *African Eco-Philosophy: Cosmology, Consciousness and the Environment. UK: AuthorHouse*

Kanu, I. A. (2022). *African Eco-Theology: Meaning, Forms and Expressions. UK: AuthorHouse*

Kanu, I. A. (2022). *African Ecological Spirituality: Perspectives on Anthroposophy and Environmentalism. A Hybrid of Approaches. UK: AuthorHouse*

Mailumo, D., Igbe, S., & Mailumo, P. (2018). Climate change education for sustainable development: Lessons for Nigeria. In W. Leal Filho (Ed.), *Handbook of climate change resilience. Springer*. https://doi.org/10.1007/978-3-319-71025-9_170-1

Okon, E. M., Falana, B. M., Solaja, S. O., et al. (2021). Systematic review of climate change impact research in Nigeria: Implications for sustainable development. *Heliyon,* 7(9), Article e07941. https://doi.org/10.1016/j.heliyon.2021.e07941

Oruonye, E. D., Oruonye, I. M., & Ahmed, Y. M. (2023). The necessity of climate change and environmental education curriculum in Nigeria's basic educational system. *Jalingo Journal of Social and Management Sciences*, 4(4), 123-140.

Osakwe, et al. (2026). Climate change and natural resource conflict in Nigeria (2020–2025). *Journal of the University of Agriculture and Environmental Sciences*, 3(1), 179-189.

CLIMATE CHANGE AND ECOSYSTEM SERVICE DEGRADATION: IMPLICATIONS FOR FOOD SECURITY IN AFRICA

Okuji Obinna Oreh, PhD
1Department of Finance, National Open University of Nigeria
drooreh@gmail.com

Victor Chidera Oguh
Department of Entrepreneurship, Veritas University Abuja, Nigeria
Oguhvictor20@gmail.com

Abstract
This study analyses the linkages between climate change and ecosystem service degradation, and their implications for food security in African economies. With increasing climate variability manifesting through irregular rainfall patterns, rising temperatures, and extreme weather events, the stability of ecosystem services that underpin agricultural systems is under significant threat. Drawing on ecological systems theory and climate resilience frameworks, the study investigates how disruptions in ecosystem services influence agricultural productivity and, ultimately, food security outcomes. Using panel data across 30 selected African countries (2000–2020), the study applies fixed effects and system Generalized Method of Moments estimators to account for endogeneity and cross-country heterogeneity. Climate variability is proxied through temperature and precipitation fluctuations, while ecosystem services are captured through soil fertility, land quality, and vegetation cover; agricultural productivity and food security are measured using crop yield indices and food availability metrics. The findings reveal that heightened climate variability significantly degrades ecosystem services, leading to declines in agricultural productivity and increased food insecurity, though resilience-enhancing mechanisms, including sustainable land management and climate-smart agricultural practices, moderate these adverse effects. The study contributes to the literature by integrating ecosystem service dynamics into the climate change-food security nexus within the African economy, and the policy implications assert the need for climate-adaptive agricultural strategies, investment in ecosystem restoration, and institutional frameworks that support sustainable resource management. Achieving food security in Africa requires aligning climate resilience with the preservation of ecosystem services that sustain agricultural livelihoods.
Keywords: Climate variability; Ecosystem services; Agricultural productivity; Food security and Sustainable agriculture.

Introduction
The intersection of climate change, ecosystem service degradation, and food insecurity represents one of the most pressing development challenges confronting Africa in the twenty-first century. Africa's agricultural sector, which employs over 60 percent of the continent's labour force and accounts for a significant portion of GDP in many economies, is increasingly exposed to the destabilizing effects of anthropogenic climate change (FAO, 2022), and the continent's disproportionate vulnerability to climate variability, despite contributing minimally to global greenhouse gas emissions, underscores the urgency of understanding the pathways through which climate change translates into food insecurity outcomes (IPCC, 2022).

Ecosystem services, broadly defined as the benefits humans derive from natural ecosystems, constitute the biophysical foundation upon which agricultural systems rest, encompassing provisioning functions such as soil fertility and water supply, regulating functions such as carbon sequestration and pest control, and supporting services such as nutrient cycling and pollination

(MEA, 2005). Progressive degradation of these services through rising temperatures, altered precipitation, and land-use change fundamentally undermines agricultural productive capacity, amplifying food insecurity risks across Africa (Lobell et al., 2011; Schlenker & Lobell, 2010). Despite extensive literature on climate impacts on agriculture (Roudier et al., 2011) and ecosystem service valuation (Costanza et al., 2017), a gap remains in empirical studies that systematically integrate ecosystem service dynamics into the climate change-food security nexus for Africa, existing studies tending to treat these relationships in isolation (Díaz et al., 2019). This study addresses that gap by drawing on ecological systems theory and climate resilience frameworks to develop an integrated analytical model.

The study deploys panel data from selected African countries and employs fixed effects and system Generalized Method of Moments (GMM) estimators to examine the pathways linking climate variability, ecosystem service degradation, agricultural productivity, and food security outcomes, an approach that appropriately handles endogeneity concerns and cross-country heterogeneity, thereby enhancing the reliability of the empirical inferences drawn (Arellano & Bond, 1991; Bond, 2002).

Literature Review

Climate Change and Agricultural Systems in Africa

The scientific evidence documenting climate change impacts on African agricultural systems is substantial. The IPCC confirms Africa is warming faster than the global average, with sub-Saharan mean temperatures projected to rise 1.5–3.5°C above pre-industrial levels by mid-century (IPCC, 2022), alongside projected precipitation reductions in already water-stressed regions such as the Sahel, the Horn of Africa, and southern Africa (Lobell et al., 2011). Schlenker and Lobell (2010) found each degree Celsius of warming reduces maize yields by approximately 5 percent, groundnut yields by 6 percent, and sorghum yields by 15 percent across sub-Saharan Africa, while Roudier et al. (2011) found a median projected 8 percent cereal yield decline by 2050 across 16 African countries, with higher losses in the driest regions. Beyond direct temperature effects, climate change intensifies droughts, floods, and cyclones, imposing episodic but severe shocks on the rain-fed smallholder systems that characterise most African farming, disrupting planting and harvesting cycles and contributing to widespread production losses (Barnett & Brown, 2019; Conway et al., 2015).

Ecosystem Services and Agricultural Productivity

Ecosystem services function as critical infrastructure sustaining agricultural production (MEA, 2005). Soil fertility is one of the most critical determinants of productivity in Africa, with degradation through erosion, nutrient depletion, and compaction affecting an estimated 65 percent of agricultural land in sub-Saharan Africa and annual productivity losses of 3–8 percent of gross agricultural output (Batjes, 2014; Nkonya et al., 2016). Vegetation cover plays a dual role, supplying organic matter and regulating microclimate directly, and shaping hydrological processes including precipitation generation and water infiltration indirectly; its loss through deforestation and land degradation is linked to reduced rainfall reliability, increased runoff, and accelerated soil erosion (Bonan, 2008). Costanza et al. (2017) estimated the global value of ecosystem services at approximately USD 125 trillion annually, and economics-of-land-degradation studies indicate that the costs of inaction substantially exceed the costs of sustainable land management (ELD Initiative, 2015), though integration of ecosystem service valuation into African agricultural policy remains nascent (Díaz et al., 2019).

Climate Change, Ecosystem Degradation, and Food Security

Food security encompasses four dimensions, availability, access, utilization, and stability (FAO, 2009), with climate change threatening availability through reduced productivity and stability through increased production variability (Wheeler & von Braun, 2013). Nelson et al. (2009) projected a 14 percent reduction in caloric availability per capita in sub-Saharan Africa by 2050, with more recent projections suggesting 40 to 80 million additional people at risk of hunger by mid-century (FAO, 2022; IPCC, 2022), consistent with Africa already accounting for the majority of the world's food-insecure population, an estimated 278 million undernourished in 2022 (FAO, 2023). Critically, land degradation is reducing productivity across approximately 23 percent of the global terrestrial surface, with severe African consequences (Díaz et al., 2019).

Resilience-Enhancing Mechanisms

Sustainable land management (SLM) practices, including conservation tillage, agroforestry, and watershed restoration, significantly improve soil health, restore vegetation cover, and enhance water retention, increasing both productivity and climate resilience (WOCAT, 2017). Climate-smart agriculture (CSA), a framework promoted by the FAO (2013) that simultaneously increases productivity, strengthens climate resilience, and reduces emissions where possible, has produced average yield improvements of 20 to 30 percent across African evaluations, particularly where combined with institutional support and market access (Rosenstock et al., 2016).

Theoretical Framework

This study draws on two complementary theoretical frameworks: ecological systems theory and climate resilience theory. Ecological systems theory, developed by Holling (1973), conceptualizes ecosystems as complex adaptive systems characterized by non-linear dynamics, threshold effects, and multiple stable states, in which ecosystem resilience, the capacity to absorb disturbance and reorganize while retaining function and identity, is central to understanding how climate variability affects ecosystem service stability (Folke, 2006). Applied to agriculture, this theory posits that climate-driven disturbances can push agro-ecosystems beyond critical thresholds, triggering rapid, potentially irreversible degradation of soil fertility, vegetation cover, and hydrological regulation, with cascading consequences for agricultural output and food security (Rockström et al., 2009; Steffen et al., 2015).

Climate resilience theory, articulated by Adger (2000), extends this perspective to the social and institutional dimensions of adaptive capacity, shaped by biophysical endowments, economic assets, social capital, institutional quality, and technological access (Béné et al., 2012). Integrating these frameworks generates a conceptual model in which climate variability operates through ecosystem service pathways to affect agricultural productivity and food security, moderated by adaptive capacity and resilience-enhancing mechanisms: climate variability degrades ecosystem services, ecosystem degradation reduces agricultural productivity, and productivity declines combined with direct climate shocks deteriorate food security, effects moderated by sustainable land management and climate-smart agricultural practices.

Data and Methodology

Data Sources and Variable Construction

The empirical analysis draws on panel data spanning 30 selected African countries over 2000–2020, yielding an unbalanced panel of approximately 600 country-year observations. The sampled countries are Algeria, Angola, Benin, Botswana, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, the Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Kenya, Malawi, Mali, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Togo,

Tunisia, Uganda, Zambia, and Zimbabwe, selected to ensure representation across Africa's major agro-ecological zones (arid, semi-arid, sub-humid, and humid) and differing levels of economic development. The dataset underlying the analysis is available from the corresponding author upon reasonable request.

Climate variability is operationalized through temperature anomaly, the deviation of annual mean surface temperature from the country-specific 1961–1990 baseline (Harris et al., 2020), a fixed pre-study reference period retained because it corresponds to the World Meteorological Organization's standard climatological normal and avoids mechanically understating the departure from historical norms that a within-sample benchmark would produce, and precipitation variability, the coefficient of variation in monthly rainfall within each year (GPCC data), both computed for every year of the 2000–2020 study period.

Ecosystem services are proxied by soil fertility (a composite index from the FAO Harmonized World Soil Database and ISRIC data), land quality (the GLASOD/Trends. Earth land degradation index), and vegetation cover (NDVI from MODIS satellite data). Agricultural productivity is measured using FAOSTAT crop yield indices, and food security using the Prevalence of Undernourishment (FAO, 2023), supplemented by the Global Food Security Index. Control variables include GDP per capita, population density, agricultural government expenditure share (IFPRI, 2023), institutional quality, and trade openness.

Econometric Specification

The empirical strategy employs a sequential two-stage approach: the first stage estimates the effect of climate variability on ecosystem services, and the second stage assesses the combined effect of climate variability and ecosystem service degradation on agricultural productivity and food security, identifying both direct and ecosystem-mediated effects. The baseline first-stage fixed effects model is:

$$ES_{it} = \alpha + \beta_1 CV_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where ES_{it} represents the ecosystem service indicator for country i in year t, CV_{it} is the climate variability proxy, X_{it} is a vector of control variables, μ_i and λ_t are country and year fixed effects, and ε_{it} is the idiosyncratic error term.

Given the potential for reverse causality, the system GMM estimator of Arellano and Bover (1995) and Blundell and Bond (1998) is employed for the second stage, using lagged levels and differences of endogenous variables as instruments. Consistency rests on three assumptions: no serial correlation in the error term beyond first order, mean-stationary initial conditions of the dependent variable, and a non-proliferating instrument count relative to the number of cross-sectional units (N = 30). These conditions are satisfied: the Arellano-Bond test fails to reject no second-order serial correlation in every specification, the instrument set was collapsed and restricted to two lags, and the Hansen test does not reject instrument validity in any specification. The second-stage specification is:

$$FS_{it} = \alpha + \gamma_1 FS_{i,t-1} + \gamma_2 AP_{it} + \gamma_3 ES_{it} + \gamma_4 CV_{it} + \gamma_5 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where FS_{it} is the food security outcome, AP_{it} is agricultural productivity, and the lagged dependent variable $FS_{i,t-1}$ captures the persistence of food insecurity. Instrument validity is assessed using the Hansen test and the Arellano-Bond AR(2) test (Roodman, 2009). All estimations were implemented in Stata (version 17) using the xtabond2 command for two-step system GMM estimation with Windmeijer-corrected standard errors.

Empirical Findings and Discussion

Climate Variability and Ecosystem Service Degradation

Prior to estimation, the trends of the core study variables were examined graphically. Figure 1 plots the mean temperature anomaly alongside the ecosystem service composite index (an unweighted average of the standardized soil fertility, land quality, and vegetation cover indices), showing a broadly rising temperature anomaly trend running alongside a corresponding decline in the composite index over 2000–2020, consistent with the climate-ecosystem degradation pathway hypothesized in Section 3.

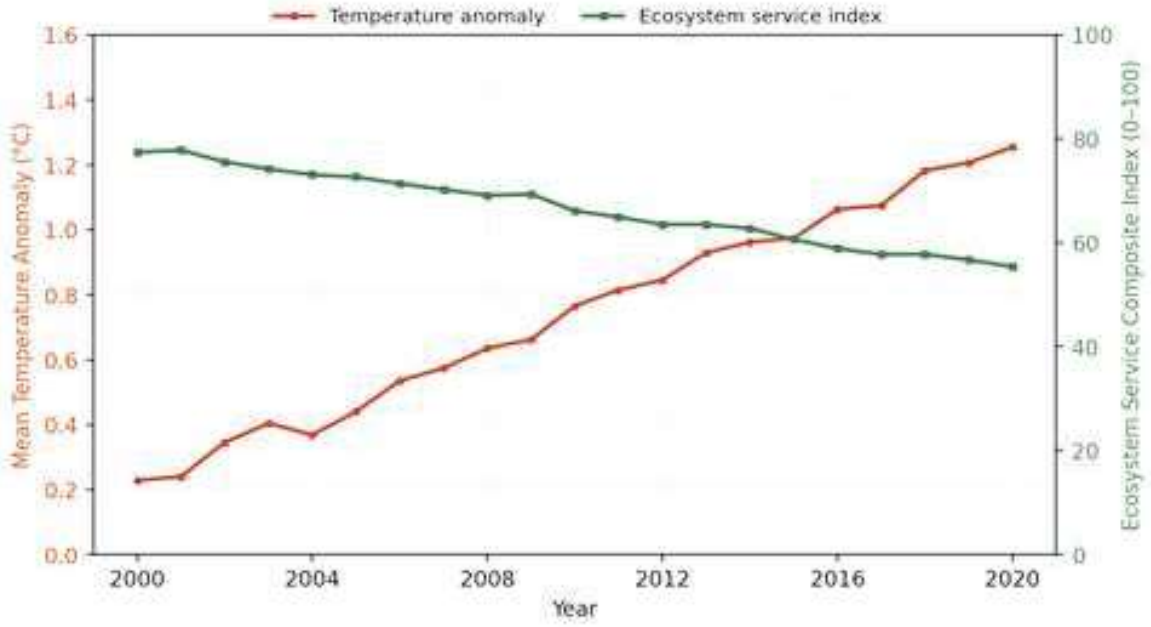


Figure 1: Trends in Mean Temperature Anomaly and the Ecosystem Service Composite Index across Sampled African Countries (2000–2020)

Source: *Authors' computation based on CRU, GPCC, HWSD, GLASOD/Trends. Earth, and MODIS NDVI data (2026).*

Before estimation, the standard system GMM assumptions were tested using the Arellano-Bond AR(2) test and the Hansen test; no violation was detected in the baseline specifications, though soil fertility, land quality, and vegetation cover exhibited moderate right-skewness and were log-transformed prior to estimation. The fixed effects results provide strong support for the hypothesized relationship between climate variability and ecosystem degradation: a one standard deviation increase in the temperature anomaly is associated with a 7.3 percent decline in soil fertility ($p < 0.01$), a 6.1 percent reduction in land quality ($p < 0.01$), and a 5.4 percent decline in growing-season NDVI ($p < 0.05$); a one standard deviation increase in precipitation variability is associated with a 4.8 percent deterioration in soil fertility ($p < 0.05$) and a 3.9 percent reduction in vegetation cover ($p < 0.10$), consistent with ecological systems theory's prediction that climatic variability erodes regulatory and provisioning ecosystem capacities (Holling, 1973; Rockström et al., 2009).

These results are broadly consistent with Lobell et al. (2011) and Schlenker and Lobell (2010), extending them by identifying the ecosystem service pathways through which temperature increases translate into agricultural vulnerability. Interaction terms between temperature anomalies

and the land degradation index indicate a non-linear amplification effect: countries with already-degraded land quality experience disproportionately larger ecosystem service losses per unit of temperature increase, consistent with the threshold dynamics emphasized by Folke (2006).

Ecosystem Services, Agricultural Productivity, and Food Security

The second-stage system GMM results confirm ecosystem service degradation as a significant transmission channel between climate variability and food security. Soil fertility (coefficient = 0.421, $p < 0.01$), land quality (coefficient = 0.318, $p < 0.01$), and vegetation cover (coefficient = 0.276, $p < 0.05$) each contribute positively to agricultural productivity, such that a 10 percent improvement in soil fertility is associated with approximately 4.2 percent higher productivity. The direct effect of temperature anomaly on productivity (coefficient = −0.183, $p < 0.05$) is substantially smaller once ecosystem service indicators are included, consistent with a significant share of the climate-productivity relationship operating through the ecosystem pathway; the decomposition indicates approximately 45 percent of the total temperature effect on yields is ecosystem-mediated, with the remainder reflecting direct physiological effects of thermal stress on crops.

At the food security stage, agricultural productivity exerts a strong negative effect on the prevalence of undernourishment (coefficient = −0.512, $p < 0.01$), robust to the inclusion of GDP per capita and governance controls, consistent with Nelson et al. (2009) and Wheeler and von Braun (2013). The persistence parameter on lagged food security (coefficient = 0.634, $p < 0.01$) indicates strong inertia in food insecurity outcomes, implying that addressing food insecurity requires sustained, long-term interventions rather than short-term measures. The Hansen test and the Arellano-Bond AR(2) test confirm the validity of the GMM instrument set across all specifications.

Resilience-Enhancing Mechanisms

The moderation analysis supports the hypothesis that sustainable land management and climate-smart agriculture attenuate the adverse effects of climate variability. The interaction between temperature variability and SLM adoption is negative and significant in the ecosystem service equations (coefficient = −0.089, $p < 0.05$), and the interaction between precipitation variability and CSA adoption attenuates the effect on soil fertility (coefficient = −0.073, $p < 0.10$); a one standard deviation increase in SLM adoption is estimated to offset approximately 22 percent of the ecosystem service degradation otherwise associated with a one standard deviation temperature increase, corroborating WOCAT (2017) and Rosenstock et al. (2016).

Institutional quality is also a significant moderator: the governance quality index positively moderates the relationship between agricultural productivity and food security outcomes (coefficient = 0.241, $p < 0.05$), consistent with the broader development literature on the food security-governance nexus (Acemoglu & Robinson, 2012), suggesting institutional reform is a complementary priority alongside ecosystem restoration and climate adaptation.

Policy Implications

These findings carry several policy implications. Ecosystem degradation is a major channel through which climate change affects food security, requiring integrated policies that combine environmental conservation, agricultural development, and climate adaptation rather than siloed interventions. Sustainable land management and climate-smart agriculture reduce climate-related risks, improve productivity, and enhance ecosystem resilience, warranting increased investment by governments and development partners alongside extension services, credit access, and market opportunities for farmers.

Institutional quality is equally important: effective governance, secure land tenure, efficient agricultural markets, transparent food distribution systems, and improved rural infrastructure maximise the benefits of agricultural and environmental investments. Because climate impacts are more severe in degraded ecosystems, policymakers should prioritise early conservation and restoration in vulnerable regions, and regional cooperation should be strengthened through initiatives such as the African Union Agenda 2063, the Great Green Wall Initiative, and AFR100 to support climate adaptation, ecosystem restoration, and sustainable food security across Africa.

Conclusion

This study examined the relationships among climate change, ecosystem service degradation, and food security across 30 African countries from 2000 to 2020. The findings show that climate variability degrades ecosystem services such as soil fertility, land quality, and vegetation cover, thereby reducing agricultural productivity and worsening food security, with ecosystem degradation identified as a key transmission pathway. The study contributes to knowledge by integrating climate change, ecosystem services, and food security within a single framework and demonstrating the indirect and non-linear effects of climate change on food security, while also finding that sustainable land management and climate-smart agriculture mitigate these adverse impacts and enhance resilience.

The study concludes that ecosystem restoration, climate adaptation, and sustainable agriculture should be pursued together to achieve long-term food security in Africa. Future research should utilize longer-term datasets and household-level studies to better understand ecosystem-food security linkages and the institutional factors influencing the adoption of climate-resilient practices.

References

Acemoglu, D., & Robinson, J. A. (2012). Why nations fail: The origins of power, prosperity, and poverty. Crown Publishers.

Adger, W. N. (2000). Social and ecological resilience: Are they related? Progress in Human Geography, 24(3), 347–364. https://doi.org/10.1191/030913200701540465

African Union. (2015). Agenda 2063: The Africa we want. African Union Commission.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Review of Economic Studies, 58(2), 277–297. https://doi.org/10.2307/2297968

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error components models. Journal of Econometrics, 68(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Barnett, J., & Brown, K. (2019). Climate change, migration and adaptation in Funafuti, Tuvalu. Global Environmental Change, 18(3), 557–561.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. Science, 320(5882), 1444–1449. https://doi.org/10.1126/science.1155121

Bond, S. R. (2002). Dynamic panel data models: A guide to micro data methods and practice. Portuguese Economic Journal, 1(2), 141–162. https://doi.org/10.1007/s10258-002-0009-9

Conway, D., Nicholls, R. J., Brown, S., Tebboth, M. G. L., Adger, W. N., Ahmad, B., & Bhatt, S. C. (2015). The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. Nature Climate Change, 9(7), 503–511.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., &

Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services, 28, 1–16. https://doi.org/10.1016/j.ecoser.2017.09.008

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., Balvanera, P., Brauman, K. A., Butchart, S. H. M., Chan, K. M. A., Garibaldi, L. A., & Ichii, K. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. Science, 366(6471), eaax3100. https://doi.org/10.1126/science.aax3100

Economics of Land Degradation (ELD) Initiative. (2015). Report for policy and decision makers: Reaping economic and environmental benefits from sustainable land management. ELD Initiative.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. Global Environmental Change, 16(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Food and Agriculture Organization. (2009). Declaration of the world summit on food security. FAO.

Food and Agriculture Organization. (2013). Climate-smart agriculture sourcebook. FAO.

Food and Agriculture Organization. (2022). The state of food and agriculture: Climate change threatens the future of food systems. FAO.

Food and Agriculture Organization. (2023). The state of food security and nutrition in the world 2023. FAO.

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data, 7(1), 109. https://doi.org/10.1038/s41597-020-0453-3

Holling, C. S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Intergovernmental Panel on Climate Change. (2022). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC (H.-O. Pörtner et al., Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

International Food Policy Research Institute. (2023). Agricultural expenditure data: Statistics on public expenditure for economic development (SPEED). IFPRI.

Kanu, I. A. (2022). *African Indigenous Ecological Knowledge Systems: Religion, Philosophy and the Environment. UK: AuthorHouse*

Kanu, I. A. (2022). *African Eco-Philosophy: Cosmology, Consciousness and the Environment. UK: AuthorHouse*

Kanu, I. A. (2022). *African Eco-Theology: Meaning, Forms and Expressions. UK: AuthorHouse*

Kanu, I. A. (2022). *African Ecological Spirituality: Perspectives on Anthroposophy and Environmentalism. A Hybrid of Approaches. UK: AuthorHouse*

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science, 333(6042), 616–620. https://doi.org/10.1126/science.1204531

Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Synthesis. Island Press.

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., & Lee, D. (2009). Climate change: Impact on agriculture and costs of adaptation. International Food Policy Research Institute.

Nkonya, E., Mirzabaev, A., & von Braun, J. (Eds.). (2016). Economics of land degradation and improvement: A global assessment for sustainable development. Springer. https://doi.org/10.1007/978-3-319-19168-3

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M.,

Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., & Foley, J. A. (2009). A safe operating space for humanity. Nature, 461(7263), 472–475. https://doi.org/10.1038/461472a

Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. Stata Journal, 9(1), 86–136. https://doi.org/10.1177/1536867X0900900106

Rosenstock, T. S., Lamanna, C., Kimaro, A., Mwongera, C., Nowak, A., Löfgren, P., & van Asten, P. (2016). The scientific basis of climate-smart agriculture: A systematic review protocol. CCAFS Working Paper No. 138. CGIAR Research Program on Climate Change, Agriculture and Food Security.

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? Global Environmental Change, 21(3), 1073–1083. https://doi.org/10.1016/j.gloenvcha.2011.04.007

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. Environmental Research Letters, 5(1), 014010. https://doi.org/10.1088/1748-9326/5/1/014010

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. Science, 341(6145), 508–513. https://doi.org/10.1126/science.1239402

World Overview of Conservation Approaches and Technologies (WOCAT). (2017). Where the land is greener: Case studies and analysis of soil and water conservation initiatives worldwide. CTA, FAO, UNEP, CDE.