Scientific Innovation Magazine
ISSN : 2584-1157

Drones as Tools for Sustainable and Climate-Resilient Agriculture

Amina S S[1]*and Punitham M[1]
[1]PG Scholar, Department of Agricultural Extension and Rural Sociology,
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu
*Correspondence e-mail address: aaminahsalim786@gmail.com

Introduction

Agriculture has entered a new era driven by technological innovation and the pressing need for climate resilience. With erratic monsoons, rising temperatures and declining soil fertility, farmers across India face the dual challenge of producing more food while safeguarding natural resources. In this context, drones also known as Unmanned Aerial Vehicles (UAVs), have emerged as powerful tools for sustainable and climate-smart farming. Once seen as tools of military surveillance or entertainment, drones are now central to precision agriculture, soil health, pest incidence and optimization of inputs like fertilizers and pesticides. Their high-resolution imaging and real-time data collection allow for targeted interventions, reducing resource waste and minimizing environmental harm (Olson & Anderson, 2021). They are enabling farmers, extension agents and researchers to make faster, smarter and more sustainable decisions. As the Food and Agriculture Organization notes, drones are "Redefining the landscape of agricultural management by combining aerial imaging, data analytics and automation for sustainability". (FAO & ITU, 2018)

Why Drones Matter for Climate-Resilient Agriculture

Climate change has made agriculture increasingly unpredictable. Extreme weather events such as droughts, floods and cyclones are becoming more frequent. Crop losses, pest outbreaks and soil degradation are common consequences.

Drones can serve as an early warning and decision-support tool in this scenario. By providing accurate and up-to-date information, they help:

- Identify crop stress due to water scarcity or disease.

- Optimize input use to reduce emissions and costs.
- Assess post-disaster crop damage for faster recovery.
- Facilitate evidence-based policy decisions for adaptation and insurance.
- Implement site-specific management practices that conserve water and maintain soil health.

In smallholder and large-scale farms alike, drones facilitate efficient resource allocation and help build resilience against climate-related risks (Gokool *et al.,* 2023; Loures *et al*., 2020).

Thus, drones play a vital role in shifting agriculture from reactive to proactive climate management.

Key Applications of Drones in Sustainable Farming

1. Precision Crop Monitoring

Drones equipped with multispectral, hyperspectral and thermal sensors can detect even slight variations in crop health. The images they capture are analyzed to generate Normalized Difference Vegetation Index (NDVI) maps, which indicate plant vigour, chlorophyll content and stress.

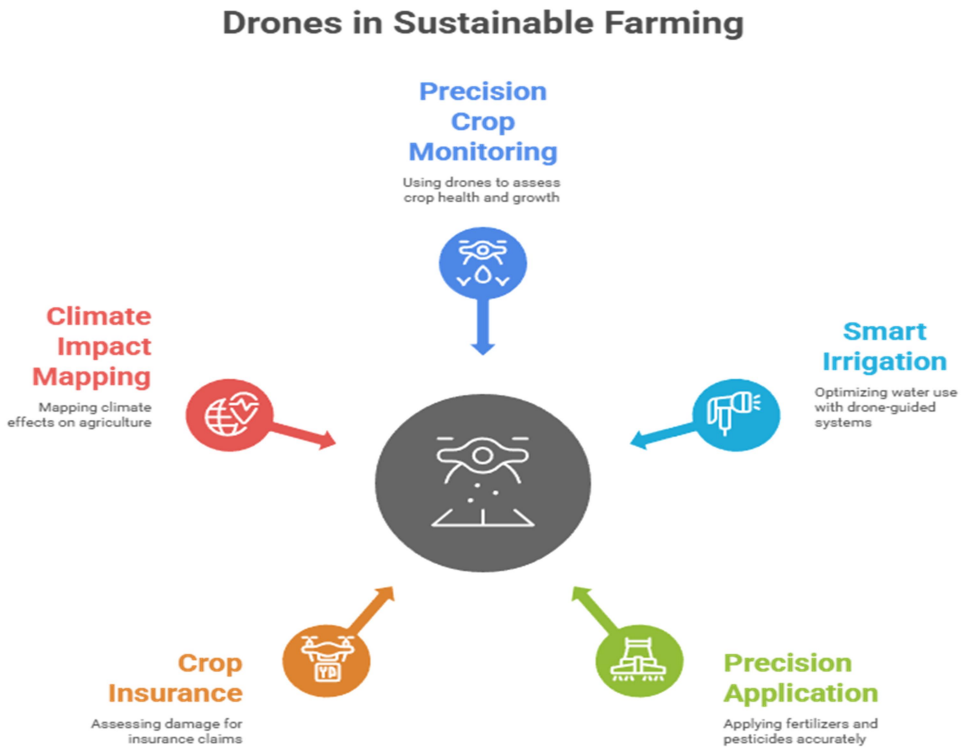
2. Smart Irrigation and Water Use Efficiency

In drought-prone regions such as Tamil Nadu's Coimbatore and Salem districts, drone-based thermal imaging has helped identify areas with low soil moisture. Smart irrigation systems use real-time data from drones, IoT sensors and artificial intelligence to deliver water accurately based on crop needs, reducing waste and improving productivity. Drones fitted with multispectral, thermal and RGB sensors track crop hydration, soil moisture levels and environmental factors, allowing for variable rate irrigation (VRI) and quick identification of water stress (Yadav *et al*., 2024; Sharma *et al*., 2025).

3. Precision Fertilizer and Pesticide Application

Traditional blanket application of fertilizers and pesticides leads to wastage, pollution and soil health deterioration. Drones fitted with spray nozzles and variable rate applicators deliver

inputs only where needed.



4. Crop Insurance and Damage Assessment

Drone imagery provides geo-tagged, time-stamped evidence for crop loss assessments, making insurance processes faster and more transparent. This is particularly useful under the Pradhan Mantri Fasal Bima Yojana (PMFBY), where drones are being piloted for loss estimation (MoA&FW, 2022)

5. Post-Disaster and Climate Impact Mapping

Post-disaster and climate impact mapping is a key function of drones, as they can quickly capture high-resolution images of affected areas. Drones provide real-time data for assessing damage to infrastructure, crops and natural resources. They help identify vulnerable zones and prioritize relief and recovery operations efficiently. Thus, drones play a vital role in rapid

response, disaster management and climate resilience planning.

Socio-Economic Benefits of Drone Adoption

Beyond their technical applications, drones generate broader socio-economic benefits:

Cost Reduction:

Optimized use of fertilizers, pesticides and water reduces operational costs and increases profit margins. Drone adoption has led to a 6% reduction in per-acre cultivation costs, with technical improvements contributing to over half of the observed output variation (Saranya *et al.,* 2024).

Labour Efficiency: In areas facing labour shortages, drones reduce drudgery and dependence on manual labour.

Rural Entrepreneurship: Trained youth can start drone service businesses, offering spraying, mapping and advisory services to small farmers.

Knowledge Empowerment: Drone imagery helps farmers visualize their farm conditions, making extension advice more practical and evidence-based.

Gender Inclusion: Women farmers engaged in farm management benefit from data-driven decisions without the need for heavy manual work.

Drones and Environmental Sustainability Drones contribute to environmental sustainability by reducing:

Chemical Load: Targeted spraying prevents chemical drift and contamination.

Water Use: Drone-based irrigation management minimizes water wastage.

Carbon Emissions: Optimized field operations reduce energy use in machinery and transport.

Land Degradation:

Soil mapping enables site-specific nutrient management, improving long-term soil fertility. In short, drones support the goals of Sustainable Development Goal (SDG) 2, Zero Hunger and SDG 13, Climate Action, through improved agricultural efficiency and resilience.

Challenges in Drone-Based Agriculture

Despite their immense potential, drone applications face several challenges:

High Initial Cost:

Commercial agricultural drones range from ₹3 to ₹10 lakh, making them unaffordable for many smallholder farmers. While high-resolution satellite imagery remains expensive, UAV imagery is becoming increasingly cost-effective, making it a more accessible tool for precision agriculture (Manfreda et al., 2018).

Lack of Technical Skills:

Many farmers need training to interpret aerial data and operate drones safely. Limited technical knowledge and insufficient training programs remain major barriers to effective drone use among smallholder farmers. Field research highlights the need for accessible and continuous capacity-building initiatives to ensure that farmers can fully leverage drone technology for sustainable agriculture (Prabhu *et al*. 2021).

Regulatory Barriers:

Permissions for flying drones under DGCA (Directorate General of Civil Aviation) rules can be complex.

Connectivity and Infrastructure:

Reliable internet and data processing facilities are needed for real-time analytics.

Data Privacy:

Secure handling of aerial data must be ensured to protect farmers' information. These challenges underline the importance of extension and policy interventions to promote equitable and responsible drone adoption. They reported that data ownership and privacy concerns remain unresolved, particularly regarding aerial imagery and geospatial data collected on private farms (Westbrooke *et al*. 2023).

Role of Agricultural Extension and Policy Support

Agricultural extension systems play a crucial role in bridging the gap between technology and farmers. The following strategies can accelerate drone adoption sustainably.

Capacity Building:

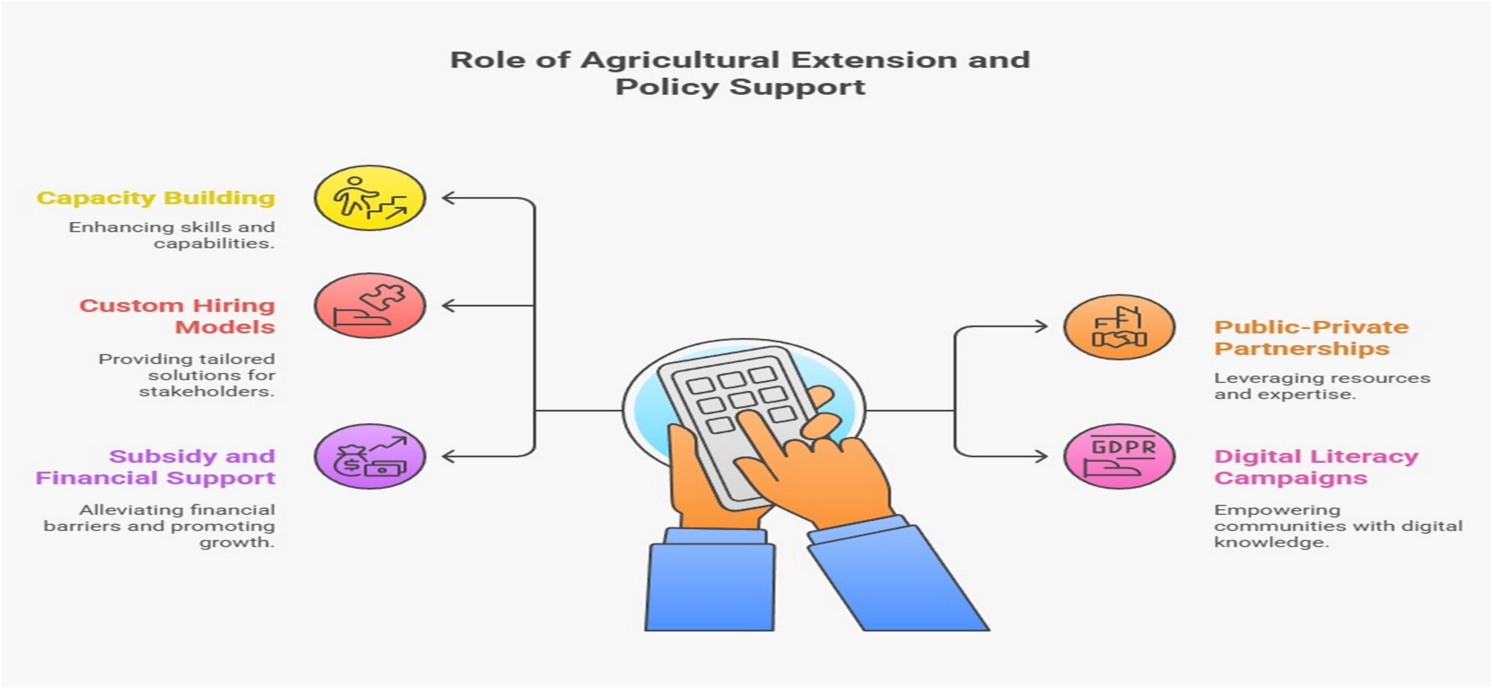
Scientific Innovation Magazine
ISSN : 2584-1157

Organizing hands-on training programs for farmers, youth and extension officers on drone operation and data use is essential. Agricultural extension services play a pivotal role in bridging the knowledge gap between advanced drone technology and traditional farming practices. Research has demonstrated that structured training programs significantly enhance farmers' ability to utilize precision agriculture tools effectively (Mogili & Deepak, 2018).

Public–Private Partnerships:

Encouraging collaborations between universities, startups and government agencies is crucial for accelerating drone adoption in agriculture. In India, the collaboration between state agricultural departments and drone manufacturers has resulted in demonstration projects across 100+ districts, showcasing practical applications in pest management and crop monitoring (Sharma *et al.*, 2020). These partnerships reduce individual investment risks while ensuring quality service delivery**.**

Custom Hiring Models: Promoting cooperative ownership and rental services for small farmers.



Digital Literacy Campaigns:

Helping farmers interpret aerial images and integrate them with traditional knowledge is vital for successful drone adoption. Mass awareness campaigns utilising radio, television and social media have proven effective in changing farmers' perceptions about agricultural technology. Research from extension programs in Southeast Asia shows that multi-channel communication strategies reach 75% more farmers than single-medium approaches (Fabregas *et al.,* 2019).

Subsidy and Financial Support:

Providing incentives through schemes like Sub-Mission on Agricultural Mechanization (SMAM) and PM-Kisan for drone-based operations is essential to promote large-scale adoption. Government subsidy schemes in several countries now offer 40–50% capital subsidies on drone purchases for registered farmers, with enhanced rates for women farmers and marginalized communities (Balafoutis et al., 2017). These interventions have catalyzed rapid growth in agricultural drone deployment.

Conclusion

As Indian agriculture moves toward the vision of "Digital and Climate-Smart Farming", drones are emerging as key enablers of sustainability. They empower farmers with precise, actionable data, helping them adapt to climate variability, conserve resources and increase profitability. With strong institutional support, skill development and inclusive policies, drones can become more than tools they can become partners in resilience. In the coming decade, the fields of India may witness not only green crops but also green technologies in the sky, symbolizing a new era of smart, sustainable and climate-resilient agriculture.

References

- Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., Wal, T. V. d., Soto, I., Gómez-Barbero, M., Barnes, A., & Eory, V. (2017). Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics. *Sustainability*, *9*(8), 1339. https://doi.org/10.3390/su9081339.

- Fabregas, R., Kremer, M., & Schilbach, F. (2019). Realizing the potential of digital development: The case of agricultural advice. *Science*, *366*(6471), eaay3038. https://doi.org/10.1126/science.aay3038
- Food and Agriculture Organization of the United Nations (FAO), & International Telecommunication Union (ITU). (2018). *E-agriculture in action: Drones for agriculture*. FAO. https://www.fao.org/family-farming/detail/en/c/1200079
- Gokool, S., Mahomed, M., Kunz, R., Clulow, A., Sibanda, M., Naiken, V., Chetty, K., & Mabhaudhi, T. (2023). Crop Monitoring in Smallholder Farms Using Unmanned Aerial Vehicles to Facilitate Precision Agriculture Practices: A Scoping Review and Bibliometric Analysis. *Sustainability*. https://doi.org/10.3390/su15043557
- Loures, L., Chamizo, A., Ferreira, P., Loures, A., Castanho, R., & Panagopoulos, T. (2020). Assessing the Effectiveness of Precision Agriculture Management Systems in Mediterranean Small Farms. *Sustainability*. https://doi.org/10.3390/su12093765
- Manfreda, S., McCabe, M. F., Miller, P. E., Lucas, R., Pajuelo Madrigal, V., Mallinis, G., Ben Dor, E., Helman, D., Estes, L., Ciraolo, G., Müllerová, J., Tauro, F., De Lima, M. I., De Lima, J. L. M. P., Maltese, A., Frances, F., Caylor, K., Kohv, M., Perks, M., ... Toth, B. (2018). On the Use of Unmanned Aerial Systems for Environmental Monitoring. *Remote Sensing*, *10*(4), 641. https://doi.org/10.3390/rs10040641
- Ministry of Agriculture and Farmers Welfare (MoA&FW). (2022). Guidelines for drone usage in agriculture under the Digital Agriculture Mission (2021–2025). Government of India
- Mogili, U. R., & Deepak, B. B. B. V. L. (2018). Review on application of drone systems in precision agriculture. *Procedia Computer Science*, *133*, 502-509. https://doi.org/10.1016/j.procs.2018.07.063
- Olson, D., & Anderson, J. (2021, March 1). Review on unmanned aerial vehicles, remote sensors, imagery processing and their applications in agriculture. *Agronomy Journal*. John Wiley and Sons Inc. https://doi.org/10.1002/agj2.20595

- Prabhu, S. S., Kumar, A. V., Murugesan, R., Saha, J., & Dasgupta, I. (2021). Adoption of precision agriculture by detecting and spraying herbicide using UAV. *Basrah Journal of Agricultural Sciences*, *34*, 21-33
- Saranya, S., et al. (2024). *Technical adoption and output variance in paddy cultivation using drones. Journal of Agricultural Technology and Innovation, 12*(3), 145–158.
- Sharma, A., Jain, A., Gupta, P., & Chowdary, V. (2020). Machine learning applications for precision agriculture: A comprehensive review. *IEEE Access*, *9*, 4843-4873. https://doi.org/10.1109/ACCESS.2020.3048415
- Sharma, H., Sidhu, H., & Bhowmik, A. (2025). Remote Sensing Using Unmanned Aerial Vehicles for Water Stress Detection: A Review Focusing on Specialty Crops. *Drones*. https://doi.org/10.3390/drones9040241
- Westbrooke, V., Lucock, X., & Greenhalgh, I. (2023). Drone Use in On-Farm Environmental Compliance: An Investigation of Regulators' Perspectives. *Sustainability*, *15*(3), 2153. https://doi.org/10.3390/su15032153
- Yadav, M., Vashisht, B., Vullaganti, N., Kumar, P., Jalota, S., Kumar, A., & Kaushik, P. (2024). UAV-enabled approaches for irrigation scheduling and water body characterization. *Agricultural Water Management*. https://doi.org/10.1016/j.agwat.2024.109091