LEVERAGING ARTIFICIAL INTELLIGENCE (AI) AND EARTH OBSERVATION DATA IN EARLY WARNING SYSTEMS FOR PEST CONTROL AND MANAGEMENT IN KENYA

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The African Technology Policy Studies Network (ATPS) is a transdisciplinarynetwork of researchers, policymakers, private sector actors and the civil society promoting the generation, dissemination, use and mastery of Science, Technology and Innovations (STI) for African development, environmental sustainability and global inclusion. In collaboration with like−minded institutions, ATPS provides platforms for regional and international research and knowledge sharing in order to build Africa's capabilities in STI policy research, policymaking and implementation for sustainable development.

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About the Project

Africa’s rapidly growing population, projected to reach 2.6 billion by 2050, posed significant challenges for agricultural and food systems. To meet the increased demand for food, production needed to rise by up to 70%. However, resource scarcity, climate change, the impact of the COVID−19 pandemic, and socioeconomic hardships made this a daunting task. Recognizing these challenges, the initiative focused on leveraging emerging technologies, particularly artificial intelligence (AI), to transform Africa’s agricultural and food systems.

The project successfully advanced the responsible development, deployment, and scaling of AI research and innovations tailored to address Africa’s agricultural challenges. A key achievement of the initiative was the establishment and management of the AI for Agriculture and Food Systems (AI4AFS) research network, which comprised ten innovation research projects. These projects focused on creating and implementing homegrown AI solutions that were tested, deployed, and scaled to meet Africa’s specific agricultural needs.

The initiative deepened the understanding of how AI can be responsibly developed and scaled for sustainable agriculture in Africa. By building the capacity of African researchers and innovators, the project equipped them to create and apply AI solutions that had a tangible impact on agriculture and food systems. Moreover, the project contributed to shaping both African and international AI policy and practice by sharing valuable insights gained through research and innovation.

Throughout the project, several key activities were carried out, including issuing calls for Expressions of Interest (EOI), conducting training workshops for preselected consortia, and engaging with selected grantees. The project was overseen by the Hub Management Committee (HMC), which worked closely with a Hub Advisory Team (HAT) of experts to ensure strategic guidance and support. A robust Monitoring, Evaluation, and Learning (MEL) framework was implemented to track progress and ensure that the project remained on course. The initiative also fostered networking and collaboration through platforms for knowledge exchange, with quality assurance mechanisms in place to ensure transparency and credibility at every stage.

As a result of the project, African researchers and innovators were empowered with enhanced research infrastructure and a conducive environment to lead in AI for

Agriculture and Food Systems (AI4AFS). The research network was strengthened, generating new AI research and innovations that tackled pressing agricultural challenges in Africa. Additionally, the project contributed to the development of more inclusive policies and strategies that supported transformative change in AI for agriculture and food systems, based on the needs of African societies.

This initiative was part of the larger Artificial Intelligence for Development Africa (AI4D Africa) program, which was co−funded by Canada's International Development Research Centre (IDRC) and the Swedish International Development Agency (Sida). AI4D Africa aimed to create a future where Africans across all regions use AI to lead healthier, happier, and greener lives. Through this completed project, the mission to promote responsible AI innovation, improve quality of life, and drive sustainable development in Africa was successfully realized.

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Key Messages:

- Poorly managed pest and disease control practices in Kenya's horticulture industry have resulted in an overreliance on agrochemicals, which significantly contributes to unsustainable crop productivity and compromises environmental health.

- Leveraging advanced technologies for early warning and management of pest occurrences, such as Geographic Information Systems (GIS), remote sensing, and Artificial Intelligence (AI), significantly improves the prediction and management of pest threats, protecting crops and enhancing food security. Investment in Geospatial Artificial Intelligence (GeoAI) based early warning systems is necessary for comprehensive and effective long-term agricultural solutions in Kenya.

- Artificial Intelligence (AI) in pest detection has resulted in a reduction in crop losses due to pests in various regions. The adoption of earth observation data has also led to improvements in the effectiveness of pest management strategies. These solutions are, therefore, paramount for the implementation of Integrated Pest Management (IPM) to achieve sustainable crop productivity and environmental protection in the horticulture industry.

1. Introduction

Agriculture in Kenya faces many challenges as the country's population is projected to reach 95.4 million by 2050 (UN, 2017). The projected worldwide 2050 population increase will necessitate a concurrent 70% increase in food production (FAO, 2009). The central goals of agriculture and food systems in Kenya focus on enhancing agricultural productivity, ensuring food security, and promoting sustainable farming practices (MoALFC, 2019). The use of nascent technologies, such as Artificial Intelligence (AI) and Earth observation data, is increasingly supporting these goals and objectives of Kenya's agriculture and food system.

There are significant impacts of AI and Earth observation data application in pest control. For instance, the use of AI in pest detection could reduce the quantity of pesticide usage and support more sustainable farming practices (Kariyanna & Sowjanya, 2024; Thenmozhi & Srinivasulu Reddy, 2019). Additionally, Earth observation data has also been important in monitoring and predicting pest outbreaks, which has resulted in enhanced pest management (Kariyanna & Sowjanya, 2024). In particular, deep learning models have been remarkably effective in the detection and early management of *Tuta absoluta* occurrence in tomato plants. In past studies, these models have achieved 70 to 90% accuracy in detecting the extent and severity of pest infestations (Giakoumoglou et al., 2023; Şahin et al., 2023). By combining these technologies, farmers can get timely alerts and suggestions for potential interventions, significantly decreasing their dependence on chemical pesticides and fostering sustainable agricultural practices.

Stakeholders' participation is crucial for the inclusive adoption of AI in agriculture. It enhances the relevance and applicability of AI solutions to specific agricultural communities. By involving farmers, agronomists, policymakers, and other stakeholders in the development and implementation process, AI technologies can be tailored to effectively address real-world challenges. The involvement of stakeholders helps build trust and acceptance of new technologies, which is essential for overcoming resistance to change and ensuring widespread adoption. For instance, farmers are more likely to trust AI tools if they understand how these tools work and see their direct benefits, leading to a more significant impact on agricultural productivity and sustainability (FAO, 2019)

Moreover, stakeholder participation promotes inclusivity and equity by ensuring that AI solutions cater to the needs of marginalised groups, such as smallholder farmers, women, and youth. This strategy helps to close the gaps on existing inequalities and encourages wider socio-economic advantages (HLPE-FSN, 2023). Furthermore, stakeholders bring essential local insights that improve the quality and relevance of data, leading to more precise AI-driven predictions and recommendations. Engaging stakeholders also promotes skill development through customised training programs, that ensure that all user groups can effectively utilise AI tools. This engagement aids in establishing supportive policy and regulatory frameworks that align with the objectives of sustainable agricultural development (OECD, 2019; World Bank, 2012).

This policy brief seeks to promote the application of Earth observation data and AI in early warning systems for pest control and management, thus ultimately improving integrated pest management (IPM) practices.

2. Rationale for the development and adoption of AI in Agriculture

Horticulture, the largest agricultural subsector in Kenya, represents 33% of the 24% of agriculture contribution to the country’s GDP and has been critical for food security, nutrition, income, employment, and foreign exchange (Kang'ethe et al., 2019). Tomatoes are a vital crop within this subsector, making up 14% of vegetable production and 6.7% of horticultural crops (CBK, 2022). These contributions underline the importance of horticulture and specific crops like tomatoes to Kenya's economy and the well-being of its population. Developing and adopting AI and Earth observation data tools is critical for addressing key challenges in Kenya's agricultural food system. These tools help solve specific challenges, such as pest control and management. AI and Earth observation data are fundamental in the development of early warning systems, enabling farmers to take preventive measures before infestations cause severe damage. AI models predict pest outbreaks based on environmental conditions and historical data (Bütüner et al., 2023; Giakoumoglou et al., 2023). This integration of technology significantly mitigates crop losses due to pests and reduces the reliance on chemical pesticides. Stakeholders must tackle several issues to ensure the success of early warning systems for pest control and management. They need to ensure data integration and accessibility, making AI and Earth observation data available to farmers. This involves investment in data infrastructure and training. Additionally, developing reliable AI models that provide timely and accurate pest outbreak predictions is essential. Stakeholders should also foster collaboration among various entities and create supportive policy and regulatory frameworks to facilitate the adoption of these technologies (OECD, 2019; World Bank, 2012).

3. Methodology

The development of the Pest Monitoring and Surveillance Tool (PeMOST), which leverages AI and Earth observation data to provide early warnings for pest control and management, began with an extensive comparison of satellite-derived land surface temperature data with field measurements to validate the influence of temperature on the occurrence of *Tuta absoluta*. Field data was collected daily from demonstration plots between November and December 2022. The field data was then compared with satellite Land Surface Temperature (LST) information obtained from a combination of Landsat 8 and MODIS data. An initial comparison of satellite-derived temperature data and field measurements revealed a strong correlation (R^2 = 0.987), confirming that satellite data could reliably predict temperature variations. Further data analysis demonstrated a clear relationship between a temperature range of 25 - 30° C and the widespread occurrence of *Tuta absoluta* adults. Following this validation, a collaborative workshop was held to discuss the field survey results and guide the development of PeMOST. After development, the tool was made available online as an Android-based app, showcasing its capabilities in predicting pest occurrences based on temperature data.

A key component of PeMOST was the development of its various comprehensive databases. During the workshop, stakeholders identified essential databases that included information on tomato crop varieties, crop growth stages, cultural practices, biological practices, and pest profiles. These databases were curated to ensure they provided relevant and context-specific data to support the tool's algorithm, ultimately enhancing the tool's ability to offer accurate and timely recommendations.

The tool's predictive ability was further strengthened through the development of various algorithms, such as LST and Machine Learning (ML) algorithms. The PeMOST's LST algorithm processes satellite data extracted from the Sentinel Hub environment. This data is then used by the ML algorithm to predict the occurrence of *Tuta absoluta*. These predictive algorithms enable PeMOST to provide early warning alerts, which helps farmers and agricultural stakeholders mitigate pest-related risks

Gender inclusivity was a major consideration in the development PeMOST tool by actively involving both men and women in its implementation, data collection, and farmer engagement, ensuring diverse perspectives and equitable benefits in pest management practices. This approach fostered a balanced representation and addressed the specific needs of all farmers, enhancing the tool's overall effectiveness and impact.

Overall, PeMOST represents a robust tool and collaborative effort to leverage satellite data and AI algorithms for effective pest management. By focusing on temperature-based predictions, the tool offers a significant advantage in enhancing agricultural practices and mitigating the risks posed by pests like *Tuta absoluta*. Furthermore, the use of tools such as the PeMOST would increase the adoption of AI and Earth observation for pest control and management. Agricultural food systems are more sustainable through pest early warning systems that enhance integrated pest management while enabling environmental protection. Figure 1 showcases the PeMOST tool workflow.

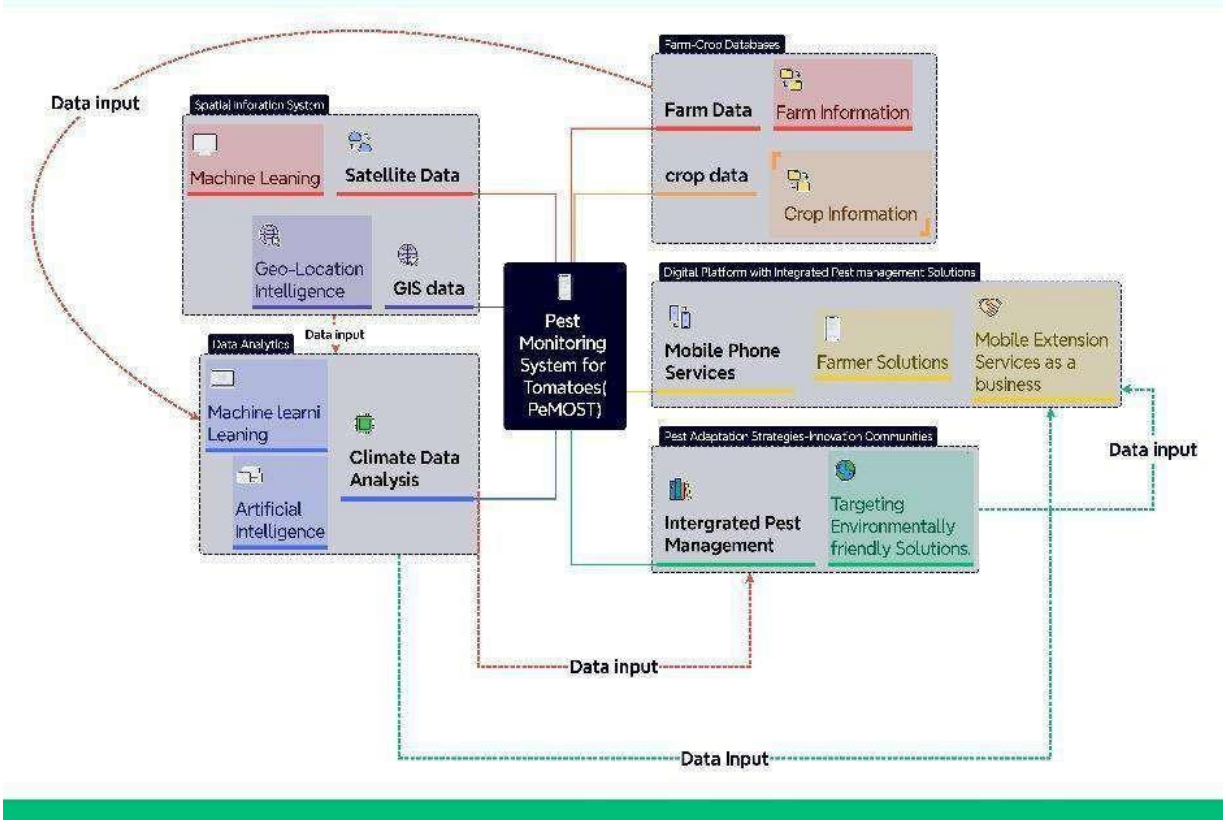

Figure 1 PeMOST tool workflow

4. Major Findings

This research project revealed that *Tuta absoluta*—a highly destructive pest known as the tomato leaf miner—poses a severe threat to tomato cultivation in Machakos County. The pest's infestation leads to extensive damage to tomato crops, resulting in yield losses exceeding 75% (Mumo et al., 2024). Such significant losses have far-reaching consequences on multiple fronts. Firstly, the reduction in tomato yields directly threatens food security in the region, as tomatoes are a staple crop and a vital source of nutrition for many households. Secondly, the loss of crops impacts job creation, particularly in rural areas where tomato farming provides employment for many people, including farm labourers, transporters, and market vendors. Lastly, the income generation potential for farmers and associated stakeholders is severely diminished, as the lower yields translate into reduced marketable produce and, consequently, lower earnings.

The compounded effect of these losses not only strains the economic stability of farming communities but also exacerbates poverty and limits opportunities for economic growth within the region. This highlights the urgent need for effective integrated pest management strategies to mitigate the impact of *Tuta absoluta* and safeguard the livelihoods dependent on tomato farming in Machakos County.

It was realised that the effectiveness of remote sensing and GIS data, enhanced through AI, plays a pivotal role in monitoring pest occurrences and understanding the environmental conditions that favour such infestations. The PeMOST tool exemplifies this by integrating these advanced technologies into a comprehensive, web-based, and mobile-friendly platform. Designed specifically for early warning and pest management, PeMOST utilizes earth observation data, particularly land surface temperature (LST), to monitor and predict the presence of pests like *Tuta absoluta*.

The tool employs a combination of sequential models and downscaling/upscaling techniques to process satellite-derived LST data, delivering precise daily updates on temperature conditions across various agricultural zones. This real-time data is crucial because *Tuta absoluta* thrives in specific temperature ranges, and understanding these conditions allows for accurate predictions of pest occurrences. PeMOST's integration of GIS data further enhances its capabilities by mapping the spatial distribution of pest outbreaks, helping to pinpoint affected farms with precision. The use of AI within the platform allows for the continuous learning and improvement of pest prediction models, ensuring that the alerts and recommendations provided to farmers are both timely and accurate. This leads to more informed decision-making, ultimately contributing to the reduction of crop losses and the promotion of sustainable agricultural practices.

5. Conclusion and Implications

AI and Earth observation increases productivity or potential by certain amount (reference field data), environmental protection through reduced use of pesticides. The PeMoST tool is one of the avenues to upscale the utilization of AI and Earth observation for pest control and management. The integration of AI and Earth observation tools in Kenya's agricultural sector presents a transformative opportunity to enhance productivity, food security, and sustainable practices. By providing precise data for pest control and resource optimization, these technologies address key challenges in the agriculture food system. To realize these benefits, stakeholders must ensure data integration and accessibility, develop accurate predictive models, and foster collaboration. Policymakers should create supportive frameworks, while research institutions and NGOs should focus on capacity building and training for farmers. This collaborative approach will drive the successful adoption and impact of AI and Earth observation technologies in agriculture.

6. Policy Recommendations

Recommendation 1: Invest in GeoAI early warning systems is necessary for more comprehensive and effective long term agricultural solutions in Kenya: Poorly managed pest and disease control practices in Kenya's horticulture industry have led to an overreliance on pesticides, negatively impacting sustainable crop productivity and environmental health. To address this issue, the adoption and scaling of advanced technologies like GIS, remote sensing, and AI for early pest warnings and integrated pest management must happen now, other than later. These technologies can be integrated into existing agricultural practices to enable real-time pest monitoring and early warning systems. Training and capacity-building programs should be provided to farmers and agricultural stakeholders to ensure effective use of these tools. Additionally, funding from both government and private sectors should be allocated to support the development and deployment of GeoAI-based pest management solutions. Partnerships with research institutions are essential for continuously improving and adapting these technologies to local contexts. Leveraging these advanced technologies will enhance the prediction and control of pest threats, protect crops, and promote sustainable agricultural practices, thereby reducing the environmental impact of excessive pesticide use.

Recommendation 2: Strengthen Farmer Capacity in Sustainable Pest Management through advanced technologies is necessary for high adoption GeoAI solutions in Kenya: The horticulture industry in Kenya is plagued by rampant abuse of pesticides as a consequence of a lack of information and training on environmentally responsible methods of pest management. In order to effectively address this problem, it is essential for the ministry of agriculture and livestock development to create comprehensive training and capacity-building programs for agricultural stakeholders and farmers. These programs should encourage the use of environmentally responsible pest control strategies that make use of latest technological advancements such as artificial intelligence (AI), GIS and remote sensing. Through the partnership with institutions to incorporate advanced pest management techniques into agricultural curriculum, the engagement of agricultural extension services to provide continuous assistance and mentorship to farmers will go a long way towards improving the adoption of the skill that farmers require for integrated pest management (IPM).

Recommendation 3: Expand access to GeoAI-Based Pest Management Solutions is necessary for improvement in the effectiveness of pest management: The ability of smallholder farmers in Kenya to effectively manage pest threats has been restricted by the limited access they have to modern pest management technology such as GeoAI. In order to ensure that these technologies are broadly accepted, economical, and user-friendly, The Ministry of Agriculture and Livestock Development must strengthen the capacity of extension workers to expand access to geo-assisted artificial intelligence (GeoAI-based) pest control solutions for smallholder farmers across Kenya. Providing smallholder farmers with a subsidy on the cost of GeoAI-based tools and services, developing mobile applications that are user-friendly and provide real-time pest alerts and management recommendations, and partnering with telecommunication companies to improve digital infrastructure in rural areas in order to enable better access to these technologies are all ways in which this can be accomplished. In addition, the introduction of awareness campaigns that educate farmers about the advantages of employing GeoAI for pest management will result in an increase in the availability of these technologies.

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