Enhancing Resilience to Climate Change in Ghana's Agriculture and Food Sector through Improved Climate Information Accessibility: A Conceptual Framework

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Abstract. This study addresses the critical need for accessible and relevant climate information in Ghana's agricultural and food sectors, disproportionately affected by climate change. Utilizing a participatory approach, we engage stakeholders such as policymakers and researchers to identify specific climate information needs and co-produce actionable data. Advanced AI technologies, including Large Language Models, are leveraged to analyze this localized information, fill gaps, and enhance agricultural decision-making. Our research identifies AI's promise and limitations in providing high-quality yet locally tailored climate information. By marrying stakeholder input with advanced technology, we aim to bolster agricultural resilience and sustainable food security in Ghana. The study holds significant implications for policy formulation, resource allocation, and adopting effective adaptation strategies, contributing to a climate-resilient agricultural ecosystem and improved livelihoods for Ghana's population.

Keywords. Climate change, Agriculture, Food security, Climate data, Stakeholder engagement, Participatory approach, Artificial intelligence (AI), resilience.

1 Introduction

Climate change poses substantial risks to agriculture and food security, most acutely felt in developing countries such as Ghana (Intergovernmental Panel on Climate Change, 2014; Niang et al., 2014). Despite contributing minimally to global greenhouse gas emissions, Ghana is vulnerable to climate change's adverse effects, like increased temperatures, changing rainfall patterns, and extreme weather events (EPA, 2015; Owusu & Waylen, 2009). These changes jeopardize the country's agricultural sector, the backbone of its economy and a critical component of national food security (Awuni et al., 2023). A significant barrier to overcoming these challenges is the lack of accessible, timely, and relevant climate information for key stakeholders such as farmers, policymakers, and researchers (Hansen et al., 2007; Vaughan & Dessai, 2014). Past efforts suggest that a tailored approach, co-produced through participatory methods involving diverse stakeholders, leads to more effective climate adaptation strategies (Jones et al., 2015; Roncoli et al., 2009; Dilling & Lemos, 2011).

Emerging research shows that Artificial Intelligence (AI), particularly Large Language Models, can complement human expertise by filling information gaps with timely and localized climate predictions (Ruiz-Real et al., 2020; Guthrie, 2019). Although nascent in Ghana, AI holds promise for significantly enhancing climate resilience and adaptation strategies (Antwi-Agyei, Dougill, et al., 2021; Manteaw et al., 2022). This study aims to bridge the climate information gap by identifying stakeholders' specific needs and leveraging AI technologies for actionable strategies. We endeavor to fortify agricultural resilience and contribute to sustainable food security in Ghana through an integrated approach, blending stakeholder engagement with technological innovation. By doing so, we hope to provide valuable insights that will inform policy development, resource allocation, and adaptation strategies, ultimately contributing to a more climate-resilient Ghana.

2 Literature Review

The impacts of climate change on agriculture and food security are well-documented, with numerous studies highlighting the vulnerability of developing countries, particularly in Africa (Niang et al., 2014; Sultan & Gaetani, 2016). In Ghana, climate change has led to increased temperatures, changing rainfall patterns, and extreme weather events, which pose significant challenges to the agricultural sector and food security (EPA, 2015; Owusu & Waylen, 2009).

The availability of accurate and timely climate information is essential for farmers and other stakeholders in agriculture to make informed decisions on crop selection, planting times, pest control, and resource management (Hansen et al., 2007). However, many developing countries, including Ghana, face challenges accessing and utilizing climate information due to inadequate infrastructure, limited awareness, and insufficient capacity among stakeholders (Vaughan & Dessai, 2014).

Several studies have highlighted the importance of tailoring climate information to the needs of agricultural stakeholders to enhance its relevance and usefulness (Jones et al., 2015; Simelton et al., 2013). Participatory approaches involving farmers, extension officers, researchers, and policymakers have been identified as effective means of identifying climate information needs and improving communication channels for information dissemination (Roncoli et al., 2009; Tall et al., 2013).

Additionally, research has shown that engaging stakeholders in the co-production of climate information can lead to better adaptation strategies and increased agricultural resilience (Dilling & Lemos, 2011; Lemos et al., 2012). This is particularly relevant for Ghana, where agriculture is a key component of the economy, and climate change poses significant risks to food security and rural livelihoods (EPA, 2015).

3 Methodology

The methodology for this study comprises a multi-stage approach, as capture in Figure 1 below, designed to address the research questions and objectives, with a strong emphasis on stakeholder engagement and participatory methods, as well as the incorporation of artificial intelligence (AI) models for data analysis.

1. Stakeholder identification and recruitment: The study will begin by identifying key agricultural stakeholders in Ghana, including farmers, extension officers, researchers, and policymakers. A purposive sampling strategy will be employed to ensure representation from various regions, agricultural sectors, and levels of decision-making (Palinkas et al., 2015).
2. Workshops and participatory methods: Stakeholders will be engaged in a series of workshops, where they will participate in activities to identify their climate information needs and preferences for data formats and communication channels. Participatory methods, such as focus group discussions and ranking exercises, will facilitate stakeholder dialogue and consensus-building (Morgan, 1996).
3. Co-production of climate information: Building on the insights gained from the workshops, stakeholders will be involved in the co-production of climate information, using a participatory approach inspired by the paper "Self-critiquing models for assisting human evaluators" (Saunders et al., 2022). This process will involve developing, reviewing, and refining questions and answers related to climate change and its impacts on agriculture.
4. Evaluation and AI-assisted analysis of climate information: The co-produced climate information will be evaluated using human evaluators, who will assess the relevance, understandability, and usability of the data for stakeholders (Saunders et al., 2022). Subsequently, AI models will be employed to analyze the evaluated climate information, identifying patterns and relationships that can further inform the study's objectives and outcomes.
5. Dissemination of tailored climate information: Finally, the tailored climate information, enhanced by AI-assisted analysis, will be disseminated to stakeholders through appropriate channels, such as workshops, extension services, and digital platforms, to improve its accessibility and impact on agricultural resilience and food security in Ghana (Tall et al., 2013).
6. Global Trends Analysis: To provide a comparative global context to our local findings, we will utilize Google Trends data on climate change-related search queries from 2020 to 2022 across

G20 countries and Ghana. The search queries will be analyzed using language-agnostic BERT (LaBSE embeddings) and Principal Component Analysis (PCA) to identify global patterns in climate information needs.

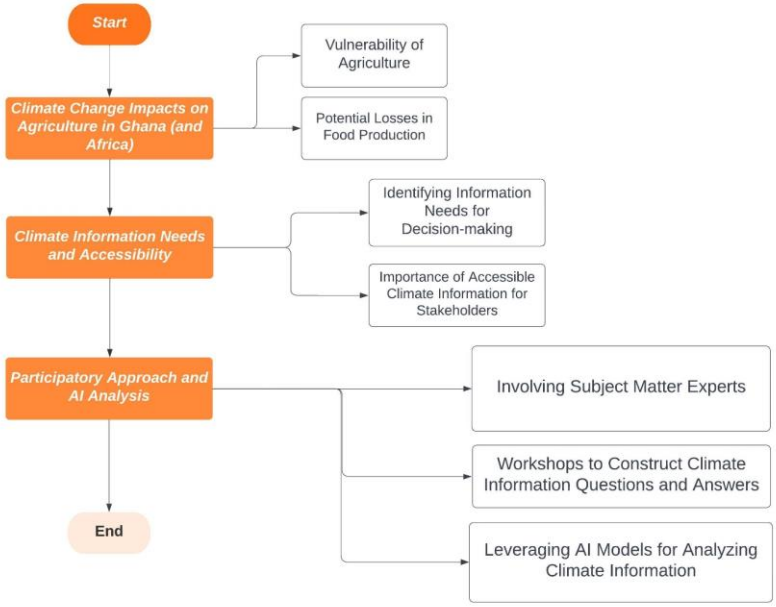

Fig. 1 Concept Framework of the methodology

4 Implementations: The Role of AI In Enhancing Climate Information Accessibility in Ghana's Agriculture Sector

The University of Ghana conducted an experimental study to explore the utility of Artificial Intelligence, specifically Large Language Models (LLMs) like ChatGPT, in addressing climate-related queries relevant to Ghana's agriculture and food sector. We compared the responses generated by ChatGPT to those from a panel of local experts from diverse sectors, including Forestry, Academia, and Energy.

A compilation of 93 climate-related questions, focused on Ghana, were prepared. We formed panels comprising 46 local experts with varying levels of self-assessed knowledge about climate change. These experts were divided into four groups to write concise answers for the set questions. Subsequently, another set of groups assessed the quality of these answers on a scale of 'Low' (4%), 'Medium' (56%), and 'High' (40%). Simultaneously, answers generated by ChatGPT were also evaluated. Interestingly, ChatGPT scored 'High' (99%) in almost all questions, with one marked as 'Medium.' However, the reason for this preference over human experts is yet to be fully understood. We suspect that stylistic elements or narrative structures, possibly influenced by RLHF algorithms (Ziegler et al., 2019), may account for this.

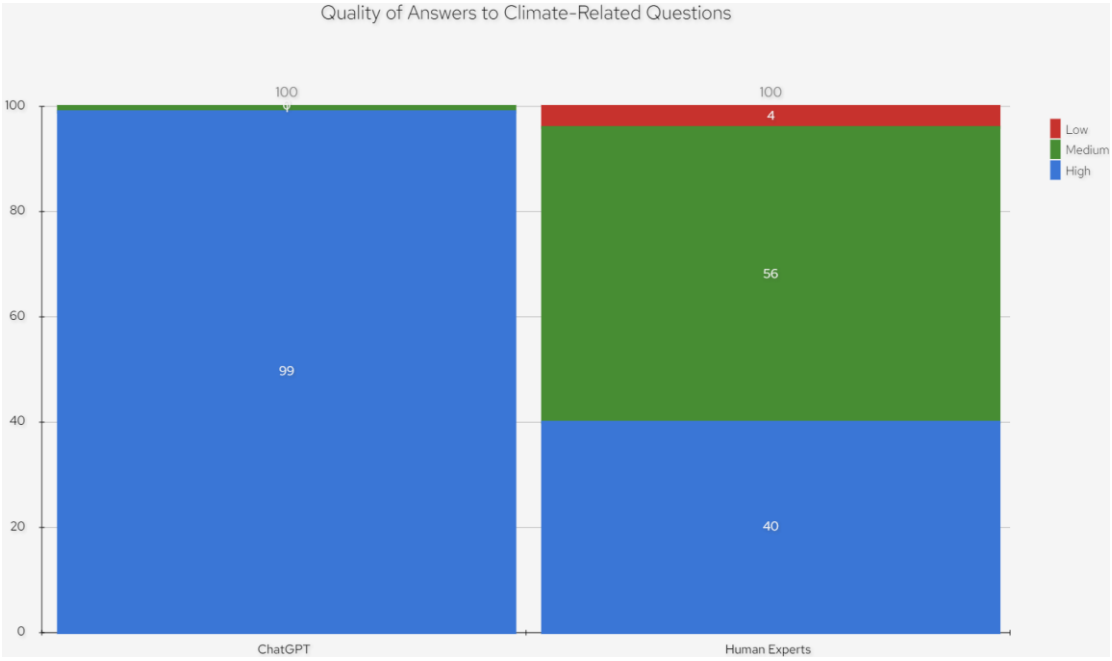

Fig. 2 The Chart compares the quality of answer generated by ChatGPT and a panel of human experts to a set of 93 climate-related questions relevant to Ghana's agricultural sector. Quality is assessed on a scale of 'Low', 'Medium', and 'High.'

One possible limitation of our study is the constrained setting in which human experts operated, leading to questions about how ChatGPT's responses compare to detailed, unrestricted expert responses. For instance, when ChatGPT was asked about the effects of climate change on agriculture in Ghana, its well-framed answer was not as specific to Ghana as a comparable expert-written answer. Moreover, ChatGPT itself recognized the expert answer as superior for its depth and relevance, especially concerning key crops like cocoa.

While ChatGPT shows promise in generating answers in a time-sensitive environment, it acknowledges the value of more specific and in-depth expert knowledge. Our findings point to the need for further research to understand the contexts in which AI can be most useful for enhancing climate information accessibility, particularly in sectors as crucial as agriculture in Ghana. The following research questions and objectives are designed to address the identified gaps in climate information accessibility and relevance for agricultural stakeholders in Ghana.

5 Conclusion

This research aimed to address the critical gaps in climate information accessibility, directly affecting Ghana's agricultural resilience and sustainable food security. Utilizing a participatory approach and AI analyses, the study provides insights that could significantly influence policy and resource allocation. Notably, Large Language Models like ChatGPT offer quality, though generalized, answers to climate-related queries, emphasizing the continued relevance of human expertise for nuanced understanding.

The study advocates for dedicating more resources to climate-specific content in local languages, enhancing the utility of AI for communities most vulnerable to climate change. Through this holistic approach that integrates stakeholder input and advanced AI, our research holds promise for not only strengthening agricultural resilience but also for securing sustainable food systems. In summary, our work highlights the vital role of accessible, relevant climate information in enhancing both agricultural resilience and food security in Ghana.

6 References

Antwi-Agyei, P., Amanor, K., Hogarh, J. N., & Dougill, A. J. (2021). Predictors of access to and willingness to pay for climate information services in north-eastern Ghana: A gendered

perspective. Environmental Development, 37. https://doi.org/10.1016/j.envdev.2020.100580

Antwi-Agyei, P., Dougill, A. J., & Abaidoo, R. C. (2021). Opportunities and barriers for using climate information for building resilient agricultural systems in Sudan savannah agro-ecological zone of north-eastern Ghana. Climate Services, 22. https://doi.org/10.1016/j.cliser.2021.100226

Awuni, S., Adarkwah, F., Ofori, B. D., Purwestri, R. C., Huertas Bernal, D. C., & Hajek, M. (2023). Managing the challenges of climate change mitigation and adaptation strategies in Ghana. In Heliyon (Vol. 9, Issue 5). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2023.e15491

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change, 21(2), 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

EPA. (2015). Republic of Ghana Ghana's Third National Communication Report to the UNFCCC 2015 Climate Change Report.

Guthrie, G. (2019). Real options analysis of climate-change adaptation: investment flexibility and extreme weather events. Climatic Change, 156(1–2), 231–253. https://doi.org/10.1007/s10584-019-02529-z

Hansen, J. W., Baethgen, W., Osgood, D., Ceccato, P., & Ngugi, R. K. (2007). Innovations in Climate Risk Management: Protecting and Building Rural Livelihoods in a Variable and Changing Climate 1 (Vol. 4, Issue 1).

Intergovernmental Panel on Climate Change. (2014). Climate Change 2014 : Synthesis Report.

Jones, L., Dougill, A., Jones, R. G., Steynor, A., Watkiss, P., Kane, C., Koelle, B., Moufouma-Okia, W., Padgham, J., Ranger, N., Roux, J. P., Suarez, P., Tanner, T., & Vincent, K. (2015). Ensuring climate information guides long-term development. In Nature Climate Change (Vol. 5, Issue 9, pp. 812–814). Nature Publishing Group. https://doi.org/10.1038/nclimate2701

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. In Nature Climate Change (Vol. 2, Issue 11, pp. 789–794). https://doi.org/10.1038/nclimate1614

Manteaw, B. O., Amoah, A. B., Ayittah, B., & Enu, K. B. (2022). Climate-Informed Decision-Making in Data-Poor Environments: Managing Climate Risk Through Citizen Science Networks. Frontiers in Climate, 4. https://doi.org/10.3389/fclim.2022.835768

Morgan, D. L. (1996). Focus Groups. In Source: Annual Review of Sociology (Vol. 22). https://about.jstor.org/terms

Niang, I., Ruppel, O. C., Abdrabo, M. A., Dube, P., Leary, N., Schulte-Uebbing, L., Field, C., Dokken, D., Mach, K., Bilir, T., Chatterjee, M., Ebi, K., Estrada, Y., Genova, R., Girma, B., Kissel, E., & Levy, A. (2014). Katrien Descheemaeker (Netherlands), Houria Djoudi (Algeria), Kristie L. Ebi (USA), Papa Demba Fall (Senegal), Ricardo Fuentes (Mexico), Rebecca Garland (South Africa). In Aissa Toure Sarr. Pieter Pauw.

Owusu, K., & Waylen, P. (2009). Trends in spatio-temporal variability in annual rainfall in Ghana (1951-2000) (Vol. 64, Issue 5). www.meteo.gov.gh/

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. Administration and Policy in Mental Health and Mental Health Services Research, 42(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Reed, M. S., Stringer, L. C., Fazey, I., Evely, A. C., & Kruijsen, J. H. J. (2014). Five principles for the practice of knowledge exchange in environmental management. Journal of Environmental Management, 146, 337–345. https://doi.org/10.1016/j.jenvman.2014.07.021

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K. T., Woodin, M., Somé, L., Ouattara, F., Sanfo, B. J., Sia, C., Yaka, P., & Hoogenboom, G. (2009). From accessing to assessing forecasts: An end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Climatic Change, 92(3–4), 433–460. https://doi.org/10.1007/s10584-008-9445-6

Ruiz-Real, J. L., Uribe-Toril, J., Arriaza, J. A. T., & Valenciano, J. de P. (2020). A look at the past, present and future research trends of artificial intelligence in agriculture. Agronomy, 10(11). https://doi.org/10.3390/agronomy10111839

Saunders, W., Yeh, C., Wu, J., Bills, S., Ouyang, L., Ward, J., & Leike, J. (2022). Self-critiquing models for assisting human evaluators. ArXiv Preprint ArXiv:2206.05802.

http://arxiv.org/abs/2206.05802

Simelton, E., Quinn, C. H., Batisani, N., Dougill, A. J., Dyer, J. C., Fraser, E. D. G., Mkwambisi, D., Sallu, S., & Stringer, L. C. (2013). Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. Climate and Development, 5(2), 123–138. https://doi.org/10.1080/17565529.2012.751893

Smith, M. J. (2019). Getting value from artificial intelligence in agriculture. In Animal Production Science (Vol. 60, Issue 1, pp. 46–54). CSIRO. https://doi.org/10.1071/AN18522

Sultan, B., & Gaetani, M. (2016). Agriculture in West Africa in the twenty-first century: Climate change and impacts scenarios, and potential for adaptation. In Frontiers in Plant Science (Vol. 7, Issue AUG2016). Frontiers Media SA https://doi.org/10.3389/fpls.2016.01262

Tall, A., Jay, A., & Hansen, J. (2013). Scaling Up Climate Services for Farmers in Africa and South Asia Workshop Report December 10-12, 2012 Saly, Senegal Working Paper. www.ccafs.cgiar.org

Vaughan, C., & Dessai, S. (2014). Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. Wiley Interdisciplinary Reviews: Climate Change, 5(5), 587–603. https://doi.org/10.1002/wcc.290

Ziegler, D. M., Stiennon, N., Wu, J., Brown, T. B., Radford, A., Amodei, D., Christiano, P., & Irving, G. (2019). Fine-Tuning Language Models from Human Preferences. http://arxiv.org/abs/1909.08593