Policy Paper

Enhancing Agricultural Productivity among Smallholder Farmers in India through Agricultural Drone Services

भाकृअनुप - राष्ट्रीय जैविक स्ट्रैस प्रबंधन संस्थान, रायपुर, छत्तीसगढ़

ICAR-National Institute Of Biotic Stress Management, Raipur, Chhattisgarh

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CONTENTS

1. INTRODUCTION

Agriculture stands as the cornerstone of India's economy, supporting the livelihoods of millions of small and marginal farmers. According to the 10th agriculture census (2015–2016), smallholder and marginal farmers, who own less than two hectares of land, constitute 86.2% of all farmers but possess only 47.3% of the arable land. In contrast, semi-medium and medium landholding farmers, owning between 2 and 10 hectares of land, account for 13.2% of all farmers but possess 43.6% of the crop area (Agriculture Census, 2015-16). This disparity, affecting close to 140 million smallholder and marginal farmers, poses significant challenges for government extension services to provide them with the necessary technologies and support.

Conventional modern farming, rooted in green revolution principles, has shown limited effectiveness in diverse smallholder Indian agroecologies. Smallholder farmers often confront obstacles such as limited access to modern technology and resources, resulting in low productivity. One technology with the potential to transform agriculture is drone technology. Drones, or unmanned aerial vehicles (UAVs), offer a range of agricultural applications, including precision farming, crop monitoring, pest control, crop surveying, and spraying.

During the COVID-19 pandemic, drones proved invaluable in addressing challenges such as labor shortages and locust infestations in crop fields. Their speed and capabilities reduce the workload for farmers, making them a critical tool for meeting the escalating demands of future agriculture. This policy brief assesses the efficacy of agricultural drone services among smallholder farmers in India and offers recommendations for policymakers to promote their adoption.

2. CURRENT SCENARIO

India has a large population of smallholder farmers who own less than 2 hectares of land. These farmers often lack access to modern agricultural machinery and rely on traditional farming methods. The use of drones in agriculture is still in its nascent stages in India, with limited adoption among small farmers. However, there is a growing interest in using drones for agricultural purposes due to their ability to provide real-time data and improve productivity.

One of the key elements of precision agriculture is monitoring crop health, which involves tasks such as irrigation, fertilization, pesticide application and timely harvesting. Monitoring the progressive changes in growth and development is crucial for making informed decisions to maintain crop health. Drones are extremely useful for on-site detection of problems, allowing for immediate corrective measures. While building algorithms and establishing relationships between ground truth and spectral signatures can be expensive, once the basic studies are completed, drone technology becomes user-friendly. In regions like India, where labor and technical expertise are limited, drones are gaining popularity in smart farming.

Insect pests are a significant threat to global food grain production, causing catastrophic losses. According to FAO, pests and diseases are responsible for over 37% of predicted losses. In India, invasive pests like the fall armyworm in corn and the rugose spiraling whitefly in coconut have caused extensive damage in recent years. Community-based plant protection measures are essential for effective pest management. However, managing invasive pests is challenging in India, where more than 80% of farmland is small or marginal (<1 ha). Pests can easily shift to neighboring fields if one field is sprayed, making drones essential for targeted pest management.

Drones, which are Unmanned Aerial Vehicles (UAVs), have been used in various fields such as defense, monitoring systems, and disaster

management. In agriculture, drones are beginning to be utilized and can be classified into fixed-wing, multi-rotor and hybrid types, depending on the application. The operational parameters of drones, such as flight speed, height, and endurance, need to be optimized for agricultural use. Parameters related to drone-based spraying, such as droplet size, spread, density, uniformity, deposition, and penetrability, should also be considered when implementing drone-based mitigation strategies. According to a 2023 report by NITI Aayog, only about 1% of farmers in India have access to drone services. Comparatively, in China, over 10 million hectares are covered annually using UAV-based spraying services.

Despite its potential, the adoption of drone technology for pest management is limited. Regulatory guidelines have been established worldwide to enable site-specific farm management with higher precision. Drones can be used in almost all agricultural operations and are considered excellent tools for rapid, reliable, and non-destructive detection of field problems.

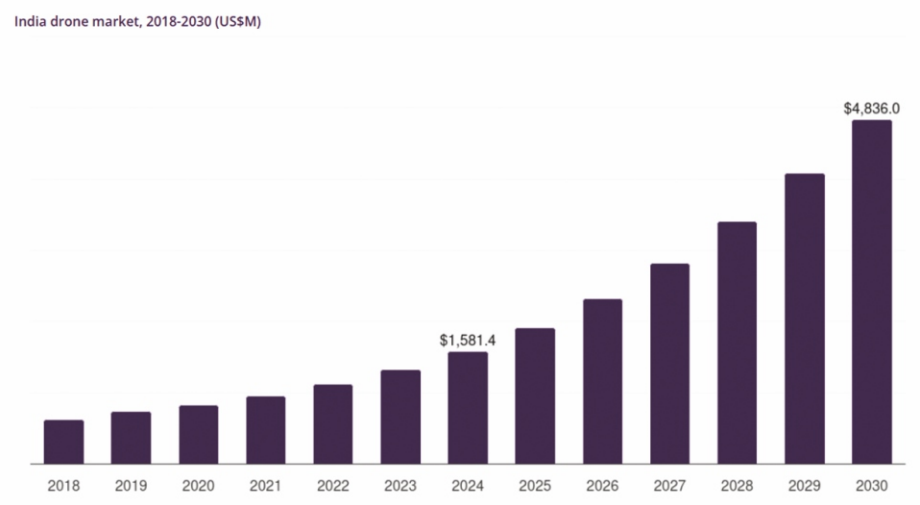
India Drone Market Size & Outlook, 2024-2030

The drone market in India is expected to reach a projected revenue of US$ 4,835.9 million by 2030. A compound annual growth rate of 20.4% is expected of India drone market from 2025 to 2030. Registering a compound annual growth rate (CAGR) of 20.4% from 2025 to 2030. In 2024, the Indian drone market generated USD 1,581.5 million in revenue, indicating strong momentum in the sector. Among the market components, hardware emerged as the largest revenue-generating segment in 2024, highlighting significant investments in drone equipment and infrastructure. However, the services segment is poised to be the fastest-growing, driven by increasing demand for drone-based solutions in agriculture, logistics, surveillance, and mapping.

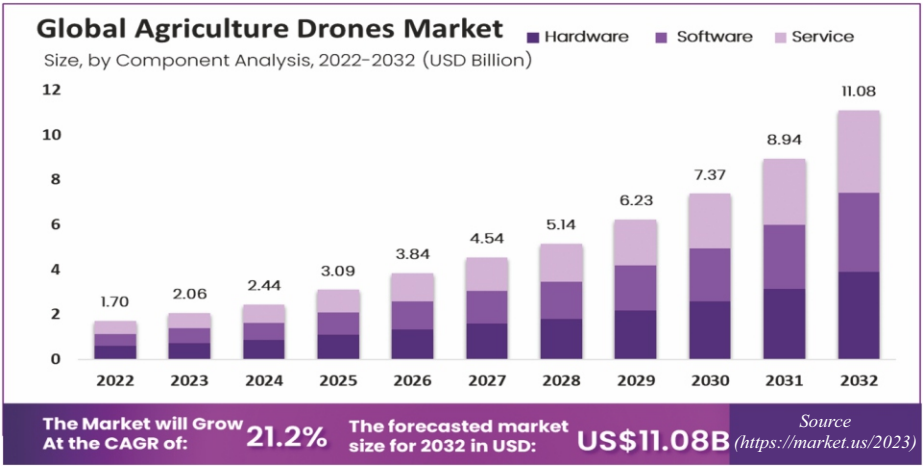
The market is segmented into hardware, software, and services, with hardware currently leading and services rapidly expanding due to the

integration of drones in various value-added applications. The historical data covers the period from 2018 to 2023, with 2024 as the base year and forecasts extending through 2030. Revenue is measured in USD million, providing a quantitative benchmark for market performance.

Globally, India accounted for 2.2% of the total drone market revenue in 2024. The United States is expected to remain the global leader in drone revenue by 2030, while China will continue to dominate the Asia-Pacific regional market. Notably, India is the fastest-growing drone market within the Asia-Pacific region, underlining its increasing technological adoption and policy support. Major international players influencing the global drone ecosystem include DJI, 3D Robotics, AgEagle Aerial Systems Inc., Airware, Autel Robotics, Mapbox, Parrot Drones, Pix4D, Skydio, Teledyne Technologies Inc., and Yuneec, many of which have or are likely to establish a stronger presence in the Indian market in the coming years.



Source: Grand View Research, 2025



Regional trends in agricultural drone adoption across Indian states

Indian State	Key Crops and Focus Areas	Notable Initiatives and Features	Drone Adoption Level
Telangana	Paddy, cotton, pulses	Major pilot projects, research hubs, and 90% of national SOPs	Very high
Maharashtra	Sugarcane, cotton, horticulture	'Namo Drone Didi' scheme, rural SHG outreach, startup partnerships	Very high
Andhra Pradesh	Paddy, cotton, horticulture	Large-scale distribution to CHCs, early adopters	High
Punjab	Rice, wheat, sugarcane	Precision spraying, partnerships with manufacturers and FPOs	High
Haryana	Rice, wheat, sugarcane	Government incentives, precision spraying	High
Tamil Nadu	Rice, cotton	State-run programs, SOP contributions, research support	High
Uttar Pradesh	Sugarcane, wheat	Custom hiring centers, rising adoption in major crop belts	High
Madhya Pradesh	Wheat, soybean	Government projects, CHC-based adoption	Moderate-High
Karnataka	Ragi, maize, horticulture	State collaboration with manufacturers, farmer training	Moderate
Gujarat	Cotton, groundnut, horticulture	State pilot projects, growing private sector involvement	Moderate
Odisha	Paddy, pulses, horticulture	Bank loan support, pilot projects	Moderate
Rajasthan	Wheat, mustard, pulses	Kisan Drone centers, government subsidies	Moderate
Kerala	Spices, rubber, coconut	Pilot projects, limited but growing adoption	Low-Moderate
Chhattisgarh	Rice, pulses	Government-supported demonstrations, CHCs	Low-Moderate
Bihar	Rice, wheat, maize	Emerging adoption, government pilot programs	Low-Moderate
Uttarakhand	Wheat, rice, fruits	Demonstrations, training programs	Low
West Bengal	Rice, jute, vegetables	Pilot projects, limited drone use	Low
Assam and NE States	Rice, tea, horticulture	Early-stage, sporadic pilots, limited infrastructure	Very low

(Source: Singh, R., Singh, S. A, 2025, https://doi.org/10.3390/s25154876)

3. INITIATIVES OF GOVERNMENT OF INDIA IN THE PROMOTION OF DRONE TECHNOLOGY AMONG SMALLHOLDER FARMERS

To promote the use of drone technology in agriculture, the Sub-Mission on Agricultural Mechanization (SMAM) guidelines, administered by the Department of Agriculture and Farmers Welfare (DA&FW), have introduced the following measures:

Financial support is provided for the purchase of drones:

- Institutes under the Indian Council of Agricultural Research, Krishi Vigyan Kendras (KVKs), State Agriculture Universities (SAUs), State and Central Government Agricultural Institutions/Departments, and Public Sector Undertakings (PSUs) of the Government of India engaged in agricultural activities can receive 100% financial assistance, up to Rs. 10 lakhs per drone.
- Farmers Producers Organizations (FPOs) can receive grants of up to 75% of the drone's cost for demonstrations in farmers' fields.
- Implementing agencies opting not to purchase drones can receive a contingency expenditure of Rs. 6000 per hectare for hiring drones from Custom Hiring Centres, Hi-tech Hubs, Drone Manufacturers, and Start-Ups for demonstrations. For agencies purchasing drones, the contingent expenditure is limited to Rs. 3000 per hectare.
- The Government of India has sanctioned the Central Sector Scheme '*Namo Drone Didi* ' under the DAY-NRLM framework, with a total allocation of ₹1,261 crores. The scheme targets the deployment of drones to 14,500 selected women-led Self-Help Groups (SHGs) during 2024–2026, enabling them to offer drone-based agricultural rental services to farmers.

- The *Namo Drone Didi* initiative supports women's Self Help Groups by offering 80% Central Financial Assistance (up to ₹8 lakhs) for drone purchases. Remaining costs can be financed via National Agriculture Infra Financing Facility (AIF) loans, with a 3% interest subvention, easing financial pressure and encouraging drone adoption among women-led Self Help Groups.

Financial assistance is provided for the establishment of Custom Hiring Centers:

- Custom Hiring Centers under the Cooperative Society of Farmers, FPOs, and Rural entrepreneurs can receive financial aid of 40%, up to Rs. 4.00 lakhs, for the purchase of drones.
- Agriculture graduates establishing Custom Hiring Centers are eligible for financial assistance of 50% of the drone's cost, up to Rs. 5.00 lakhs per drone.

Financial assistance for individual farmers:

- Small and Marginal, Scheduled Caste/Scheduled Tribe, Women, and farmers from North Eastern States can receive financial assistance of 50% of the drone's cost, up to Rs. 5.00 lakhs.
- Other farmers can receive financial assistance of 40% of the drone's cost, up to Rs. 4.00 lakhs.

The DA&FW has issued Standard Operating Procedures (SOPs) for safe and effective drone operations in pesticide and nutrient application in agriculture. All drone operations in the country are regulated by the Drone (Amendment) Rules, 2022, notified by the Ministry of Civil Aviation (MoCA). The Central Insecticides Board & Registration Committee (CIB&RC) has prescribed guidelines/protocols for pesticide registration requirements for drone application and finalized test protocols for phyto-toxicity and bio-efficacy evaluation of pesticide formulations.

4. POLICY FRAMEWORK IN INDIA

Drones have the potential to revolutionize Indian agriculture by enhancing productivity, reducing costs, and improving sustainability. However, the integration of drones into agriculture requires a well-defined policy framework that addresses issues related to regulations, safety, data privacy, and technology adoption. The following

Current Regulatory Landscape:

India has established a regulatory framework for drone operations through the Directorate General of Civil Aviation (DGCA) and the Ministry of Civil Aviation (MoCA). Key aspects of the current regulatory landscape include:

- **Drone Categories:** Drones are categorized based on their weight and intended use (e.g., nano, micro, small, medium, large). Different categories have varying operational restrictions and requirements.
- **Digital Sky Platform:** The Digital Sky platform is an online portal for registering drones and obtaining permission for their operations. Users must comply with no-fly zones, flight altitude limits, and other safety guidelines.
- **Remote Pilot License (RPL):** Operators require an RPL to fly drones, which necessitates training and certification.
- **Data Privacy:** Data collected by drones, especially in agriculture, may raise concerns related to data privacy, protection, and ownership.

Challenges in the Policy framework:

- **Complexity and Lack of Awareness:** The current regulatory framework is complex and often misunderstood, leading to barriers in drone adoption, particularly among farmers and small-scale users.

- **Restrictive Regulations:** Some regulations, such as no-fly zones, altitude restrictions, and the requirement for an RPL, can limit the utility of drones in agriculture.
- **Data Privacy Concerns:** There is a lack of clarity regarding the ownership and use of data collected by drones, raising privacy concerns among stakeholders.
- **Lack of Training Infrastructure:** Availability of training facilities and resources for obtaining an RPL is limited, hindering skill development.

Recommendations for better use of Drones:

To foster the responsible and effective use of drones in Indian agriculture, the following recommendations are proposed:

- **Simplify Regulations:** Streamline and simplify the regulatory framework, making it more accessible and comprehensible for farmers. This could involve revisiting altitude restrictions, reducing the burden of RPL requirements for agricultural use, and creating a farmer-friendly version of the Digital Sky platform.
- **Promote Awareness:** Launch awareness campaigns and training programs to educate farmers and rural communities about the benefits and responsible use of drones in agriculture. This includes familiarizing them with the regulatory framework, data privacy, and safe drone operation.
- **Data Governance:** Develop clear guidelines on data ownership, sharing, and privacy in agriculture. Encourage the use of secure and standardized data handling practices to ensure data privacy and security.
- **Research and Development:** Invest in research and development

to create cost-effective, India-specific drone solutions for agriculture. Support innovation and the development of customized drone applications.

- **Skill Development:** Establish more training centers and infrastructure for drone pilot training, making it accessible and affordable, particularly in rural areas. Encourage institutions to offer courses in precision agriculture and drone technology.

- **Collaboration:** Foster collaboration between government bodies, the private sector, and agricultural research institutions to promote the development and adoption of drone technology in agriculture.

The use of drones in Indian agriculture holds great promise, but to harness their potential, a more accessible regulatory framework, awareness campaigns, and data governance are essential. By implementing these recommendations and collaborating with stakeholders, Indian agriculture can benefit from the advantages that drones offer, contributing to increased agricultural productivity and sustainability.

Guidelines for drone application in agriculture:

The additional guidelines for providing agricultural services through drone technology under Sub-Mission on Agricultural Mechanization (SMAM) has been released by Mechanization & Technology Division of Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India on 17th January, 2022 (For further reading https://farmech.dac.gov.in/revised/2022/OM_for_Drone_Guidelines_underSMAM.pdf).

Standard operating procedures (SOPs) for use of drones:

The Government of India has brought Standard Operating Procedures (SOPs) for use of drones in pesticide and nutrient applications that provide concise instructions for effective and safe operations of drones. The detail guidelines are available at (https://farmech.gov.in/New_Folder/SOPforDrone.pdf).

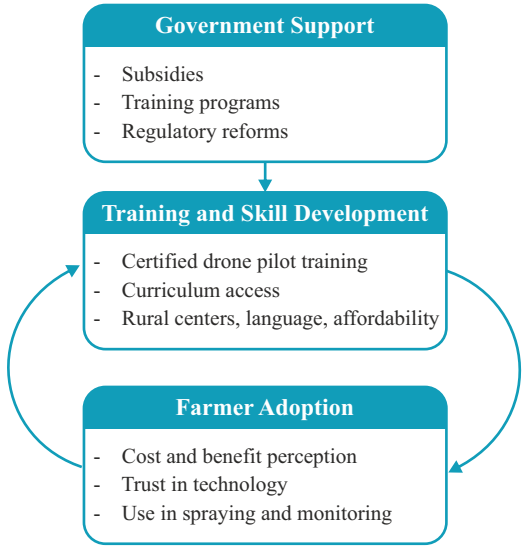


Fig. 1: Conceptual framework illustrating the interaction between government policies, farmer adoption, and training in the agricultural drone ecosystem in India.

5. COMPREHENSIVE SWOT ANALYSIS OF AGRICULTURAL DRONE USE IN INDIA

This integrated SWOT analysis combines macro-level (policy and technology) and micro-level (farmer-centric) perspectives to holistically evaluate the potential and limitations of drone use in Indian agriculture.

Strengths

- **Precision and Efficiency:** Drones enable precise application of inputs like pesticides and fertilizers, reducing wastage and improving yields. They can cover large areas swiftly, saving time and labor—especially critical during labor shortages (Maja & Francis, 2016; Nukala *et al.*, 2016).
- **Real-Time Monitoring and Data Collection:** Drones provide instant data on crop health, soil conditions, and environmental changes, allowing farmers and agronomists to make timely decisions and interventions (Rajinder Singh & Sandeep Singh, 2018).
- **Cost Reduction and Resource Optimization:** By minimizing input usage and manual labor, drones contribute to lower production costs and enhance profitability for smallholder farmers (Puri *et al.*, 2017).
- **Environmental Benefits:** Precision in application reduces excess use of agrochemicals, minimizing environmental degradation and promoting more sustainable farming practices.

Weaknesses

- **High Initial Investment:** The cost of purchasing and maintaining drones remains prohibitive for many small and marginal farmers, limiting widespread adoption (Mahesh *et al.*, 2015).

- **Skill and Knowledge Gaps:** Successful drone use requires technical skills in operation, maintenance, and data analysis—skills often lacking in rural areas (Anupam Barik *et al.*, 2020).
- **Regulatory Complexity:** Evolving and often restrictive drone regulations can hinder access, especially among smallholder farmers unfamiliar with legal compliance requirements (Khandelwal, 2018).
- **Potential Environmental Misuse:** Improper or excessive use of drones—especially for chemical spraying—can harm non-target organisms and reduce biodiversity (Venugopalan *et al.*, 2019).
- **Data Governance Challenges:** Inadequate frameworks for data security and ownership raise concerns about the misuse of sensitive agricultural data.

Opportunities

- **Biotic Stress and Pest Management:** Drones offer targeted pest and disease detection and mitigation, leading to reduced crop losses and higher productivity (Mishra *et al.*, 2017).
- **Data-Driven Agriculture:** Drone-generated data can be used for AI-powered analytics, improving crop planning, yield forecasting, and input management (Abhijit *et al.*, 2019).
- **Smallholder Empowerment:** With appropriate service models, drones can bridge the technology gap for small and marginal farmers, democratizing access to precision agriculture (Fountas *et al.*, 2005).
- **Innovation and R&D:** India's dynamic tech ecosystem and policy push under 'Atmanirbhar Bharat' open new avenues for localized R&D and development of affordable, India-specific drone solutions (Sundmaeker *et al.*, 2016).

Threats

- **Privacy and Ethical Concerns:** As drone data becomes granular and geo-referenced, issues of farmer privacy and data misuse could pose legal and ethical risks (Pooja & Singh, 2020).
- **Weather Vulnerability:** Indian climatic conditions—particularly high winds, rainfall, and extreme heat—can restrict drone usability and effectiveness (Anupam Barik *et al.*, 2020).
- **Market Saturation and Service Quality:** Increased competition among drone service providers could lead to uneven quality and pricing, particularly in underserved rural markets (Acharya *et al.*, 2021).
- **Regulatory Instability:** Constant policy shifts or unclear guidelines can deter long-term investments by drone startups and service aggregators (Bhat & Bhat, 2021).
- **Alternative Technologies:** In some regions, traditional farming methods may still be more economically viable, especially where infrastructure and digital literacy are lacking.

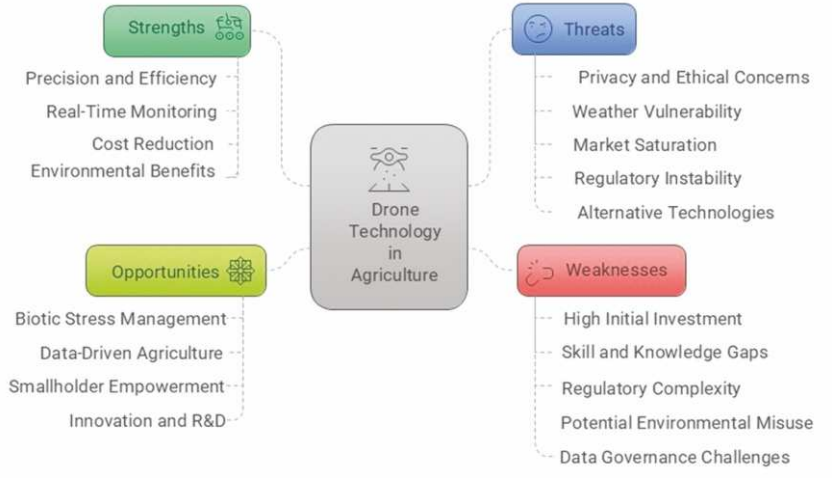


Fig. 2: SWOT Analysis of Drone Technology in Agriculture
(Authors' self conceptualisation)

This unified SWOT analysis provides an integrated lens for understanding both the systemic potential and ground-level realities of deploying drone technology in Indian agriculture. Policymakers, entrepreneurs, and farmers must collaborate to mitigate weaknesses and threats while leveraging strengths and opportunities for inclusive, tech-driven agricultural transformation.

ICAR-NIBSM organised drone demonstrations to smallholder farmers

6. APPLICATIONS OF DRONES IN AGRICULTURE

The advent of drone technology has dramatically changed modern agricultural practices, offering farmers innovative tools for crop and livestock management. This section explores the various uses of drones in agriculture and highlights their benefits.

Crop Monitoring

Drones equipped with high-resolution cameras and multispectral sensors enable comprehensive crop monitoring by capturing detailed aerial imagery. These images provide valuable insights into plant health, growth patterns, and field conditions. Early detection of issues such as pest infestations, nutrient deficiencies, and water stress is made possible through this technology, allowing for timely and precise interventions that can mitigate potential losses.

Precision Agriculture

A core component of modern farming, precision agriculture benefits significantly from drone technology. By analysing aerial data, farmers can make informed decisions regarding the application of fertilizers, pesticides, and irrigation. This site-specific management approach minimizes resource wastage and environmental impact while maximizing crop yields. The accuracy and efficiency provided by drones contribute to more sustainable and profitable agricultural practices.

Soil Analysis

Pre-planting soil analysis is another area where drones play a crucial role. By capturing data on soil composition, texture and moisture levels, drones aid in determining the suitability of land for specific crops. This information supports decisions related to crop selection and soil amendment strategies, ultimately enhancing soil fertility and crop performance.

Livestock Monitoring

Beyond crop management, drones offer significant advantages in the monitoring of livestock. Equipped with thermal imaging and video surveillance capabilities, drones provide real-time data on animal location, movement, and behaviour. This facilitates efficient herd management, improves animal welfare, and reduces the labour and time traditionally required for manual observation.

Irrigation Management

Effective water management is critical in agriculture, particularly in regions prone to water scarcity. Drones contribute to irrigation efficiency by detecting spatial variations in soil moisture through thermal imaging. This allows for the precise adjustment of irrigation schedules, ensuring that water is applied only where and when it is needed. Such practices conserve water, reduce costs, and promote uniform crop development.

Fig. 3: Applications of Drones in Agriculture
(Authors' self-conceptualisation)

7. COMPARATIVE ANALYSIS OF DIFFERENT SPRAYING METHODS WITH DRONE

A comparative analysis of different spraying methods with drones involves evaluating how drone-based spraying compares with traditional and alternative spraying methods in agriculture, horticulture or farm forestry.

Efficiency:

Drone spraying is significantly faster, completing 1 acre in just 10 minutes, compared to 90 minutes with a tractor and 180 minutes with a knapsack sprayer. This time-saving capacity allows farmers to cover larger areas within shorter windows, especially critical during pest outbreaks.

Water Usage:

Drones use only 10–20 liters of water per acre, representing a 90% reduction compared to traditional methods. This makes drone spraying ideal for regions facing water scarcity or aiming for sustainable practices.

Energy Source:

While knapsack and tractor methods rely on manual labor and fossil fuels, drones operate on rechargeable batteries, offering a cleaner, more eco-friendly alternative.

Pesticide Efficiency:

With a lower pesticide usage of 30–50 ml/liter, drones reduce chemical input, minimizing environmental contamination and potential harm to non-target organisms, while still ensuring effective crop protection.

Physical Strain:

The required break time for drone operators is just 3–5 minutes, indicating reduced physical labor. In contrast, manual spraying necessitates longer breaks due to its strenuous nature, raising concerns about operator fatigue

and long-term health impacts.

Table 1. Comparative analysis of spraying methods for 1 acre of agricultural land

S. No.	Parameter	Knapsack Spraying	Tractor Spraying	Drone Spraying
1	Time Required (minutes)	180	90	10
2	Water Consumption (liters/acre)	200	200–300	10–20
3	Fuel Usage	5 liters (manual effort)	10 liters (diesel)	Battery operated (electric)
4	Pesticide Application (ml/liter)	100	75	30–50
5	Rest/Break Duration (minutes/acre)	30–45	15–20	3–5

Source: Jaffar Sadiq Ali. A and G. Srinivasan (2024)

8. PROJECTED MILESTONES FOR DRONE INTEGRATION IN INDIAN AGRICULTURE (2025–2030)

Capacity Building and Infrastructure Development

By 2025, the Indian government aims to train 10,000 certified drone pilots, primarily targeting youth and women in rural areas. Concurrently, 5,000 Custom Hiring Centres (CHCs) are to be equipped with agricultural drones. This dual-pronged approach is designed to create a skilled workforce and ensure last-mile availability of drone services for small and marginal farmers. The CHCs will act as key infrastructure hubs enabling farmers to access drone-based services for crop monitoring, spraying, and data collection without owning the equipment.

Integration with Agricultural Institutions

The second phase focuses on institutional integration, with drone services being operationalized in 50 Krishi Vigyan Kendras (KVKs) and 500 Farmer Producer Organizations (FPOs). The number of KVKs and FPOs needs to be increased for better outcomes. These institutions will serve as demonstration and dissemination nodes for drone technologies, promoting large-scale adoption through farmer training, field trials, and awareness campaigns. This also aligns with public-private partnership models where FPOs act as service providers, helping farmers adopt precision agriculture tools.

Digitization of Crop Insurance Assessments

By 2027, it is targeted that 20% of claims under the *Pradhan Mantri Fasal Bima Yojana* (PMFBY), India's flagship crop insurance scheme will be assessed using drone-captured imagery and geospatial analytics. This marks a significant shift toward evidence-based, time-efficient, and objective crop loss assessments, reducing disputes and expediting compensation. The integration of AI-based image processing will enhance

the accuracy of yield estimation and damage classification.

Expansion of Precision Farming

An estimated 2 million hectares of farmland are expected to be managed using drone-aided precision agriculture techniques by 2028. This includes variable-rate application of inputs (e.g., fertilizers and pesticides) early detection of pest and disease outbreaks, and real-time crop health monitoring. The emphasis is on improving input efficiency, yield optimization, and environmental sustainability. The large-scale adoption of these practices represents a pivotal transition from traditional to data-driven agriculture.

Global Competitiveness in Drone Technology

By 2030, India aspires to become a net exporter of agricultural drones and analytics software, leveraging its growing domestic ecosystem of drone startups, R&D institutions, and manufacturing capabilities. This milestone reflects a strategic vision of technological self-reliance (Atmanirbhar Bharat) and leadership in the global agri-tech market. It also implies the standardization of Indian-made drones to international quality and compliance benchmarks, fostering cross-border collaborations.

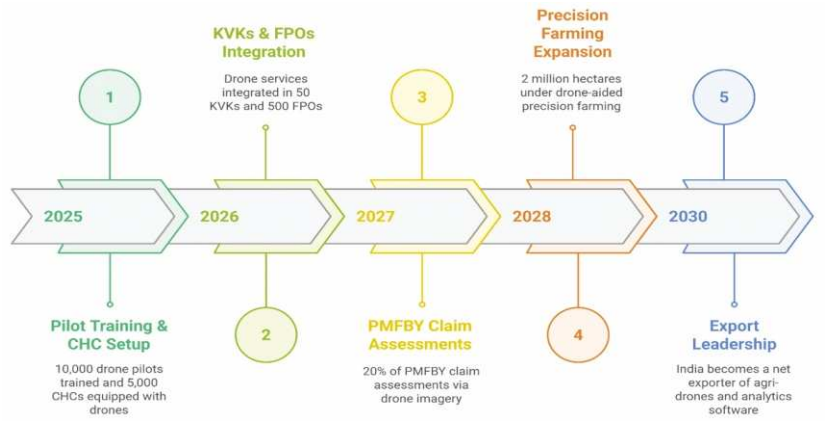


Fig. 4: Key Milestones in Drone Technology for Agriculture in India (Authors' self-Conceptualisation)

These recommendations aim to create an enabling environment for the effective and sustainable use of drones among smallholder farmers in India, ultimately contributing to improved agricultural productivity, food security, and rural livelihoods. Agricultural drone technology has the potential to significantly improve the efficiency and productivity of small farmers in India. However, several challenges need to be addressed to promote its widespread adoption. By implementing the recommended policies, policymakers can support small farmers in harnessing the benefits of drone technology and contribute to the overall growth and sustainability of the agriculture sector in India.

Capacity building programmes for smallholder farmers
for effective utilisation of drone services

9. POLICY RECOMMENDATIONS FOR BETTER USE OF DRONES AMONG SMALLHOLDER FARMERS IN INDIA

To support the widespread adoption and effective utilization of drones among smallholder farmers in India, a series of policy recommendations are proposed under the thematic pillar of Financial Support and Market Enablement.

Financial Assistance & Affordability

- Provide subsidies and grants to make drone services accessible for smallholder farmers.
- Support both direct ownership and community-based hiring models.
- Tailor support schemes specifically for marginal, tribal, and women farmers.

Risk Mitigation through Insurance

- Introduce insurance coverage for drones, including: damages, accidents and technical failures
- Reduce perceived financial risks and build trust in drone technology.

Enhanced Market Access

- Use drones to improve last-mile logistics and aerial delivery of produce.
- Enable real-time dissemination of market intelligence.
- Empower farmers with timely information, better market connectivity, and awareness of price trends.

Strengthening Collectives

- Support farmer cooperatives and producer organizations to:
  - Access drone services collectively.

- Use shared ownership models and centralized service hubs.
- Benefit from targeted incentives to reduce individual costs.

Fostering Innovation Ecosystems

- Encourage start-ups and agri-tech enterprises to develop affordable, farmer-friendly drone solutions.
- Offer support through seed funding, innovation challenges and performance-linked incentives
- Focus on addressing the specific needs of smallholder farmers.

Infrastructure and Ecosystem Development

To enable the efficient and sustainable use of drones among smallholder farmers, robust infrastructure and ecosystem development are essential. First, the establishment of charging stations, maintenance depots, and warehousing facilities in rural areas is crucial to support regular drone operations. These facilities would ensure timely servicing, reduce equipment downtime, and make drone technology more reliable and accessible for farmers. In addition, the creation of local innovation hubs in rural regions would serve as critical support centers for drone deployment. These hubs should function as demonstration units, training centers, and data interpretation facilities, thereby bridging the technology gap and making advanced drone services accessible to farmers in remote and underserved areas. To simplify usage and lower operational costs, there is a need to enforce standardization of drone hardware and software platforms. Mandating interoperability standards would reduce training complexity, ease maintenance requirements, and drive down the cost of equipment and services for providers and users alike. Lastly, promoting local manufacturing of agricultural drones and related accessories under the 'Make in India' initiative is imperative. This would not only reduce

dependency on imports but also stimulate rural employment and strengthen the domestic agri-tech ecosystem.

Capacity Building and Skill Development

- Structured training programs should be introduced to equip farmers, technicians, and extension personnel with knowledge on drone operation, maintenance, safety protocols, data interpretation, and agronomic applications, ensuring safe and effective usage in agricultural contexts.
- These training initiatives can be delivered through established institutions such as agricultural universities, Krishi Vigyan Kendras (KVKs), and Industrial Training Institutes (ITIs), leveraging their outreach and infrastructure to reach grassroots stakeholders.
- Capacity building for rural drone service providers must be prioritized, with a special focus on engaging youth and women, by offering both technical and entrepreneurial training to help them establish viable drone-based service businesses.
- To support these emerging entrepreneurs, seed funding, incubation support, and mentorship should be provided to facilitate the setup and sustainable operation of drone service units in rural and underserved areas.
- Collaborations with academic and research institutions should be strengthened to co-develop region-specific drone applications and localized training curricula, ensuring that technologies and skills are relevant to local farming systems and agro-climatic conditions.
- These efforts will contribute to creating a technically skilled rural workforce capable of sustaining drone-based agricultural services and driving inclusive, technology-led growth in the agricultural sector.

Policy, Regulation, and Governance

A well-defined and enabling policy environment is crucial for promoting the safe and effective use of drones in Indian agriculture. A simplified regulatory framework is needed to ease the adoption process, particularly for smallholder farmers. This includes streamlining procedures for pilot licensing, drone registration, and obtaining exemptions from no-fly zones for low-altitude rural operations, which are typically non-sensitive areas. Policies must also be flexible and adaptive, evolving in response to technological advancements and real-time feedback from the field. Such dynamic policy design will allow for greater alignment with farmers' evolving needs and facilitate continuous innovation. Furthermore, drone-based interventions should be integrated with existing government schemes like the *Pradhan Mantri Fasal Bima Yojana* (PMFBY), Soil Health Card scheme, and *Rashtriya Krishi Vikas Yojana* (RKVY) to create synergistic effects and maximize outreach and effectiveness. Lastly, a participatory approach to policymaking is essential. Engaging smallholder farmers, local governance bodies, and civil society organizations in the policy formulation process will ensure that regulations are context-specific, need-based, and widely accepted. This inclusivity will not only enhance compliance but also foster a greater sense of ownership and trust in drone-enabled agricultural development.

Technology and Research

- Investing in adaptive R&D is essential to develop drone technologies that effectively cater to the needs of smallholder farmers in India, particularly considering fragmented landholdings, diverse cropping systems, and varied geographical terrains.
- Research efforts must prioritize region- and crop-specific drone solutions, ensuring viability across India's multiple agro-climatic

zones, and enhancing the technology's relevance and scalability for small-scale farming.

- Tailored drone applications should be developed for specific use cases—such as targeted pest management in cotton, or NDVI analysis in wheat—to enable data-driven, crop-specific decisions that improve productivity and input efficiency.
- To unlock the full potential of drone data, farmers should be incentivized to share data by receiving value-added services in return, including real-time advisories, weather alerts, and predictive yield forecasts, which can directly enhance farm-level decision-making.
- The aggregation of drone-generated data can also support better crop planning, disaster preparedness, and evidence-based agricultural policymaking, especially when integrated with other data sources and analytics.
- Integrating indigenous knowledge systems with drone intelligence can enrich the technology’s relevance and sustainability, combining traditional farming practices with modern insights to promote environmentally sound and culturally rooted agricultural innovations.

Information, Communication, and Outreach

Effective information dissemination and outreach are critical to accelerating the adoption of drone technology among smallholder farmers. Establishing digital platforms and mobile applications is essential for sharing knowledge on best practices, available drone services, government schemes, and training modules. These tools can serve as one-stop information hubs, enabling farmers to make informed decisions and access support when needed. In parallel, targeted awareness campaigns must be conducted to reach farmers across diverse linguistic and cultural backgrounds. These campaigns should leverage multiple channels including community radio, local television,

social media, and village-level events to demystify drone technology and address misconceptions. By communicating in local languages and using relatable success stories, such outreach efforts can effectively engage skeptical or less-informed farmers, fostering trust and interest in adopting drone-based solutions for agricultural advancement.

Inclusion, Ethics, and Environmental Sustainability

- Policies must ensure inclusive access to drone technology, especially for marginalized groups such as women, Scheduled Castes (SC), Scheduled Tribes (ST), and tribal farmers, who often face systemic barriers in accessing modern agricultural tools.
- Gender-sensitive service delivery models, community-based ownership structures, and targeted support programs should be promoted to bridge existing social and economic divides in drone adoption.
- A robust data privacy and security framework is essential to protect farmers' rights over drone-collected data, ensuring that ownership remains with the farmers and access is based on informed consent and transparent usage protocols.
- Clear legal guidelines should govern data storage, access, and third-party use, preventing misuse, unauthorized surveillance, or exploitation of sensitive farm-level information.
- Environmental safeguards must be embedded into drone operations, particularly where chemical spraying or intensive monitoring is involved, with mandatory assessments of impacts on soil health, biodiversity, and air quality.
- Drone deployment strategies should align with climate-resilient and ecologically sustainable practices, avoiding unintended environmental degradation while improving efficiency.
- Monitoring and evaluation (M&E) systems should be established to

assess the real-world outcomes of drone adoption, focusing on measurable changes in farm productivity, input use, cost-efficiency, and farmer livelihoods.

- Insights from ongoing assessments should be used to refine policies, update regulatory frameworks, and ensure that drone technology evolves in a way that is socially responsible, ethically sound, and environmentally sustainable.

SUCCESS CASE: I

"Can Drones Help Smallholder Farmers Improve Agriculture Efficiencies and Reduce Food Insecurity in Sub-Saharan Africa? Local Perceptions from Malawi"

Smallholder farmers in sub-Saharan Africa play a vital role in achieving food security and nutrition, yet they are often overlooked by development policies and lack access to the technology and information needed to increase their agricultural productivity. This is particularly true in Malawi, where smallholder farmers make up over 80% of the population and face a range of risks and challenges, including vulnerability to climate change, that threaten their livelihoods, food security, and nutrition. While drones and precision agriculture technology have had a significant impact on agriculture in high-income countries, their application by smallholder farmers in low-income countries is not well understood. This study, conducted in 2022, examines how drones can assist smallholder farmers in increasing their agricultural productivity and food security in Malawi. It explores how smallholders perceive the use of drones and the potential benefits and limitations of using drones in their farming operations. A unique aspect of this study aims to understand smallholders' perceptions of open data and data privacy. The results show that when smallholder farmers interact with drone data, they have a better understanding of their farm and are able to make more informed decisions that use fewer inputs and reduce production costs. Overall, this study demonstrates the potential for drones to assist smallholder farmers improve their on-farm knowledge, increase agricultural productivity, and mitigate the risks and challenges they face, leading to improved livelihoods and a more sustainable and secure food supply. Policymakers can promote the adoption of drone technology among smallholder farmers by developing policies that encourage public–private partnerships to create affordable, locally adapted drone technologies and programs that meet their unique needs, while also ensuring responsible use of drones in agriculture through regulations that address concerns about data privacy and security. (McCarthy *et., al* 2023, DOI:10.3390/agriculture13051075)

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> A drone's eye sees what the farmer's eye misses - saving time, inputs, and soil.

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