

Artificial Intelligence, Climate Change and Sustainable Agriculture: A Method for Improving Food Security in Enugu State, Nigeria

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Abstract- Climate change poses a serious threat to agricultural productivity, rural livelihoods and food security in Enugu State, Nigeria. Rising temperatures, irregular rainfall, flooding, soil degradation and erosion increase farmers' vulnerability and may reduce crop yields. Artificial Intelligence (AI) provides emerging opportunities to address these challenges through data-driven and climate-smart agricultural practices. This paper examines the role of AI, climate-change adaptation and sustainable agriculture in improving food security in Enugu State. The study adopts a qualitative desk-review approach, drawing on relevant scholarly literature, policy documents and institutional reports. It examines AI applications in weather forecasting, crop and soil monitoring, pest and disease detection, precision farming, irrigation management, yield prediction and digital agricultural extension services. The review indicates that integrating AI with sustainable agricultural practices can improve farm productivity, resource-use efficiency, climate resilience and farmers' decision-making. However, inadequate digital infrastructure, limited technical skills, high technology costs, poor internet connectivity, insufficient agricultural data and weak extension services may constrain adoption, particularly among smallholder farmers. The paper recommends investment in digital infrastructure, farmer training, affordable AI technologies, research, extension services and supportive policies to strengthen sustainable food production and food security in Enugu State.

Keywords: Artificial Intelligence; Climate Change; Sustainable Agriculture; Food Security; Climate-Smart Agriculture; Agricultural Productivity; Smallholder Farmers; Enugu State.

Agriculture remains an important source of food, employment and rural livelihood in Enugu State, Nigeria. Its sustainability, however, is being challenged by climate-related conditions such as irregular rainfall, increasing temperatures, flooding, soil degradation and erosion. These changes can disturb planting and harvesting periods, affect crop development, lower farm output and place pressure on household food supplies. The Intergovernmental Panel on Climate Change (IPCC, 2022) notes that climate change is increasing risks to agricultural production and food security, particularly in communities with limited capacity to adapt.

Artificial intelligence (AI) provides a range of tools that could help farmers respond to these pressures. Examples include weather forecasting, crop monitoring, early identification of pests and diseases, yield estimation and improved water management. According to Liakos et al. (2018), machine-learning techniques have applications in crop, soil and water management. Used alongside sustainable agricultural practices, such tools can help farmers make more timely decisions, reduce unnecessary use of resources and adapt to changing conditions. Their usefulness in Enugu State will nevertheless depend on factors such as affordability, reliable digital infrastructure, quality local data and effective agricultural extension. This study therefore considers the ways AI and sustainable agriculture can contribute to climate adaptation and food security.

I. INTRODUCTION

Statement of the Problem

Agricultural production in Enugu State is increasingly exposed to climate variability. Irregular rainfall,

erosion, flooding, declining soil quality and changing growing conditions can interfere with normal farming activities, reduce harvests and affect the livelihoods of households that depend on agriculture. The IPCC (2022) reports that climate-related extremes can adversely affect agricultural productivity and food availability, thereby increasing food-security concerns. Farmers consequently need timely and dependable information, together with sustainable production methods, to manage changing environmental conditions.

Although AI can provide support for weather forecasting, crop monitoring, disease detection and farm management, its use at the farm level may be limited by several practical challenges. These include the cost of technology, inadequate digital skills, unreliable internet services and limited availability of relevant local agricultural data. Liakos et al. (2018) document the usefulness of machine learning in crop, soil and water management, but the successful application of these technologies depends on suitable data and their adaptation to real farming situations. The central problem addressed in this study is therefore how AI can be linked with sustainable agricultural practices in ways that support climate adaptation and improve food security in Enugu State.

Significance of the Study

The significance of this study lies in its examination of how artificial intelligence can be applied to agricultural problems associated with climate change in Enugu State. For farmers, the study highlights how weather information, crop monitoring, pest detection and digital advisory services may assist day-to-day farm decisions. Agricultural extension personnel may also benefit from the findings because digital tools can complement farmer education, demonstrations and conventional advisory activities.

The study is also relevant to policymakers because it draws attention to the need for investment in digital infrastructure, agricultural research, farmer capacity building and climate information services. The Food and Agriculture Organization of the United Nations (FAO, n.d.) describes climate-smart agriculture as an approach that seeks to improve sustainable productivity, build resilience and respond to climate-related pressures. Researchers and technology

developers may use the issues raised in this study to identify areas requiring further investigation, particularly affordability, data quality and farmers' access to digital services. More broadly, the study contributes to discussion of sustainable food production, rural livelihoods and climate resilience, while recognising that the proposed benefits need to be tested under local conditions.

Aim and Objectives of the Study

Aim of the Study

The study aims to examine how artificial intelligence can be used alongside sustainable agricultural practices to address climate-related challenges and support food security in Enugu State, Nigeria.

Objectives of the Study

The study seeks to:

Examine the major climate-change challenges affecting agricultural production and food security in Enugu State.

Identify AI applications that can assist climate adaptation and sustainable agricultural production.

Assess the possible contribution of AI-supported agricultural practices to productivity, efficient resource use and food security.

Identify the major factors that may limit farmers' adoption of artificial intelligence in Enugu State.

Suggest practical strategies for combining artificial intelligence with sustainable agriculture to strengthen food security in the state.

Research Questions

The study is guided by the following research questions:

What major climate-change challenges affect agricultural production and food security in Enugu State?

Which artificial intelligence applications can support climate adaptation and sustainable agriculture in the state?

In what ways can AI-supported agricultural practices contribute to productivity, efficient resource use and food security?

What factors may hinder the adoption of artificial intelligence among farmers in Enugu State?

What strategies can encourage the integration of artificial intelligence and sustainable agriculture to improve food security in Enugu State?

II. LITERATURE REVIEW

This chapter examines the major concepts, empirical evidence, conceptual relationships and knowledge gaps associated with the use of artificial intelligence for climate adaptation and sustainable agriculture. The review is based on the focus of the study, particularly AI applications, adoption challenges and possible strategies for strengthening food security in Enugu State.

Conceptual Review

Artificial intelligence refers to computer-based systems that can process information, identify patterns and assist with decision-making. In agriculture, these systems can be applied to areas such as weather forecasting, soil and crop monitoring, pest identification, yield prediction and irrigation scheduling (Liakos et al., 2018). Climate change refers to long-term changes in temperature and weather patterns that can influence farming through irregular rainfall, flooding, erosion and heat stress (IPCC, 2022). Sustainable agriculture focuses on maintaining productive farming while protecting soil, water, biodiversity and the livelihoods of farming communities. Food security exists when people have dependable physical and economic access to adequate, safe and nutritious food. In the context of Enugu State, combining AI with sustainable farming practices could improve climate-related decision-making and resource use, although the extent of the benefits will depend on access to technology, infrastructure, appropriate data and farmers' ability to use digital tools.

Empirical Review

Liakos et al. (2018) reviewed the application of machine learning in agriculture and identified its use in areas such as crop management, disease detection, yield prediction and livestock monitoring. Their review demonstrates the potential of data-driven technologies to improve agricultural decision-making, although it does not show the level of adoption or

actual impact among farmers in Enugu State. The IPCC (2022) examined evidence on climate impacts, adaptation and vulnerability and highlighted the risks that climate change poses to food production and rural livelihoods. Similarly, the Food and Agriculture Organization (FAO, 2013) presented climate-smart agriculture as an approach aimed at improving productivity, strengthening adaptation and, where possible, reducing greenhouse-gas emissions. Taken together, these sources provide a basis for considering digital technologies as part of climate adaptation and sustainable farming. However, findings from international literature cannot automatically be regarded as evidence of AI effectiveness in Enugu State. Local access to digital services, the quality of available agricultural data and the strength of extension support still require context-specific investigation. This study therefore considers both the opportunities and the constraints surrounding AI-supported agriculture and their possible implications for food security.

Conceptual Framework

The conceptual framework assumes that AI applications can support sustainable agricultural practices and, through these practices, contribute to improved food-security outcomes. The AI component includes weather information, crop and soil monitoring, pest detection, precision farming, irrigation guidance and yield prediction. These applications may improve farm decisions, increase input efficiency, support productivity and strengthen adaptation to climate variability. Sustainable practices such as soil conservation, careful water use and climate-smart crop management provide the practical connection between digital information and agricultural outcomes. The relationship is also affected by enabling and limiting conditions, including internet access, electricity, cost, digital literacy, availability of agricultural data, extension services and government support. Food security is considered in terms of food availability, access, utilisation and stability.

Knowledge Gap

Previous studies have established the potential of machine learning and other digital technologies for crop monitoring, disease identification and agricultural decision-making (Liakos et al., 2018). Climate assessments have likewise shown the

importance of adaptation in protecting agricultural production and rural livelihoods (IPCC, 2022). What remains less clear is how these technologies can be accessed, understood and practically used by smallholder farmers in Enugu State. There is therefore a contextual gap concerning the relationship among AI availability, farmers' digital skills, extension support, sustainable farming practices and food-security outcomes. This study responds to that gap by examining the opportunities, limitations and practical measures for integrating AI-supported climate adaptation with sustainable agriculture in Enugu State.

Summary of Literature Review

The literature reviewed shows that AI can be applied to agricultural forecasting, crop and soil monitoring, pest and disease detection, irrigation management and yield prediction. Such applications can complement sustainable farming methods and climate-adaptation efforts and may, in turn, support food security. However, the availability of technology does not automatically lead to its adoption or to better agricultural outcomes. Farmers may encounter financial, infrastructural, technical and institutional difficulties, especially where internet services, reliable data and extension support are inadequate. Although international studies provide useful background, they do not replace evidence from Enugu State. The study therefore considers both the potential value of AI and the conditions needed for its effective and inclusive use.

III. METHODOLOGY

Research Design

For the questionnaire-based version of the study, a descriptive survey design is proposed. The design would make it possible to obtain respondents' views on climate-related agricultural challenges, available AI applications, expected benefits and barriers to adoption in Enugu State. It should be noted that this proposed survey approach differs from the qualitative desk-review method stated in the original abstract. The final manuscript should adopt one design consistently.

Area of the Study

The study is located in Enugu State, southeastern Nigeria. Agriculture provides food, raw materials and livelihoods for many households in the state. The

study concentrates on climate-related agricultural concerns, including irregular rainfall, flooding, erosion and soil degradation, as well as the possible use of digital technologies to support sustainable farming.

Population and Sample

The proposed study population consists of smallholder farmers, agricultural extension personnel and relevant agricultural officers in selected communities in Enugu State. For the illustrative analysis presented in Chapter Four, a hypothetical sample of 100 respondents is used. This figure is only for demonstrating the presentation of questionnaire results and does not represent actual respondents or completed questionnaires.

Sampling and Instrument

A field study involve purposive selection of communities and relevant agricultural stakeholders, followed by an appropriate sampling procedure for qualified respondents. Data was collected with a structured questionnaire organised around the five research questions, with six statements under each question. Responses would be measured on a five-point Likert scale: Strongly Agree (SA), Agree (A), Undecided (N), Disagree (D) and Strongly Disagree (SD).

Data Analysis and Ethical Considerations

The response was analysed using frequencies, percentages and weighted mean scores. Participation should be voluntary, informed consent should be obtained, and respondents' identities should be protected. The simulated figures in this document must be replaced with verified field data before they are presented as empirical findings. If the desk-review design is retained, the analysis should instead focus on themes and evidence drawn from published literature and other documented sources.

Results and Discussion

This chapter illustrates how responses to the five research questions can be organised in separate Likert-scale tables. Each research question contains six statements, and the tables use 100 hypothetical respondents so that frequencies correspond directly to percentages. The figures are simulated for presentation purposes only; they should not be reported as actual

findings from farmers in Enugu State without genuine data collection and analysis.

Presentation and Analysis of Results

Likert-Scale Decision Rule

Response Score

Strongly Agree (SA) 5

Agree (A) 4

Undecided (N) 3

Disagree (D) 2

Strongly Disagree (SD) 1

For this illustrative analysis, a mean score of 3.00 or above is taken to indicate agreement, whereas a mean below 3.00 indicates disagreement. This rule is used only for interpreting the demonstration tables and should not be treated as evidence of statistical significance.

Research Question One

What major climate-change challenges affect agricultural production in Enugu State?

The weighted mean is calculated as:

Table 4.1: Respondents' views on climate-change challenges

S/N	Statement	SA	A	U	D	SD	M
1	Irregular rainfall affects planting and harvesting schedules	45	30	10	10	5	4.00
2	Rising temperatures can reduce crop performance	40	32	12	11	5	3.91
3	Flooding damages farmland and agricultural produce	42	31	10	12	5	3.93
4	Soil erosion reduces the quality of agricultural land	48	28	9	10	5	4.04
5	Climate variability makes farm planning more difficult	43	32	10	10	5	3.98
6	Climate-related crop losses can threaten household food supply	46	29	10	10	5	4.01

SOURCE: Field Data 2025

Interpretation and Discussion:

All six statements have illustrative mean scores above 3.00 and therefore indicate agreement according to the stated decision rule. Soil erosion has the highest mean score (4.04), followed by the view that climate-related crop losses can threaten household food supply (4.01). The pattern suggests that the questionnaire is capable of capturing concerns relating to land degradation, changing weather conditions and food availability. These themes are in line with the broader climate-

vulnerability concerns reported by the IPCC (2022). However, because the figures are simulated, they cannot be used to determine the actual extent or severity of these challenges among farmers in Enugu State.

Research Question Two

Which AI applications can support sustainable agriculture in Enugu State?

Table 4.2: Views on possible AI applications in agriculture

S/N	Statement	SA	A	U	D	SD	M
1	AI-supported weather forecasts can assist farm planning.	44	32	10	9	5	
2	Digital tools can help monitor crop and soil conditions.	40	34	11	10	5	
3	AI can help identify crop pests and diseases early.	46	30	10	9	5	
4	Precision-farming tools can support efficient input use.	38	34	13	10	5	
5	Digital systems can assist irrigation and water management.	39	33	12	11	5	

6	AI-enabled extension services can provide useful farm advice.	42	31	12	10	5	
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The illustrative mean scores fall between 3.90 and 4.03. Early identification of crop pests and diseases has the highest mean, indicating that respondents in this hypothetical example place considerable value on timely information about crop health. Weather forecasting, crop and soil monitoring, precision farming, irrigation management and digital extension

also receive agreement. Liakos et al. (2018) identifies these types of machine-learning applications as relevant to agricultural decision-making. In practice, however, their usefulness in Enugu State would depend on the accuracy of the technology, the availability of local crop information, affordability and farmers' ability to access and understand the advice.

Research Question Three

How can AI-supported sustainable agriculture contribute to productivity, resource efficiency and food security?

Table 4.3: Views on the expected benefits of AI-supported agriculture

S/N	Statement	SA	A	U	D	SD	M
1	AI-based advice may help farmers improve crop productivity	42	32	11	10	5	3.96
2	Better forecasts can help farmers reduce avoidable crop losses.	45	30	10	10	5	4.00
3	Digital monitoring can support more efficient use of farm inputs	40	33	12	10	5	4.00
4	AI-supported planning can improve water-use efficiency	39	34	12	10	5	3.92
5	Climate information can help farmers adapt to changing weather	46	29	10	10	5	4.01
6	Improved farm decisions may contribute to household food security	43	31	11	10	5	3.97

SOURCE: Field Data 2025

Interpretation and discussion:

All statements achieve illustrative means above 3.00. Climate adaptation and reduction of avoidable crop losses have the highest means, at 4.01 and 4.00 respectively. The pattern suggests that the proposed questionnaire would explore benefits beyond yield alone, including efficient use of water and inputs and the stability of household food supply. This is compatible with the climate-smart agriculture approach described by the FAO (2013), which links productivity and resilience. Nevertheless, the table records hypothetical perceptions, not measured yield increases or verified improvements in food security.

Research Question Four

What barriers may limit the adoption of AI in sustainable agriculture in Enugu State?

Table 4.4: Views on barriers to AI adoption

S/N	Statement	SA	A	U	D	SD	M
1	High technology costs may discourage farmers from adopting AI	48	27	10	10	5	4.03
2	Poor internet connectivity may limit farmers' access to AI-supported services.	46	30	11	10	5	4.01

3	Limited digital skills may make AI tools difficult to use	44	30	11	10	5	3.98
4	Inadequate electricity may restrict the use of digital technology.	43	31	11	10	5	3.97
5	Insufficient local agricultural data may reduce the usefulness of AI	40	32	13	10	5	3.92
6	Weak agricultural extension services may slow AI adoption	42	31	12	10	5	3.93

Interpretation and Discussion: The simulated responses show mean scores above 3.00 for all six barriers. Technology cost records the highest mean (4.03), followed by the barrier relating to poor connectivity (4.01) and limited digital skills (3.98). The pattern demonstrates that the questionnaire considers financial, infrastructural, educational and institutional issues together. These concerns are also reflected in the study's abstract. The results suggest that introducing AI tools without addressing access, infrastructure, relevant information and technical

support may limit their usefulness. Actual field data would still be necessary to determine which barriers are most significant in the communities selected for the study.

Research Question Five

What strategies could improve the integration of AI and sustainable agriculture for food security in Enugu State?

Table 4.5: Views on strategies for improving AI adoption

S/N	Statement	SA	A	U	D	SD	M
1	Training programmes should improve farmers' digital skills	50	28	9	8	5	4.10
2	Better internet and electricity infrastructure would support adoption	47	30	9	9	5	4.05
3	Affordable AI tools should be made available to smallholder farmers	49	28	9	9	5	4.07
4	Agricultural extension officers should receive AI-related training.	45	31	10	9	5	4.02
5	Partnerships between government, researchers and technology providers should be encouraged	42	32	11	10	5	3.96
6	Policies should promote responsible and inclusive agricultural technology use.	44	31	10	10	5	3.99

Interpretation and Discussion: The six simulated mean scores range from 3.96 to 4.10, which represents agreement under the decision rule used in the demonstration. Farmer training has the highest mean score (4.10), followed by affordable AI tools (4.07) and improved digital infrastructure (4.05). The pattern draws attention to the need to develop farmers' skills alongside the provision of technology. Training can help farmers understand digital forecasts, recognise the limitations of automated recommendations and relate technological advice to local farming conditions. Extension workers, research institutions and public agencies can also help bridge the gap between technology providers and farming communities. Although the pattern agrees with the strategies proposed in the abstract, it still requires confirmation through actual survey responses or documented evidence.

Summary of the Results

The illustrative analysis covers five areas: climate-related agricultural challenges, possible AI applications, expected benefits, barriers to adoption and strategies for implementation. All 30 statements have simulated mean scores above 3.00 and therefore indicate agreement under the stated decision rule. Soil erosion and climate-related crop losses appear among the identified challenges, while pest and disease detection emerges as a notable potential AI application. Climate adaptation and reduction of avoidable crop losses are among the expected benefits. High technology costs, connectivity problems and limited digital skills are identified as important illustrative barriers, while farmer training, affordable tools and better infrastructure feature prominently among the proposed strategies. These patterns show

how questionnaire findings can be organised and interpreted, but they should not be presented as empirical evidence. Final conclusions must be based on verified field data or a systematic qualitative review of published evidence.

Conclusion

Artificial intelligence has the potential to support sustainable agriculture through applications such as weather forecasting, crop and soil monitoring, pest detection, irrigation management and digital agricultural extension. When these technologies are used together with appropriate sustainable farming practices, they may help improve productivity, resource efficiency and farmers' ability to respond to climate variability, with possible benefits for food security. Their effectiveness, however, depends on factors such as affordability, dependable infrastructure, relevant agricultural data, farmers' digital competence and effective extension support. The Likert-scale tables in this document illustrate how questionnaire responses could be presented, but they do not establish the actual situation in Enugu State. The final conclusion should therefore be aligned with genuine field findings if a survey is conducted, or with documented evidence if the desk-review approach is retained.

Recommendations

- Provide farmer training: Agricultural agencies and extension services should organise practical training on the use of digital weather information, crop-monitoring tools and AI-supported agricultural services.
- Improve infrastructure: Relevant authorities and service providers should expand reliable rural internet access, electricity supply and other digital services needed for the practical use of agricultural technologies.
- Promote affordability: Technology providers and agricultural support programmes should consider low-cost AI tools and financing arrangements that are realistic for smallholder farmers.
- Strengthen extension services: Extension personnel should receive appropriate training in AI-supported agricultural information so they can interpret the advice and communicate it in forms that farmers can readily understand.

- Support research and partnerships: Universities, government agencies, farmers and technology providers should work together to test AI tools under local farming conditions and assess their actual costs, usefulness and limitations.
- Evaluate outcomes: Future research should collect reliable evidence on technology adoption, productivity, resource use and food-security indicators before making claims about measurable improvements.

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