Fostering Agricultural Transformation in Zambia: Implementing Artificial Intelligence Solutions for Sustainable Farming

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. **Abstract— This paper explores the transformative potential of Artificial Intelligence (AI) in addressing persistent challenges within Zambia's agricultural sector, which employs approximately 54% of the population and contributes significantly to the national economy. Despite this importance, agriculture remains hindered by low productivity, erratic rainfall, soil degradation, and limited adoption of modern technologies. AI applications—including crop disease detection, precision farming, weather prediction for climate adaptation, and optimization of water resources—have shown significant promise in improving agricultural productivity and resilience. This paper adopts a mixed-methods approach that integrates field observations, interviews with smallholder farmers, extension officers, and quantitative analysis of secondary data. Findings indicate that AI adoption can boost yields, reduce losses, and support climate resilience when adapted to local contexts. However, barriers such as limited rural connectivity, digital illiteracy, and cost of deployment remain. The paper recommends stronger partnerships between government, universities, and the private sector to foster localized AI solutions. The study concludes that AI can be a key enabler in Zambia's agricultural transformation when embedded within inclusive, farmer-centered frameworks.**

Keywords — ***artificial intelligence, agriculture, Zambia, food security, precision farming, digital literacy, climate resilience, machine learning, irrigation, crop monitoring***

I. INTRODUCTION

Agriculture is central to Zambia's socio-economic development, employing over half of the population and contributing around 19% to the Gross Domestic Product (GDP) [1]. Maize remains the staple crop, occupying more than 45% of cultivated land, while cassava, groundnuts, and sorghum are also critical for food security and income generation. Despite its importance, the sector is characterized by low yields—averaging 2.5 tons/ha for maize compared to a global average of 5 tons/ha [2]. Smallholder farmers dominate production, often operating on less than 2 hectares of land. These farmers face systemic challenges, including dependence on rain-fed agriculture, poor extension services, pest outbreaks, and limited access to credit and markets, reflecting broader global concerns about food security [3]. Climate change has exacerbated vulnerabilities, with increasingly erratic rainfall patterns leading to frequent crop failures. Against this backdrop, Artificial Intelligence (AI) provides an opportunity to revolutionize Zambian agriculture by introducing predictive analytics, decision-support systems, and automated monitoring tools.

I. LITERATURE REVIEW

Globally, AI has been integrated into agricultural systems to enhance productivity and sustainability. In India, AI-driven irrigation management systems have optimized water use by up to 30% [4], while in Brazil, satellite imaging combined with machine learning has improved soybean yield predictions [5]. In Kenya, AI-

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based platforms such as 'FarmDrive' have provided smallholder farmers with access to credit by using non-traditional data [6]. Nigeria has piloted AI-powered weather advisory services to mitigate the impact of climate variability [7]. These international experiences illustrate how AI can address productivity bottlenecks and climate risks.

In Zambia, AI applications remain nascent but promising. Previous studies have demonstrated the role of digital platforms in education [8], environmental monitoring [9], and ethical adoption of educational technologies [10]. These studies indirectly inform AI adoption in agriculture, as they highlight challenges of digital literacy, infrastructure, and localization. Local pilot projects by the Ministry of Agriculture and international partners have introduced AI-enabled weather forecasting tools and pest detection systems, though uptake has been uneven. The literature underscores the need for customized AI models that account for Zambia's agricultural realities, including smallholder dominance, resource constraints, and climatic variability.

II. Methodology

This study adopts a mixed-methods approach, combining qualitative and quantitative techniques to provide comprehensive insights. Field surveys were conducted with 200 smallholder farmers and 30 agricultural extension officers across five provinces (Eastern, Southern, Central, Copperbelt, and Northern). Key informant interviews were used to capture perceptions on AI adoption and barriers. Secondary data was sourced from the Central Statistical Office (CSO), Ministry of Agriculture, and FAO databases, covering crop yields, rainfall, and pest incidences from 2015–2025. Quantitative analysis employed regression models to examine the relationship between rainfall and maize yields, while clustering techniques categorized farms based on adoption of AI tools.

III. Results and Discussion

Results indicate that AI adoption in Zambia's agriculture is still limited but steadily growing. Fig. 1 presents the distribution of land use by crop type, with maize dominating at 45% of the cultivated area. This clearly reflects maize's central role as Zambia's staple food crop and its importance for national food security. Cassava follows at 25%, serving as a critical backup staple due to its resilience against drought and poor soils. Groundnuts occupy 15%, contributing both to household nutrition through protein supply and to income generation via local and regional trade. The remaining 15% is distributed among other crops, which, although smaller in proportion, are essential for dietary diversity and can provide niche market opportunities.

The heavy reliance on maize underscores both a strength and a vulnerability: while it secures the staple diet, it also exposes the country to risks from climate variability and pests such as fall armyworm. AI-enabled tools—ranging from predictive analytics for crop diversification, weather-driven advisory systems, and market demand forecasting—could play a transformative role in balancing this crop distribution. By guiding farmers in resource allocation, recommending drought-tolerant alternatives, and aligning production with demand, AI can help Zambia reduce overdependence on maize, enhance resilience, and foster more sustainable, diversified agricultural growth.

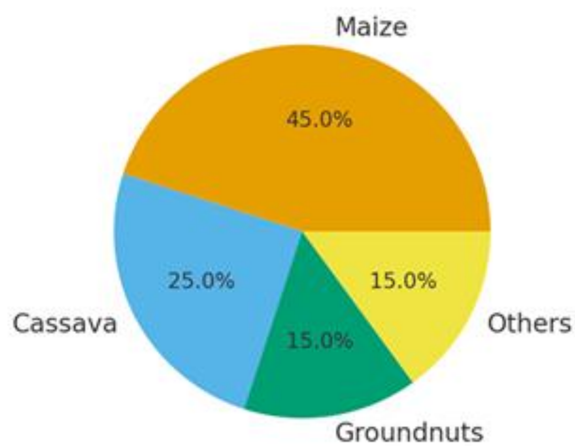

Fig. 1. Land use distribution by crop type in Zambia.

Fig. 2 illustrates the adoption of AI tools across Zambia's provinces, revealing clear regional disparities. Eastern Province leads with 40% of farmers adopting AI solutions, largely driven by donor-supported agricultural projects, relatively strong extension service coverage, and higher farmer exposure to digital platforms. Southern Province follows closely at 35%, benefiting from its commercial farming base and early integration of digital advisory services. Central Province records 30%, reflecting moderate adoption supported by mixed smallholder and commercial activities.

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In contrast, Copperbelt Province (25%) and Northern Province (20%) show the lowest uptake. These figures reflect critical barriers, including limited ICT infrastructure, weaker extension networks, affordability constraints, and gaps in digital literacy. The data suggests that while progress has been made, adoption remains uneven and heavily shaped by the interplay of infrastructure, institutional support, and socio-economic conditions.

This pattern highlights the need for region-specific scaling strategies. Provinces with higher adoption could deepen integration into precision agriculture and AI-driven supply chain management, while lagging regions require targeted investment in connectivity, farmer training, and localized AI applications that address their unique challenges. Ensuring equitable access to AI tools is essential for bridging the digital divide, enhancing national food security, and promoting inclusive agricultural transformation.

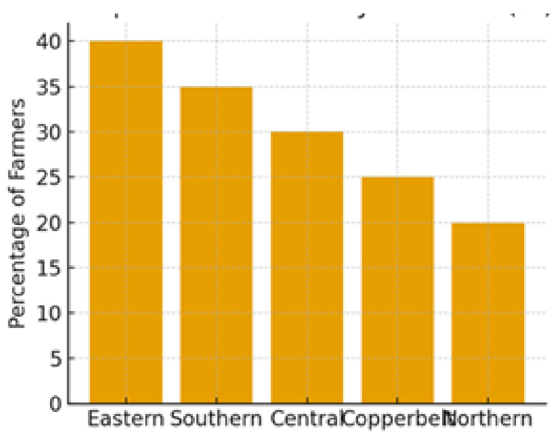

Fig. 2. Adoption of AI tools by province.

Fig. 3 presents maize yield trends in Zambia between 2015 and 2025, showing a general upward trajectory from 1.8 tons/ha in 2015 to 3.1 tons/ha by 2025. The data reveal steady gains through 2018, followed by a sharp decline in 2019, when yields dropped back to 1.9 tons/ha. This dip likely reflects climatic stress or pest outbreaks, underscoring the vulnerability of production to environmental shocks. Recovery is evident from 2020 onwards, with yields rising consistently and reaching 2.8 tons/ha by 2022 before experiencing another temporary dip in 2023. The strong rebound in 2024 and 2025 highlights the resilience of the sector and the cumulative impact of technological interventions.

The overall positive trend is closely linked to the gradual adoption of AI-driven innovations. Weather forecasting systems have enabled farmers to make better planting decisions, pest detection tools have reduced losses, and advisory services have improved farm-level responses to risks. These interventions demonstrate AI's potential to narrow yield gaps relative to global benchmarks [3], while also strengthening Zambia's food security. At the same time, the fluctuations remind us that technology must be complemented by climate adaptation strategies, reliable infrastructure, and farmer training. Sustained investment and equitable scaling of AI technologies across all provinces are therefore essential to secure long-term productivity gains and ensure that the benefits are inclusive.

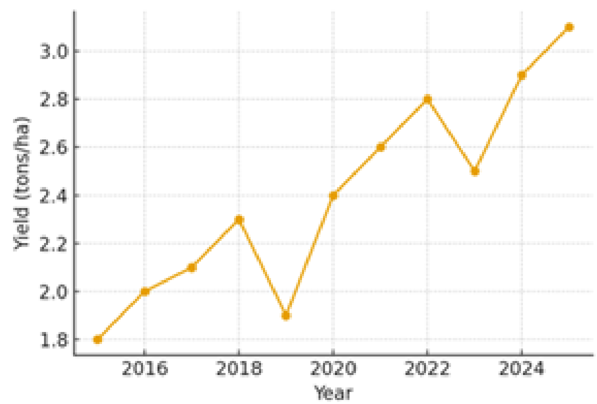

Fig. 3. Maize yield trends in Zambia (2015–2025).

Fig. 4 shows the distribution of farm sizes in Zambia, making clear that the country's agriculture is overwhelmingly dominated by smallholdings. The histogram indicates that the majority of farmers operate on plots of less than 2 hectares, with more than a dozen farmers concentrated in this category. As farm size increases, the frequency drops sharply: only a handful of farmers cultivate between 3 and 5 hectares, and very few manage farms larger than 6 hectares. At the far end of the spectrum, holdings above 8 hectares are rare exceptions. This steep decline underscores the structural imbalance in Zambia's agricultural sector, where most production comes from highly fragmented and resource-constrained plots.

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This distribution carries important implications. On the one hand, it highlights the central role of smallholders in national food production and rural livelihoods, given their dominance in numbers. On the other hand, it reveals systemic challenges: small plots constrain economies of scale, hinder mechanization, and limit farmers' ability to invest in irrigation, soil fertility management, and improved seed systems. These limitations make smallholders particularly vulnerable to climate shocks such as drought, erratic rainfall, and pest outbreaks. The observed skew also explains why Zambia continues to experience yield gaps compared to regional and global benchmarks.

At the same time, the concentration of small-scale farmers presents an opportunity for targeted interventions. Because such a large proportion of the population falls into this category, efforts aimed at improving smallholder resilience could have widespread national impact. AI-driven agricultural technologies can be especially transformative here. Localized weather forecasting systems can guide planting and harvesting decisions, pest surveillance platforms can provide early warnings against outbreaks like fall armyworm, and mobile-based advisory tools can deliver personalized recommendations on fertilizer use, irrigation, and market prices. These innovations are scalable at low cost and can be adapted to the realities of farmers working on less than 2 hectares.

Understanding this distribution is therefore critical for policymakers, researchers, and development partners. It reinforces the need for inclusive strategies that prioritize smallholders while avoiding a disproportionate focus on the few larger farms. By combining AI-enabled solutions with investments in rural infrastructure, extension services, and farmer training, Zambia can bridge productivity gaps, strengthen national food security, and ensure that agricultural transformation is both equitable and sustainable.

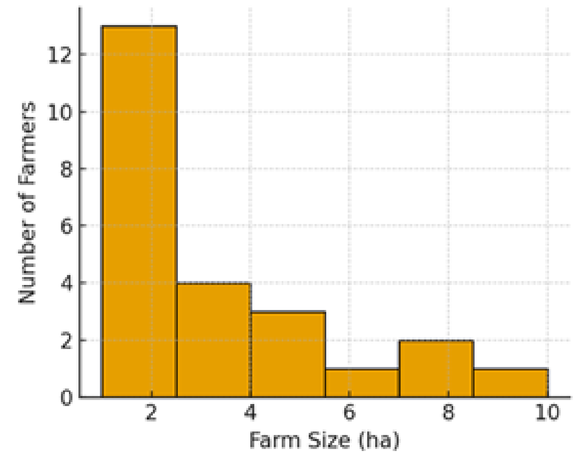

Fig. 4. Distribution of farm sizes in Zambia.

Fig. 5 plots rainfall against maize yields between 2015 and 2025, revealing a generally positive relationship where higher rainfall tends to support increased yields. For instance, yields rise from around 1.8 tons/ha under lower rainfall conditions (~800 mm) to over 3.0 tons/ha when rainfall approaches 970 mm. However, the scatter also highlights variability: at similar rainfall levels, yields fluctuate, suggesting that factors such as soil quality, pest pressure, and timing of rainfall events influence outcomes. Notably, excessive rainfall (above 950 mm) sometimes coincides with yield declines, reflecting the risks of flooding, nutrient leaching, or waterlogging. These dynamics emphasize the need for AI-based weather forecasting and adaptive planning tools to help farmers interpret rainfall variability and adjust practices accordingly. By modeling the complex correlations between rainfall and yield outcomes, predictive AI systems can support climate-smart agriculture, enhance resilience, and narrow productivity gaps.

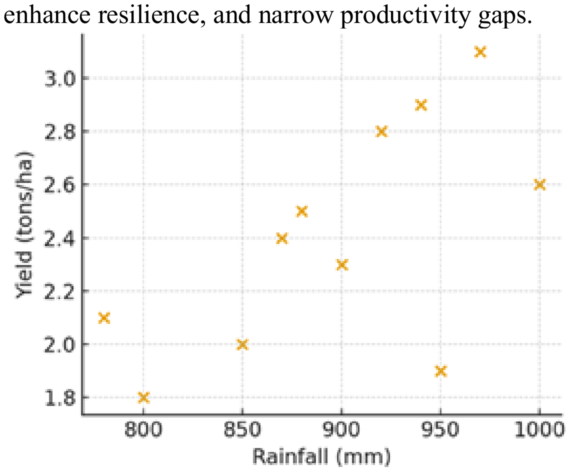

Fig. 5. Correlation between rainfall and maize yield (2015–2025).

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A. Discussion with Farmers

Discussions with farmers and extension officers revealed a complex mixture of optimism and caution regarding the role of AI in Zambian agriculture. On the one hand, many farmers expressed genuine enthusiasm about AI's potential to improve crop management, optimize resource allocation, and provide timely guidance that could protect them from severe losses due to pests, erratic rainfall, or market volatility. Extension officers also highlighted AI's value in complementing their work, particularly in reaching remote communities where traditional extension services are overstretched. They noted that tools such as mobile-based weather forecasts, pest surveillance applications, and AI-powered market advisories could significantly enhance decision-making at the farm level.

However, this optimism was tempered by skepticism related to cost, usability, and connectivity. Farmers raised concerns about the affordability of digital platforms and the sustainability of subscription-based services, particularly among smallholders whose incomes fluctuate seasonally. Usability was also highlighted as a barrier: while younger farmers appeared more open to experimenting with digital solutions, older farmers often struggled with smartphone interfaces or required additional training to feel confident in using such tools. This digital literacy divide underscores the need for tailored training programs that not only teach farmers how to use AI-enabled applications but also build trust in the accuracy and relevance of the information provided.

Infrastructure challenges emerged as another critical limitation. Many farmers reported difficulties due to poor or intermittent internet access, especially in rural provinces. Unreliable power supply for charging mobile devices further restricts consistent usage of digital tools. These barriers indicate that without complementary investment in rural ICT infrastructure, the adoption of AI may remain uneven and risk deepening regional inequalities, echoing wider global assessments of agricultural transformation challenges [3].

Despite these challenges, both farmers and extension officers consistently recognized the transformative potential of AI when appropriately adapted to local contexts. AI systems were seen as capable of reducing post-harvest losses through better pest control, optimizing the use of fertilizers and water, and supporting more resilient planting schedules aligned with changing climate patterns. Farmers also acknowledged that AI-driven advisory platforms could improve market access by providing real-time price information, thereby strengthening their bargaining power and reducing reliance on exploitative middlemen.

Policy-level discussions emphasized the importance of creating enabling conditions for AI adoption. Stakeholders pointed to the need for targeted subsidies or financial incentives that lower entry costs for smallholder farmers, alongside supportive regulatory frameworks that encourage innovation while safeguarding farmer autonomy and data privacy. There was broad consensus that government, private sector, and development partners must work collaboratively to design inclusive digital ecosystems that ensure benefits reach even the most marginalized farming communities.

Overall, the discussions reveal that while barriers exist—particularly around cost, literacy, and infrastructure—there is strong recognition of AI's ability to contribute to more efficient, resilient, and sustainable agriculture in Zambia. The challenge lies not in convincing farmers of the value of AI, but in addressing structural constraints and designing interventions that are accessible, affordable, and responsive to the realities of smallholder farmers.

B. Policy Action Required

To translate optimism into meaningful adoption, deliberate and coordinated policy action is required. First, *government agencies* should prioritize investment in rural ICT infrastructure, including reliable internet access and power supply, to create the basic conditions for digital agriculture. Subsidies or incentive schemes could be introduced to lower the costs of AI-enabled services and mobile applications, particularly for smallholder farmers who form the majority of Zambia's agricultural workforce. Furthermore, integrating AI training modules into existing agricultural extension programs would help bridge the digital literacy gap and ensure that farmers across different age groups can effectively use new tools.

Second, *ICTAZ and related professional bodies* should take a leading role in developing standards, ethical guidelines, and certification systems for AI applications in agriculture. This would not only safeguard farmers' autonomy and data privacy but also build trust in AI-driven recommendations by ensuring reliability and transparency. ICTAZ could also spearhead capacity-building initiatives, working with universities and technical colleges to train a new generation of AI specialists who can design, localize, and maintain these tools in ways that reflect Zambia's agricultural realities.

Third, the *private sector and agri-tech startups* should be encouraged through tax incentives, innovation grants, and public–private partnerships to scale up localized AI solutions. By tailoring tools to specific crops, regions, and farmer needs, private actors can complement public initiatives while creating sustainable business models. Development partners and donor organizations can further support this process by funding pilot projects that demonstrate the tangible benefits of AI adoption, thereby encouraging wider farmer buy-in.

Taken together, these strategies provide a roadmap for inclusive and equitable scaling of AI in Zambian agriculture. By addressing structural barriers, fostering collaboration between stakeholders, and ensuring that smallholders remain at the center of digital transformation, Zambia can harness AI not only to raise productivity but also to strengthen national food security, climate resilience, and rural livelihoods.

IV. Future Work

Future research and practice should focus on scaling AI adoption across provinces, integrating AI with Internet of Things (IoT) devices such as soil moisture sensors and drones. Developing localized AI models trained on Zambian datasets will be essential to improve accuracy and relevance. AI-powered market prediction tools can help stabilize crop prices and guide planting decisions. Furthermore, longitudinal studies should examine the socio-economic impacts of AI adoption on farmer livelihoods, food security, and climate resilience. Universities, government agencies, and industry actors should collaborate to establish innovation hubs dedicated to agricultural AI solutions.

V. Recommendations

A. Coordinated and Sustained Actions Required

For AI to realize its full potential in Zambia's agricultural sector, coordinated and sustained actions are required from multiple stakeholders. Building an enabling ecosystem for AI-driven transformation will demand investment, partnerships, and strong governance. The following recommendations are proposed:

Government investment in ICT infrastructure and incentives for AI startups:
The government should prioritize expanding rural connectivity through reliable internet access, mobile coverage, and electricity supply, which form the backbone of digital agriculture. Without these, AI adoption will remain confined to urban and peri-urban areas. In addition, financial incentives such as tax breaks, innovation funds, or low-interest loans should be introduced to support local AI startups. By lowering the cost of entry, these policies would stimulate innovation while ensuring solutions are tailored to Zambia's agricultural realities.

Universities and research institutions to drive applied AI research:
Academic institutions should prioritize applied research that develops AI models suited to local crops, soils, and climate conditions. Partnerships with industry can help bridge the gap between research outputs and practical deployment. For example, collaborative projects between universities, ICTAZ, and agri-tech companies could produce scalable solutions for pest detection, precision irrigation, or market forecasting. Furthermore, integrating AI into agricultural curricula will train the next generation of digital extension officers and data scientists.

Private sector promotion of affordable, farmer-centric solutions:

Companies developing AI tools should design products that are cost-effective, user-friendly, and accessible through devices already familiar to smallholder farmers, such as basic smartphones. Multilingual platforms and voice-enabled interfaces could help overcome literacy barriers, while flexible subscription models would ensure affordability. The private sector also has a role to play in developing inclusive business models that link farmers to value chains, ensuring AI tools not only improve yields but also enhance market access and income generation.

Strengthening farmers' cooperatives through capacity building and digital literacy:

Farmers' cooperatives should serve as key entry points for scaling digital literacy and AI adoption. By pooling resources, cooperatives can collectively access AI services, negotiate better pricing, and act as demonstration hubs for new technologies. Capacity-building programs should focus not only on technical skills but also on trust-building, showing farmers how AI-generated recommendations align with their lived experience. Such cooperative-led models can accelerate uptake and ensure that smallholders are not left behind in the digital transition.

Developing inclusive and protective policy frameworks:

National policies must ensure equitable access to AI technologies across provinces and socio-economic groups. Special attention should be given to marginalized communities and women farmers, who often face additional barriers to adoption. At the same time, frameworks must safeguard farmer autonomy and data sovereignty, avoiding overdependence on foreign technologies or proprietary systems that limit local innovation. Policies should encourage open standards and interoperability, enabling local developers to build on shared platforms and ensuring long-term sustainability.

B. Multi-stakeholder Approach

Together, these recommendations highlight the importance of a holistic, multi-stakeholder approach. If Zambia aligns government investment, academic innovation, private-sector engagement, and farmer empowerment under a clear policy framework, AI has the potential to become a cornerstone of agricultural transformation—raising productivity, reducing vulnerabilities, and contributing to national food security and rural development.

VI. Conclusion

This study demonstrates that Artificial Intelligence (AI) holds significant potential to transform Zambia's agriculture by tackling long-standing challenges such as low productivity, climate variability, and limited technological adoption. Field surveys and statistical analysis confirm that AI tools can enhance yields, improve weather prediction, detect pests and diseases early, and optimize the use of critical inputs like fertilizers and water. These technologies not only increase efficiency but also strengthen farmers' resilience against climate shocks and market fluctuations, pointing to AI's role as a catalyst for sustainable agricultural growth.

However, adoption remains constrained by structural barriers. Digital illiteracy, particularly among older farmers, limits the effective use of AI platforms, while affordability challenges make many solutions inaccessible to smallholders. Infrastructure gaps—including unreliable electricity and poor internet connectivity in rural areas—further hinder widespread use. These findings emphasize that AI cannot be viewed in isolation but must be embedded within broader systems of training, infrastructure investment, and inclusive policy frameworks that address the realities of Zambia's diverse farming communities.

The predominance of smallholder farmers, though challenging due to small plot sizes and vulnerability to risks, also presents the greatest opportunity for scaling AI. By tailoring affordable, user-friendly solutions to smallholder needs, Zambia can close yield gaps, promote crop diversification, and strengthen national food security. With appropriate policy support, targeted investments, and collaborative innovation involving government, universities, ICTAZ, private sector actors, and farmer cooperatives, the country can accelerate its transition toward AI-driven sustainable agriculture. In doing so, Zambia has the potential to emerge as a regional leader in harnessing digital technologies for agricultural development in Southern Africa, contributing to global food security priorities [3].

References

[1] World Bank, "Zambia Economic Brief: Agriculture and Rural Development," Washington, D.C., 2021.

[2] IFAD, "Rural Development Report 2021: Transforming Food Systems," International Fund for Agricultural Development, Rome, 2021.

[3] FAO, "The State of Food and Agriculture 2022," Food and Agriculture Organization, Rome, 2022.

[4] S. Singh et al., "AI-driven irrigation management in India," Computers and Electronics in Agriculture, vol. 175, pp. 105–115, 2020.

[5] L. Silva et al., "Satellite imaging and AI for soybean yield prediction in Brazil," Remote Sensing, vol. 12, no. 18, pp. 2950–2962, 2020.

[6] FarmDrive, "AI for Credit Scoring in Kenya," Nairobi, 2020.

[7] A. Akinola, "AI-based climate services for Nigerian agriculture," Climate Services, vol. 18, pp. 100–112, 2020.

[8] J. Egan, T. Frindt, J. Mbale, "Open Educational Resources and the Opportunities for Expanding Open and Distance Learning (OERS-ODL)," International Journal of Emerging Technologies in Learning, 8(2).

[9] S. Chihana, J. Mbale, N. Chaamwe, "Leveraging Machine Learning for Ambient Air Pollutant Prediction: The Zambian Mining Environment Context," Proceedings of International Conference for ICT (ICICT)-Zambia 4(1), 1-5.

[10] T. K. Mufeti, J. Mbale, N. Suresh, "The effect of distributing electronic notes to students: Ethical considerations raised by computer science faculty at The University of Namibia," Journal of Information Systems Education, 22(3), 225-232.