



Charting a Resilient Future: Climate Change as a Catalyst for Sustainable National Development

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INTEGRATING AI TECHNOLOGIES INTO CLIMATE RISK MANAGEMENT FRAMEWORKS IN NIGERIAN AGRICULTURE FOR FOOD SECURITY

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Abstract

Nigeria faces escalating climate challenges, including intensified droughts, erratic rainfall patterns, and rising temperatures, threatening ecosystems, agriculture, and livelihoods. Climate change increasingly threatens Nigeria's largely rainfed smallholder agriculture, contributing to declining crop yields and threatening food security. This study investigates the role of Artificial Intelligence (AI) in enhancing climate risk management in Nigerian agriculture. This study utilizes the concept of climate action as a lens, and an extensive desk review of existing literature. Findings reveal that AI technologies are increasingly employed in climate adaptation and mitigation strategies. Applications include predictive analytics for weather forecasting, optimization of water resource management, and enhancement of agricultural practices through precision farming, focusing on capacity building and community engagement. However, this study identifies significant barriers to the widespread adoption of AI in climate resilience efforts in Nigeria. Challenges encompass data scarcity, limited digital infrastructure, and a shortage of localized AI solutions tailored to specific Nigerian agriculture. Interviewees underscore the necessity for collaborative approaches that involve stakeholders at all levels, from grassroots organizations to international bodies, to develop and implement effective AI-driven climate strategies. The research concludes that while AI holds substantial promise for enhancing climate resilience in Nigeria, realizing its full potential requires addressing infrastructural and capacity-related challenges. Strategic investments in data infrastructure, education, and policy frameworks are essential to empower communities and ensure the equitable deployment of AI technologies in combating climate change across the continent.

Keywords: Artificial intelligence, Climate Risks, Climate Action, Food Security, Nigeria, Sustainable Agriculture

INTRODUCTION

Nigeria is at a critical point where the fast-growing population requires action-driven and technological advancement to meet both present and future food demands. The increasing population will undoubtedly place significant strain on food systems that are already struggling to meet the demand for food. This challenge is exacerbated by climate-related disruptions, inefficiencies after harvest, and limited access to contemporary agricultural resources (IPCC, 2023 & World Bank, 2022).

Climate change poses serious risks to agriculture in Nigeria, where a considerable number of livelihoods depend on small-scale farming (Okoronkwo et al. 2024 & Akanwa et al, 2022). In Nigeria, Africa's most populous country, the effects of climate change are already evident, with recurring floods, erosion, droughts, desertification, and extreme heat deteriorating soil quality and reducing crop yields (Akanwa et al. 2024; Akanwa & Ezeomdeo, 2018; Okon et al., 2021).

Abu and Ibebuchi (2025) indicated that floods in Nigeria in 2022 inundated over 200,000 hectares of farmland (an increase from 50,000 hectares mid-season) due to heavy rainfall and dam discharges, impacting millions. These events underscore the region's vulnerability, as Okon et al. (2021) noted, who estimated that Nigeria is among the top 10 countries most at risk from climate extremes, with some regions experiencing a loss of up to 20% of their growing season. Thus, transforming agriculture in Nigeria is crucial to ensure food security, sustain farm incomes, and support rural livelihoods (Muoghalu & Akanwa, 2021). Hence, the application of AI and other related technological advancements in transforming Nigerian agriculture is not just an option but an essential requirement.

Artificial intelligence (AI) has emerged as a powerful tool, capable of tackling systemic inefficiencies, assessing risks, and enhancing agricultural productivity. However, integrating AI into agriculture presents several challenges, including issues of technological equity and the potential displacement of rural workers (Jenane, 2025).

AI offers both opportunities and risks for Nigerian agriculture. It has the potential to drive agricultural transformation and highlights the importance of inclusive frameworks to manage risks and achieve fair outcomes. With a population surpassing 221 million and a growth rate exceeding 2.6% annually, Nigeria faces significant challenges in meeting the food security needs of its people. Smallholder farmers are grappling with problems such as inadequate seed quality, labor shortages, and urban encroachment on valuable farmland (Muoghalu & Akanwa, 2021).

AI introduces new possibilities for addressing these challenges. Technologies such as machine learning (ML) algorithms and satellite-based remote sensing can analyse extensive environmental data to provide actionable insights (Chakib, 2025). These technologies can improve weather and yield forecasts, facilitate early detection of pests and plant diseases, and optimize resource usage, such as water and fertilizers, through precision agriculture (Wayan, 2024). Growing evidence from Nigeria indicates that the integration of AI with agriculture and climate adaptation can enhance productivity and resilience (Squatrito, 2025). Nevertheless, these technologies remain largely underutilized in many Nigerian policy frameworks.

The escalation of agricultural activities and the increased demand for real-time data significantly drive the need for AI in agriculture. Real-time data enables swift decision-making regarding preventative actions. Farmers in North America, South America, and Europe employ sensors, drones, guidance technologies, and soil sampling techniques to gather information on soil moisture and nutrient content across their fields (NASA, 2023; European Commission, 2019). The use of advanced tools for data collection and analysis, particularly drone-enabled scouting, stands out as one of the most effective methods for obtaining farm data.

The swift adoption of AI in agriculture is fuelled by the need for more sustainable farming practices, labour shortages, rising costs, and increasing food demand. AI provides multiple benefits to farmers, offering real-time insights into their fields, monitoring soil quality, plant health, temperature, and automating irrigation and pesticide applications (Birhane et al., 2022). These innovations contribute to improved harvest quality and precision. Applications of AI in agriculture focus on enhancing crop production efficiency, including precision farming, livestock monitoring, drone analytics, agricultural

robotics, and labour management. Deep learning technologies are boosting crop productivity, thus propelling the growth of the AI agriculture market (Rolnick et al. 2022).

This paper explores the integration of AI applications within climate risk management frameworks for Nigerian agriculture. We reviewed existing literature on AI and climate-smart agriculture, identified key AI technologies, provided Nigeria-specific data and case studies, and examined the barriers, opportunities, and policy implications. The goal is to inform both academic researchers and policymakers about harnessing digital innovations to construct climate-resilient food systems in the country.

LITERATURE REVIEW

Climate Risk in Nigerian Agriculture

Nigerian agriculture is extremely vulnerable to climate variability and extremes. Studies predict that rising temperatures and erratic rains will substantially reduce staple crop yields in the region by mid-century (IPCC, 2023; Okoronkwo et al., 2024; Okon et al., 2021). Further, evidential studies in Nigeria confirm these concerns, where surveys report frequent flooding destroying infrastructure and crops, irregular rainfall patterns, drought, desert encroachment in the north, and diminishing water availability (Akanwa et al. 2024).

Akinkuolie *et al.* (2025) noted that 2020s-era floods in Nigeria have eroded topsoil and flooded settlements, while droughts in the Sahel north have sharply cut crop outputs. These climate shocks drive higher food prices, provided and worsen malnutrition and poverty among smallholders. Integrated Climate Risk Management (CRM) is a holistic framework that blends climate science, risk reduction, and adaptive planning to manage and minimize climate-related threats. It aligns forecasting, policy, and local action to strengthen resilience across sectors, helping communities anticipate, absorb, and adapt to climate extremes (WMO, 2021; UNDRR, 2019). Conceptually, integrated *climate risk management (CRM)* frameworks have emerged, blending adaptation, early warning, and mitigation. Key elements of CRM in agriculture include climate-smart practices such as drought-resistant varieties, agroforestry, insurance schemes, and climate services, weather forecasts, and advisories (Moughalu & Akanwa, 2021).

Nigeria has developed policies such as a National Adaptation Plan (NAP) and a Climate-Smart Agriculture Framework to coordinate such efforts (Climate Smart Agriculture Framework for Nigeria, 2024). However, studies highlight that these policies often suffer from fragmentation and a lack of implementation capacity in Nigeria's National Adaptation Plan Framework (2020). Notably, Akinkuolie *et al.* (2025) emphasize that adaptation policies in Nigeria remain incomplete and inadequately enforced, limiting their effectiveness despite high vulnerability.

Climate Action as a Framework for AI-Enhanced Climate Risk Management in Nigerian Agriculture

Climate action refers to deliberate and systematic interventions aimed at mitigating and adapting to the adverse effects of climate change (United Nations, 2015). It is enshrined in Sustainable Development Goal 13 (SDG 13), which calls for urgent action to combat climate change and its impacts. In agricultural systems, particularly in climate-vulnerable countries like Nigeria, climate action has evolved from a policy concept to a strategic framework guiding technological innovation, adaptive capacity-building, and risk reduction (IPCC, 2022; FAO, 2021).

In this context, climate action provides a multidimensional framework for evaluating how emerging technologies such as Artificial Intelligence (AI) can support climate risk management (CRM) in

agriculture. Climate risk management involves assessing, monitoring, and responding to climate-related hazards such as floods, droughts, and temperature extremes (Hellmuth et al., 2007). For Nigeria, where over 70% of the rural population depends on rainfed farming, climate variability significantly threatens food security and livelihoods (Ayanlade et al., 2018). Climate action in Nigeria's agriculture, therefore, requires more than policy formulation; it demands robust, data-driven, and adaptive systems an area where AI becomes indispensable.

By integrating AI into CRM, Nigeria can operationalize climate action at both macro and micro levels. Machine learning (ML) and predictive analytics, for example, are being employed to improve seasonal forecasting, monitor crop vulnerability, and optimize planting schedules based on climatic trends (Aggarwal et al., 2022; Yakubu et al., 2024). These technologies align with the adaptation pillar of climate action by enhancing anticipatory decision-making and reducing exposure to risk. Similarly, remote sensing and AI-powered geospatial analysis support climate mitigation through more efficient land use and resource management, which can minimize greenhouse gas emissions from unsustainable practices (Jenane, 2025; FAO, 2021).

Moreover, climate action emphasizes inclusivity, particularly the empowerment of marginalized groups such as smallholder farmers. AI can contribute to this equity dimension by democratizing access to climate information through mobile platforms, SMS alerts, and localized advisory services (Abo & Ibebuchi, 2025; Mohammed & Shehu, 2023). In this way, AI enhances not only technical adaptation but also social resilience, a key element of transformative climate action (Schipper et al., 2020).

Nonetheless, embedding AI within climate action frameworks necessitates an enabling policy and infrastructure environment. National adaptation plans (NAPs), climate-smart agriculture policies, and digital innovation strategies must align to create synergies across climate governance, technology deployment, and agricultural extension (FMARD, 2024; UNEP, 2022). Without coherent integration, AI applications risk becoming isolated or inaccessible to those most in need.

In summary, using climate action as a conceptual framework reveals how AI can transcend its role as a technical tool to become a transformative enabler of resilient, adaptive, and inclusive agricultural systems in Nigeria. The convergence of climate action and AI technologies offers a strategic pathway to modernize farming, reduce vulnerability, and secure long-term food systems in the face of climate change.

AI in Agriculture and Climate Adaptation

AI tools are now transforming agriculture on a global scale. Scholarly reviews and case studies indicate that machine learning models, computer vision, and IoT sensors can significantly enhance agricultural efficiency and sustainability (Aggarwal et al., 2024; Dawn et al., 2023). For example, machine learning algorithms such as random forests and neural networks are employed to predict crop yields, optimize irrigation schedules, and classify crop health based on imagery (Yakubu et al., 2024). Remote sensing technologies, including satellites and drones, provide real-time monitoring of soil moisture, vegetation indices, and pest outbreaks across large areas (Jenane, 2025). Predictive analytics and data-driven models of climate and market trends enable proactive decision-making, allowing farmers to adjust planting dates or prepare for adverse weather conditions (World Bank, 2022).

In Africa, initial applications of AI demonstrate significant potential. For instance, companies like Akamai (Kenya) and Apollo (Kenya and Nigeria) utilize machine learning on satellite data to advise smallholder farmers on inputs and credit, resulting in farm income gains of approximately 15–20% (<https://stanfordeconreview.com/>). The Africa Agriculture Watch (AAgWa) platform, launched in 2023 by Akademiya2063, is a web-based tool that combines machine learning and remote sensing to forecast crop production across 47 countries

(<https://akademiya2063.org/event.php?id=120#:~:text=In%20response%20to%20the%20agricultural,intervention%20planning%20in%20local%20communities>).

In Nigeria, several AI-driven startups are making significant strides. Apollo Agriculture provides machine learning-based credit and input services, while AirSmat utilizes drones and sensors to optimize the use of water and fertilizer (Wayan, 2024). Additionally, AI-focused agricultural research in Nigeria is on the rise. Yakubu et al. (2024) document numerous studies that use machine learning for yield prediction, the Internet of Things (IoT) for precision farming, and computer vision for pest detection, reporting a 72% accuracy rate in some Nigerian crop models. Similarly, Agoh et al. (2024) emphasize that AI applications, including expert systems and remote sensing, can enhance Nigeria's extension services, and although challenges related to cost and technical expertise remain.

Digital Innovation and Policy

Policy frameworks are increasingly acknowledging the role of digital tools in various sectors. In Nigeria, the government is developing a National AI Strategy that encompasses agriculture and has established the National AI Research Fund (NAIRS) to support agri-tech initiatives (Wayan, 2024). According to the World Bank (2022) report, investment in African agri-tech has surged from about ten million dollars in 2014 to six hundred million dollars in 2022. The reports recommend scaling up digital platforms, such as Hello Tractor, and improving digital extension services (Jenane, 2025).

However, several challenges still exist, including a digital divide characterized by low internet access, limited data infrastructure, and literacy gaps among farmers in rural areas of Nigeria. These factors can impede the adoption of AI technologies (Rolnick et al., 2022). Additionally, ethical and governance issues, such as data privacy and algorithmic transparency, are emerging as significant concerns (Nishant et al., 2020).

In summary, existing research suggests that AI has the potential to enhance climate resilience and productivity in agriculture through improved forecasting and resource management. However, the success of these technologies largely depends on the presence of supportive infrastructure, capacity building, and alignment with relevant policies (Akinkuolie et al., 2025; Yakubu et al., 2024; Strubell et al., 2019; European Commission, 2019).

METHODOLOGY

This paper is based on a mixed approach of qualitative methodology, including key informant interviews (KII), involving AI practitioners and climate scientists in Nigeria. Additionally, a comprehensive literature review and policy analysis with illustrative case studies. We followed a systematic approach, searching academic databases (Web of Science, Scopus, Google Scholar) and institutional reports for keywords such as “artificial intelligence”, “machine learning”, “remote sensing”, “predictive analytics”, “climate adaptation”, and “agriculture” in the context of Nigeria and Sub-Saharan Africa. We included peer-reviewed journals, conference papers, government and UN/NGO reports (such as the Nigerian NAP framework) to capture diverse perspectives. We prioritized recent publications (2006–2025) focusing on practical applications of AI in agriculture and climate risk management. The selected literature was synthesized to identify common themes: AI technology types, use cases in climate-smart agriculture, and enabling/buffering factors in Nigeria. Also, we integrated data from national policy documents such as the CSA policy framework, climate assessments, and published project results. Where relevant, we highlighted empirical findings from Nigeria, such as flood extents, crop data, to ground the discussion in local reality.

AI Technologies Overview

Modern AI encompasses several interlinked technologies:

- **Machine Learning (ML) and Data Analytics:** Machine learning algorithms, including random forests, support vector machines, and neural networks, learn from large datasets to recognize patterns and make predictions. In agriculture, ML is used to predict crop yields based on factors such as weather and soil data. For example, Yakubu et al. (2024) reported a 72% accuracy in predicting millet yields using decision trees. Additionally, ML powers computer vision systems; convolutional neural networks can analyse drone or satellite imagery to detect plant diseases or nutrient deficiencies, allowing for targeted interventions (Oluwaseun et al., 2024).
- **Remote Sensing and GIS:** Satellite and aerial imagery provide near-real-time observations of land and the atmosphere. Vegetation indices, such as NDVI, derived from satellites can monitor crop health, while radar and LiDAR technology can map soil moisture and topography. Remote sensing plays a critical role in climate risk management; for instance, it has been used to quantify the extent of Nigeria's 2022 floods, which revealed that floodwaters expanded from 50,000 hectares to 200,000 hectares after the release of water from a dam (Abu & Ibebuchi, 2025). Drones equipped with multispectral cameras are increasingly deployed on farms to identify pests or assess irrigation needs. Geospatial AI combines these data with machine learning to produce risk maps for various hazards, such as flood risk and drought, as well as to generate early warnings.
- **Predictive Analytics and Climate Modelling:** Predictive analytics utilizes historical and real-time data to forecast future conditions. In agriculture, these predictive models can issue weather alerts, project seasonal rainfall, or simulate crop growth under various scenarios. Artificial Intelligence (AI) enhances these forecasts by learning complex nonlinear relationships between climate and crops. For instance, ensemble machine learning models trained on climate and soil data can predict harvest dates or potential yield shortfalls weeks in advance. By integrating with climate models, these systems can downscale broad forecasts to local farm levels. Additionally, predictive analytics can improve financial risk management; weather-index insurance schemes can leverage AI to set triggers and premiums based on location-specific satellite data.
- **Internet of Things (IoT) and Sensors:** IoT networks that include ground sensors, soil moisture probes, and weather stations can provide detailed data to AI systems. Intelligent IoT devices can autonomously adjust irrigation and nutrient delivery. For example, an IoT-based irrigation system could use machine learning to estimate crop water requirements and operate valves accordingly, thereby reducing waste. In Nigeria, pilot projects have implemented soil and weather sensors on demonstration farms to validate machine learning-based irrigation scheduling.
- **Robotics and Automation:** Though less common on smallholder farms in Africa, autonomous machinery such as tractors and sprayers is an integral part of precision agriculture. These systems rely on AI for navigation and decision-making. While the initial investment can be high, robotics can help address labour shortages, a concern highlighted by the World Bank in 2025 due to rural-to-urban migration.

In summary, AI technologies provide essential tools for collecting, processing, and utilizing climate and agricultural data at an unprecedented scale and speed. They lay the technical foundation for climate risk management, improving seasonal forecasts, and optimizing daily farm operations.

Case Study: Nigerian Context

Agricultural and Climate Profile

Nigeria's agriculture is primarily dominated by smallholder farmers, with over 90% of its food production coming from farms smaller than 2 hectares. These small farms contribute roughly 24% of the country's Gross Domestic Product (GDP) and produce about 85% of the nation's crops (CSAF, 2024).

The country features a range of agro-ecological zones, from the humid mangrove and coastal forests in the south, with annual rainfall of less than 2,000 mm, to the Guinea and Sudan savannahs in the mid-belt, and finally to the arid Sahel region in the far north, which receives more than 600 mm of rainfall annually (CSAF, 2024).

This climatic diversity poses significant challenges: northern Nigeria is particularly susceptible to drought and desertification, while the southern regions struggle with flooding and waterlogging. Nigeria experienced catastrophic floods in 2022 that affected an estimated 3.2 million people nationwide (Akanwa et al., 2024). Rivers such as the Niger and Benue frequently overflow, and storms can severely damage crops. On the flip side, prolonged droughts in recent decades have led to the shrinking of wetlands and reduced river flows (Okon et al., 2021).

These climate-related risks are compounded by structural constraints within the agricultural sector. Most Nigerian farmers lack access to irrigation; only about 7% of irrigable land is currently utilized, and the majority depend on rainfed cropping. As a result, average crop yields are significantly lower than their potential, averaging around 4 tonnes per hectare compared to approximately 13-14 tonnes per hectare in developed countries (Yakubu et al., 2024). Extension services are inconsistent, and many farmers have limited access to weather forecasts or insurance (Okoronkwo et al., 2024).

The National Adaptation Plan (2020) and a recent Climate-Smart Agriculture policy (2024) emphasize the need to modernize farming practices through science and technology; however, the implementation of these initiatives has been slow.

AI and Data Initiatives in Nigeria

Some initiatives exemplify the integration of AI tools in Nigerian agriculture:

- **Satellite Analytics for Weather and Crop Forecasts:** Nigeria's meteorological agency (NiMet) provides seasonal weather forecasts, but artificial intelligence (AI) can enhance these services. By using satellite imagery and machine learning (ML), it is possible to predict the yields of staple crops across Nigeria and neighbouring countries (Africa Agricultural Watch, 2023). Policymakers can utilize these forecasts for planning purposes and emergency preparedness.
- **Crop Disease Surveillance:** Researchers have started applying machine learning for monitoring plant health. For example, an AI model trained on field and satellite data successfully predicted outbreaks of potato late blight on the Jos Plateau, allowing for earlier intervention (Ahamed et al., 2023). This approach could similarly be extended to diseases such as the cassava mosaic virus or the maize fall armyworm in Nigeria.
- **Precision Farming Tools:** Local start-ups are leveraging AI technology to assist farmers. Apollo Agriculture, a fintech-agricultural company originally from Kenya, is now operating in Nigeria. Their ML algorithms analyse soil and weather data to recommend farming inputs and financing to smallholders. Another Nigerian start-up, Kitovu, uses remote sensing and AI to provide

tailored agronomic advice for individual fields, demonstrating how digital tools can effectively reach smallholder farmers (Wayan, 2024).

- **Flood Risk Assessment:** In a 2022 flood risk study, Abu and Ibebuchi (2025) applied remote sensing and climate data to map flood extents by state. They found that northern states experienced greater flooded areas (up to 200,000 hectares) following dam releases, while southeastern Anambra state had the highest affected population due to its dense population. Similarly, Akanwa et al. (2024) used remote sensing and Geographic Information Systems (GIS) to investigate the effects of climatic risks on soil erosion and desertification in both Southern and Northern Nigeria. These studies applied AI and satellite data to quantify climate risks in real terms. They highlighted how failures in urban planning and unregulated human activities exacerbate flood impacts and contribute to climatic risks such as deforestation, soil erosion, and desertification. Insights from this research can inform infrastructure improvements and emergency responses.
- **Policy and Digital Extension:** Nigeria's National Artificial Intelligence Strategy is currently under development, with programs from the National Information Technology Development Agency (NITDA) beginning to incorporate agriculture. For instance, NITDA's AI Research Scheme (NAIRS) funds projects that include agricultural applications. Additionally, World Bank-funded "Digital Agriculture" projects in Nigeria aim to increase agricultural yields through technology, likely integrating some AI components, although further details are still emerging.

Climate Risk Management Frameworks

Nigeria has several formal policies relevant to climate risk in agriculture, though they do not yet emphasize AI. The Climate-Smart Agriculture Framework (2024) outlines strategies for resilient farming, sustainable intensification, and greenhouse gas reduction. It calls for "science-driven" and "data-enabled" agriculture, but does not specify AI per se. The National Adaptation Plan Framework (2020) sets broad goals for integrating adaptation across sectors, including agriculture and forestry. Notably, the NAP process involves stakeholders from the government, the private sector, and NGOs to align climate responses (Dazé *et al.*, 2019). A key conclusion from these frameworks is the emphasis on institutional coordination – bringing together agriculture, meteorology, environment, and development sectors – as critical for climate resiliency. AI could serve as a bridge in this coordination by providing shared data platforms and decision support tools for multiple agencies.

DISCUSSION

Opportunities

Integrating AI into Nigeria's climate risk management presents numerous opportunities. First, it provides improved climate services, AI can enhance weather forecasting and provide early warnings for extreme weather events. For instance, machine learning models can downscale seasonal climate predictions to local levels, helping farmers determine optimal planting dates or diversify their crops before droughts or floods occur. An analysis of Nigeria's 2022 floods demonstrated how satellite and AI systems can deliver rapid situational awareness during disasters (Abu and Ibebuchi, 2025). By extending these systems, an AI-based flood early warning system could alert communities when heavy rains coincide with upstream dam releases.

Second, precision resource management: Remote sensing and the Internet of Things (IoT), powered by AI, can optimize the use of irrigation and other inputs. In Nigeria's arid northern regions, automated irrigation scheduling based on machine learning predictions of soil moisture can conserve water while maintaining crop yields. In the southern regions, AI-driven drainage mapping can target flood mitigation efforts. Additionally, machine learning image analysis can detect pest or disease outbreaks early, even from photos taken by farmers on their smartphones, allowing for timely and localized treatment. This approach reduces crop losses and minimizes pesticide overuse, contributing to sustainability.

Third, yield and market forecasting: AI-based yield models can predict harvest outcomes weeks in advance, aiding agricultural planning. At the national level, these forecasts enable governments to anticipate potential food shortages, adjust import policies, or manage buffer stocks accordingly. AI can also forecast crop price trends, assisting farmers and cooperatives in deciding when and where to sell their produce. By linking predicted drought conditions to expected yield reductions, AI provides a robust decision support tool.

Fourth, financial and insurance products: AI can enhance climate risk financing. For example, weather-index insurance can be improved with AI-derived risk layers, ensuring that payouts are triggered only for genuine losses. Moreover, AI could facilitate microloans by analysing crop risk profiles using satellite data. Apollo Agriculture's platform exemplifies this integration of credit and crop risk analytics through machine learning (Wayan, 2024).

Finally, AI fosters innovation and inclusivity. Digital platforms can deliver agronomic advice to remote farmers via SMS or voice applications, tailored through AI in local languages. This approach democratizes access to expertise. The entrepreneurship landscape in AI agriculture is expanding in Nigeria, as evidenced by the rise of agritech startups and increased investments (Jeane, 2025). The collaboration between public and private sectors, including academia, ICT firms, and agricultural extension agencies, can stimulate broader rural development through AI.

Barriers

Despite its potential, Nigeria faces significant barriers to leveraging AI in agriculture. One of the foremost issues is data limitations: high-quality, high-resolution climate and crop data are scarce. Many farmers' fields lack ground sensors, and satellite imagery is often compromised by cloud cover. AI models require robust training data, yet Nigeria has limited field trial data on crop-climate interactions. Incomplete data on farm boundaries and soil properties complicates precision targeting (Okon et al., 2021).

Infrastructure gaps further hinder deployment. Many rural areas lack reliable internet access and electricity, which makes it difficult to run IoT sensors or AI-driven apps on smartphones. Even where connectivity exists, many smallholder farmers have low digital literacy, which diminishes the adoption of new tools. Additionally, the high initial costs of technology, such as drones, sensors, or even smartphones, can be prohibitive for poorer farmers. As noted by Yakubu et al. (2024), these high costs and a lack of expertise have restricted agricultural AI trials in Nigeria.

Furthermore, institutional and policy challenges persist. Nigeria's climate and agriculture policies rarely mention AI explicitly, leading to a lack of regulatory support and, at times, no clear guidelines for data sharing and privacy. The relevant ministries are still limited in scope, and coordination for data-driven agricultural initiatives remains weak (UNEP, 2022). Although organizations like the National Bureau of Statistics and various universities possess some capabilities, there is no unified platform for climate and agricultural data. Without institutional mandates or incentives, stakeholders may not prioritize AI projects. In surveys, Nigerian farmers reported challenges in accessing trustworthy climate information and noted the "high cost of weather data" as a major constraint (Okoronkwo et al., 2024).

Skills and trust are also bottlenecks. AI is a technical domain, and Nigeria does not have enough agricultural data scientists or extension officers trained in digital tools. The "black box" nature of some AI models can lead to distrust, as farmers may resist following advice if they do not understand it. Mohammed and Shehu (2023) suggest that "Explainable AI" could help build user confidence, but such approaches are still in their infancy. Lastly, equity concerns must be addressed: if AI solutions are only available to larger or better-off farmers, smallholders and women may be left behind. This social dimension of AI adoption is rarely highlighted in technical literature but is crucial for fostering inclusive climate resilience.

Policy Implications

These findings suggest several policy actions. Governments and development partners should invest in data infrastructure by expanding weather stations, promoting the use of open satellite data, and supporting data annotation projects. Partnerships with technology firms that utilize low-cost drones could speed up data collection. Additionally, policies should encourage the establishment of open-data platforms so that researchers and entrepreneurs can develop AI tools without facing legal obstacles (Ashley & Husain, 2023).

Secondly, building human capacity is crucial. Training programs for extension officers, young agronomists, and IT professionals should include skills in AI and GIS. Nigeria's National Information Technology Development Agency (NITDA) and universities could collaborate with international centres like the Consultative Group on International Agricultural Research (CGIAR) and AI institutes to enhance the skills of professionals. On the user side, extension campaigns need to raise farmers' awareness of digital tools and provide hands-on support for using apps or AI-driven advisory services.

Thirdly, financing and incentives are essential. Public funds or subsidies could help cover the costs of field sensors or software for pilot projects, thereby reducing entry barriers. The National Adaptation Fund and climate finance programs should specifically allocate funds for "digital agriculture" pilot projects (Adebisi, 2020). Meanwhile, regulatory frameworks should protect farmers' data from exploitation while also enabling beneficial uses by AI providers. For instance, Nigeria could develop guidelines for agricultural data sharing, learning from draft frameworks in other countries.

Finally, AI should be integrated into climate policies. Nigeria's Climate Smart Agriculture (CSA) framework and National Adaptation Plan (NAP) should explicitly reference digital innovation. This would signal to ministries and donors the importance of coordinating on AI-driven solutions. It may be beneficial to establish a cross-sectoral "Climate-Agri Data Consortium" that includes meteorology, agriculture, and ICT agencies to oversee data integration and AI tool deployment (Agoh & Chukwuemeka, 2024). Such an institutional mechanism could also align with broader United Nations Framework Convention on Climate Change (UNFCCC) efforts, particularly regarding Nationally Determined Contributions (NDCs), by providing measurable indicators—such as improvements in climate models and insured agricultural areas—to track progress in technology adaptation.

RECOMMENDATIONS

To effectively integrate AI into Nigeria's climate risk management in agriculture, we recommend the following actions:

1. **Strengthen Data Systems:** Expand networks of ground sensors for weather and soil moisture, while encouraging the use of satellite products. Develop an open-access Nigerian Agri-Climate data portal

where the government, researchers, and farmers can upload and access localized climate and crop information.

2. **Invest in Human Capital:** Launch targeted training and capacity-building programs focused on AI in agriculture. For example, offer certificate courses in precision farming for extension workers. Encourage universities to include agri-AI modules in their curricula and fund PhD research focused on local climate and agricultural data modelling.
3. **Support Public-Private Partnerships:** Provide seed funding or tax incentives for startups developing AI tools tailored for smallholder farmers. Facilitate collaboration between tech companies and research institutions, such as national universities, to pilot AI solutions in farming communities, incorporating co-designed feedback loops.
4. **Integrate AI into Policies:** Explicitly include AI and digital agriculture in the next revision of Nigeria's Climate Smart Agriculture (CSA) strategy and National Adaptation Plan (NAP). Create inter-ministerial committees, involving agriculture, science and technology, and the environment, to coordinate digital adaptation initiatives. Ensure climate finance proposals, such as those from the Green Climate Fund (GCF) or World Bank, include components for AI-enhanced risk management.
5. **Enhance Communication and Trust:** Develop localized advisory services using AI, such as SMS alerts in local languages for weather warnings. Emphasize the importance of transparent and explainable AI outputs so that farmers can understand and trust the recommendations. Share case studies from early adopters widely to build community confidence.
6. **Prioritize Equity:** Ensure that AI solutions are accessible to smallholder and female farmers. This could involve subsidizing devices, partnering with farmer cooperatives to reach remote areas, and tailoring technology for low-literacy users, such as providing voice-based advisories. By implementing these actions, Nigeria can bridge the gap between the potential of AI and its practical application in agriculture, significantly enhancing its climate risk management efforts.

CONCLUSION

Climate change presents significant risks to Nigeria's agriculture, threatening food security and the livelihoods of its largely smallholder farming population. Integrating artificial intelligence (AI) technologies, such as remote sensing and machine learning, into Nigeria's climate adaptation and agricultural frameworks holds great promise for enhancing resilience. AI can improve the forecasting of droughts and floods, optimize the use of water and agricultural inputs, and facilitate smarter agronomic decisions all of which can increase productivity and help mitigate the effects of climate-related shocks. Additionally, digital innovation aligns well with Nigeria's development goals, harnessing its growing technology sector and youthful population.

However, to realize these benefits, concerted efforts are needed to overcome several barriers, including investments in data and infrastructure, capacity building, regulatory support, and inclusive outreach. Policymakers must understand that AI is a tool that should be carefully integrated into broader, climate-smart strategies. By drawing on international best practices and tailoring approaches to Nigeria's specific context, we can create a roadmap for AI-enabled climate-resilient agriculture. In doing so, Nigeria can not only mitigate risks but also capitalize on opportunities for a more productive and sustainable agri-food system in the face of climate change.

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