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Study of Agriculture Using Drones in India: Evaluation of Feasibility, Impact, and Adoption Challenges

Kazi Kutubuddin Sayyad Liyakat[1,*], Muskan Pathan[2]

Abstract

Background: Indian agriculture, characterized by land fragmentation, high dependency on monsoon cycles, and increasing input costs, necessitates scalable solutions for precision farming. Unmanned Aerial Vehicles (UAVs), or drones, offer capabilities ranging from high-definition spectral imaging and swift crop health assessment to localized nutrient and pesticide application. This study investigates the practical efficacy, cost-benefit ratio, and infrastructural challenges associated with integrating drone technology into diverse agro-climatic zones across India Methodology: A mixed-methods approach was employed, combining controlled field trials across four states (representing irrigated wheat, rain-fed cotton, horticultural crops, and paddy) with qualitative interviews with farmer cooperatives, agronomists, and drone service providers. Key performance indicators (KPIs) measured included reduction in water and chemical usage, time efficiency compared to traditional methods (e.g., manual spraying), improvement in early pest/disease detection accuracy, and ultimately, changes in yield per hectare. A comprehensive economic model assessed the Return on Investment (ROI) for farmers with varying landholding sizes, differentiating between direct ownership and "Drone-as-a-Service" (DaaS) models Conclusion/Implications: Drone technology is not merely an optional tool but a proven accelerator for sustainable intensification in Indian agriculture. While the technological efficacy is established, successful national integration hinges on supportive policy frameworks, targeted subsidies for service providers, and extensive training programs tailored to local languages and farming practices.

Keywords: Drone, agriculture, crop yield, water usage, project garuda

INTRODUCTION

Studies in India show that drone technology is revolutionizing agriculture by enabling precision farming, increasing crop yields, reducing costs, and improving sustainability. Key applications include using drones for efficient spraying, crop monitoring via multispectral sensors, soil health analysis, and optimized water management. Government initiatives like the "Kisan Drones" program are promoting adoption, supported by research that demonstrates significant benefits like yield increases and resource savings[1-3]. Figure 1 shows the usage of drone in Agriculture.

***Author for Correspondence**
Kazi Kutubuddin Sayyad Liyakat
E-mail: drkkazi@gmail.com

[1]Professor, Brahmdevdada Mane Institute of Technology, Solapur, Maharashtra, India
[2]UG Student Brahmdevdada Mane Institute of Technology, Solapur, Maharashtra, India

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Key Findings from Studies and Applications

- *Increased crop yields*: Studies and case examples show yield increases of 15-25% due to optimized farming practices.
- *Reduced input costs*: Precision application of fertilizers and pesticides can lead to a 20-35% reduction in these costs.
- *Improved efficiency*: Drones can complete tasks like spraying and scouting 5-30 times faster than traditional methods and reduce labor costs.

- *Enhanced sustainability*: Targeted spraying minimizes chemical runoff, and drones help with water conservation through efficient irrigation management.
- *Data-driven decision making*: Multispectral sensors capture data on crop health (like NDVI), helping farmers make timely decisions about nutrient deficiencies or pest attacks.
- *Government support*: Initiatives like the "Kisan Drones" program and subsidies under the SMAM scheme are making the technology more accessible to farmers (Figure 1).

Specific applications

- *Crop spraying*: Drones can precisely and efficiently spray pesticides, herbicides, and fertilizers, reducing the amount of chemicals used and worker exposure.
- *Crop monitoring*: Drones provide a bird's-eye view, allowing for quick and comprehensive assessment of large fields to identify problem areas.
- *Soil analysis*: Drones with sensors can map and analyze soil conditions, helping with decisions on seed planting, irrigation, and fertilization.
- *Water management*: They can monitor soil moisture and crop water stress, allowing for more efficient irrigation practices.

HOW DRONES ARE REDEFINING THE INDIAN FARM

The Indian agricultural landscape is a tapestry woven from millennia of tradition, unpredictable monsoon cycles, and the immense pressure of feeding a billion-plus population. For generations, farming has been inherently tactile—a dialogue between the farmer's hand and the soil. But today, the most transformative conversation is happening miles above the field, spearheaded by a fleet of silent, buzzing emissaries: drones.

The study and application of Unmanned Aerial Vehicles (UAVs) in Indian agriculture promise not just incremental improvements, but a fundamental paradigm shift toward Precision Agriculture. This is the tech revolution that India’s 140 million farmers have long awaited, transforming uncertainty into actionable data, and vast fields into manageable, microscopic zones. The primary strength of drone technology lies in its ability to move agriculture away from generalized, often wasteful, farming practices toward hyper-localized intervention[4-9].

Diagnostic Mapping and Health Assessment

Traditionally, a farmer detects distress—water stress, pest infestation, or nutrient deficiency—only when symptoms are visible to the human eye, by which time significant damage may have already occurred. Drones, equipped with multispectral and Normalized Difference Vegetation Index (NDVI) cameras, change this timeline dramatically.

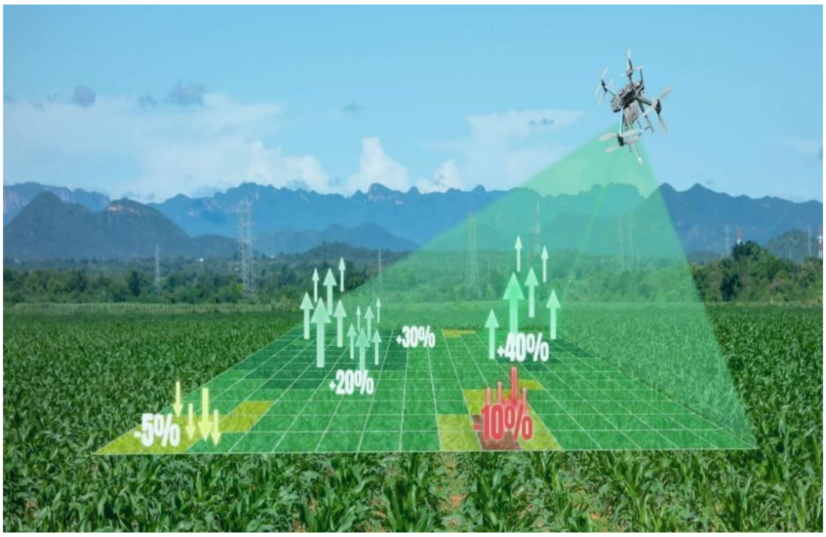

Figure 1. Drone in agriculture.

The study: UAVs fly systematically over fields, capturing data points far beyond the visible spectrum. The resulting NDVI maps reveal plant health by measuring how much infrared light the foliage reflects. Areas of low health or stress appear in stark contrast to healthy regions, allowing researchers and farmers to identify problems before they manifest physically.

This data is crucial for:

- *Early disease detection*: Spotting localized fungal infections or pest damage weeks ahead of traditional scouting.
- *Water stress* Analysis: Identifying precise sections of a field that require more or less irrigation.
- *Yield prediction*: Accurately estimating harvest volume based on canopy density and plant vigor, aiding market planning.

Variable Rate Application (VRA)

Perhaps the most economically significant application is the shift from blanket spraying to Variable Rate Application (VRA). In the traditional method, fertilizers, pesticides, and herbicides are sprayed uniformly across the entire field, leading to waste, chemical runoff, and excessive saturation in healthy areas.

The application: Drones equipped with low-volume sprayers are programmed to follow the VRA maps generated by the diagnostic flight. They apply chemicals only where absolutely necessary—a targeted, surgical intervention. Studies have demonstrated that this can reduce the consumption of pesticides and fertilizer by 15% to 30%, drastically cutting input costs while minimizing environmental impact. For the smallholder farmer, this translates directly into higher profits and healthier soil.

While the technology has existed globally for years, the primary barrier to widespread adoption in India was regulatory ambiguity. Until recently, operating drones commercially required complex approvals from the Directorate General of Civil Aviation (DGCA) and the Ministry of Defence.

Recognizing the immense potential, the Indian government introduced the Drone Rules, 2021. These simplified policies significantly, creating 'green zones' for easy operation and promoting the manufacturing and deployment of drones, particularly "Kisan Drones" (Farmer Drones) for agricultural usep[10].

This policy push has fostered a vibrant ecosystem:

- *Start-up boom*: Numerous agri-tech companies are now offering Drone-as-a-Service (DaaS), making sophisticated mapping and spraying affordable even for farmers with fragmented landholdings.
- *Subsidies and training*: Government schemes now offer subsidies for purchasing agricultural drones, coupled with training programs to educate young rural entrepreneurs in drone piloting and data analysis.
- *Efficiency on small plots*: Given the small and often fragmented nature of Indian landholding, drones provide unmatched efficiency. A single drone can map several acres in minutes—a task that would take days for human labor scouting.

The study of drone integration in Indian agriculture is revealing powerful socio-economic benefits that extend beyond mere yield maximization:

- *Pesticide application is often a labor-intensive and hazardous task*. Drones eliminate the need for human personnel to walk through freshly sprayed fields or carry heavy loads of chemicals, significantly reducing exposure to toxic substances and lowering the incidence of pesticide poisoning among farm workers. Furthermore, in regions facing acute labor shortages, drones offer a robust technological substitute, ensuring timely application regardless of manpower availability.

- *The rise of agri-drones is creating a new category of skilled rural employment*: the Drone Pilot and Data Analyst. These roles require technical training but offer high value, positioning the youth not merely as farm laborers, but as custodians of cutting-edge technology, bridging the urban-rural opportunity gap.

The current applications of drones—mapping and spraying—are just the starting point. The deeper study of this technology is leading towards complete farm automation and hyper-local Artificial Intelligence (AI)[11].

In the near future, Indian agricultural systems will utilize drones not just for observation, but for continuous, automated feedback loops:

- *AI-Driven diagnostics*: AI models will analyze drone imagery in real-time, automatically distinguishing between weeds and crops, identifying the specific species of pest, and cross-referencing this with localized weather data to predict outbreak severity.
- *Seeding and pollination*: Trials are underway for drones that can precisely seed remote or difficult terrain, or even assist in delicate tasks like forced pollination in orchards where natural pollinators are scarce.

The deployment of drones in Indian agriculture is more than a technological upgrade; it is a vital catalyst for resilience, efficiency, and sustainability. By equipping the farmer with an "eye in the sky," India is safeguarding its food security, modernizing its oldest industry, and ensuring that the future of its fields is managed not just with tradition, but with intelligent, data-driven conviction[12].

FEASIBILITY, IMPACT ON STUDY OF AGRICULTURE USING DRONES IN INDIA

The timeless image of Indian agriculture is etched in our minds: the farmer, back bent, eyes scanning the sea of green, his wisdom drawn from generations of toil and an intimate dialogue with the earth. It is a picture of resilience. But today, a new, faint buzzing sound is weaving itself into this pastoral symphony. It's the sound of a drone, hovering like a mechanical dragonfly, and it carries the potential to not just observe this ancient field, but to converse with it in a language of data, pixel by pixel, leaf by leaf.

The question is no longer if drones can be used in Indian agriculture, but how feasible their widespread adoption truly is, and what seismic impact they promise on the very study and practice of farming[13].

On paper, the feasibility is tantalizing. The technology is proven. Multispectral sensors can detect plant health long before the human eye can see a blight. A drone can cover an acre in minutes, not hours. The data it collects can generate precise maps for irrigation, fertilization, and pesticide application. Yet, the Indian field is not a blank slate; it is a complex ecosystem of small landholdings, economic constraints, and deep-seated traditions. The feasibility, therefore, is a story of two intersecting realities[14].

The Hurdles:

- *The cost conundrum*: For a marginal farmer with two hectares, a high-tech drone with advanced sensors represents a significant investment. The initial outlay for the hardware, the software for data analysis, and the training to operate it is a formidable barrier.
- *The skill gap*: A farmer's genius lies in reading the soil and the sky, not necessarily in piloting a UAV or interpreting NDVI (Normalized Difference Vegetation Index) maps. Bridging this digital divide requires robust training and support systems.
- *The regulatory maze*: Indian airspace is tightly controlled. While the government has made strides with the "Drone Rules 2021," navigating permissions, licenses, and no-fly zones adds a layer of bureaucratic complexity.
- *Infrastructure*: Charging stations, repair networks, and high-speed internet in rural areas for data upload and analysis are not yet ubiquitous.

The Springboards:

- *The service model*: Feasibility skyrockets with the rise of drone-as-a-service (DaaS) startups. Instead of buying the drone, a farmer can hire a service provider to survey, spray, or map their field, paying per acre. This democratizes access, turning a capital expense into an operational one.
- *Government push*: Schemes like the "Kisan Drone" initiative, providing subsidies for purchase and demonstration, are powerful catalysts. They legitimize the technology and absorb part of the financial risk for early adopters.
- *The youth dividend:* A new generation of tech-savvy agriculturists is returning to the land. They see a drone not as a foreign object, but as a tool—the smartphone of the sky. Their enthusiasm is infectious and crucial for adoption.
- *The ROI argument:* The feasibility argument is ultimately won by demonstrable Return on Investment. A 20% reduction in pesticide use, a 15% increase in yield, and 90% savings in water—these are not fantasies but documented outcomes. This economic logic is the most potent force for change.

The true revolution lies not in the drone itself, but in the data it harvests. Its impact on the study of agriculture is transformative, shifting the paradigm from reactive to predictive, from blanket treatment to micro-medication[15].

1. *The classroom without walls:* Agricultural universities and research institutes are no longer confined to small test plots. A doctoral student can now study crop stress patterns across a thousand acres in a single district, gathering hyper-localized data on a massive scale. This enables research that is both macro and micro, revealing patterns and correlations previously invisible.
2. *The demise of the "blanket approach":* We are moving from asking "Does my field need water?" to "Which specific 10-square-meter patch of my field is under hydric stress and needs exactly 2 liters of water?" This precision conserves vital resources, cuts costs drastically, and minimizes environmental damage from chemical runoff.
3. *Predictive power and risk mitigation:* By consistently monitoring crop health, algorithms can predict an outbreak of pest infestation or a fungal disease days before it becomes visible. This is a quantum leap from damage control to prevention. For the first time, farmers can get ahead of the seasons, insured by data.
4. *Democratizing expertise:* A drone's data can be uploaded to the cloud and analyzed by an agronomist hundreds of miles away. This means a farmer in a remote village can access expert advice based on precise, real-time conditions of their own field, breaking down geographical barriers to knowledge.

The integration of drones into Indian agriculture is not about replacing the farmer; it is about augmenting his legendary intuition with godlike clarity. It is the marriage of vrikshayurveda (the ancient science of plant life) with data science.

The fields of Punjab, the vineyards of Maharashtra, the tea estates of Assam—all are poised on the brink of this change. The buzzing overhead is the sound of a new dialogue beginning. It is the sound of the land whispering its secrets to the sky, and the sky, through the lens of a drone, answering back with the precise, actionable wisdom to cultivate a smarter, greener, and more abundant future for India. The feasibility is being proven one flight at a time, and the impact will be measured not just in tons of produce, but in generations of farmers empowered to write a new, more sustainable chapter in the world's oldest story.

NAVIGATING THE ADOPTION CHALLENGES OF AGRICULTURAL DRONES IN INDIA

India's agricultural landscape, characterized by its vastness, diversity, and the sheer number of smallholder farmers (over 86% of landholdings are less than two hectares), stands at a critical juncture.

The promise of the drone—a compact, high-tech flying platform capable of precision spraying, real-time crop health monitoring, and advanced topographic analysis—represents the potential for a Green Revolution 2.0. Studies and pilot projects consistently demonstrate remarkable benefits: optimized fertilizer use, early detection of pest infestations, and resulting yield increases of 15% or more.

Yet, the gap between the theoretical efficiency of Unmanned Aerial Vehicles (UAVs) and their widespread, practical adoption on Indian farms remains a significant chasm. The challenges are not merely technical; they are deeply rooted in economics, infrastructure, human psychology, and policy formulation. For the drone revolution to truly take flight, India must navigate a complex set of hurdles that dim the bright promise of the sky.

The Economic Barrier: Scale, Cost, and Return on Investment

The most immediate impediment to adopting drone technology is simple affordability, particularly for the small and marginal farmer.

Prohibitive Capital Expenditure

A high-quality agricultural drone, equipped with multispectral cameras or spraying components, represents a capital outlay far exceeding the annual income of most Indian farming households. While the government offers subsidies (often 50% to 100% for custom hiring centres), the initial investment still requires significant credit access and financial literacy.

The Scale Paradox

Drones are highly efficient, but their ROI peaks with large, consolidated land parcels. The prevalent fragmentation of landholdings in India (where one farmer may manage several tiny, non-contiguous plots) dramatically dilutes the efficiency gains. Furthermore, a farmer cannot justify owning a costly drone for only a few hectares of operation per season. This necessitates the development of robust "Drone-as-a-Service" (DaaS) rental models, which themselves face logistical and pricing complications.

The Policy and Regulatory Labyrinth

While the Directorate General of Civil Aviation (DGCA) has significantly liberalized drone policy since 2021, the regulatory landscape remains a significant source of confusion and friction for potential adopters.

Licensing and Compliance

Operating agricultural drones requires specific permissions, licensing, and adherence to drone pilot training requirements. For traditionally educated farmers or rural entrepreneurs, navigating the complex rules surrounding air space management, payload restrictions, and mandatory insurance/registration often proves intimidating and prohibitive. This bureaucracy slows down the necessary penetration of trained personnel into remote rural areas.

Data Sovereignty and Privacy

Drones generate massive amounts of high-resolution data. A significant policy challenge lies in clarifying who owns this data—the farmer, the drone operator, or the service provider? Farmers are often wary of sharing intimate details about their land and yields, fearing misuse or exploitation by corporate entities, creating a deep-seated resistance to data-driven farming solutions.

Infrastructure and Technical Constraints

The operational environment of rural India imposes unique technical burdens that challenge the reliability of UAVs.

The Connectivity Gap

Precision agriculture relies on seamless, high-speed connectivity to transmit large data packets for analysis and to receive accurate GNSS (Global Navigation Satellite System) corrections. Many remote farming areas suffer from poor internet connectivity, rendering advanced data processing features useless. This forces operators to manually transfer large files, undermining the real-time efficiency that drones are meant to provide.

Endurance Under Heat

India's semi-arid and tropical climates present severe challenges for battery life and electronic components. Extreme summer heat drastically shortens flight times and accelerates component degradation, demanding more frequent replacement and sophisticated cooling solutions that add to the operational cost.

Maintenance and Local Expertise

Unlike a tractor, drone maintenance requires specialized technical expertise. The lack of readily available, localized repair and maintenance infrastructure means that a breakdown often requires sending the unit back to a distant city. This downtime is unacceptable during critical planting or harvesting seasons, eroding farmer trust in the technology's reliability.

The Human Element: Tradition, Trust, and Training

Perhaps the most crucial challenge is overcoming the skepticism and adapting the traditional mindset of the Indian farmer.

Digital Literacy and Skepticism

While younger generations may embrace technology, many established farmers rely on centuries of passed-down wisdom regarding soil, weather, and crop management. Introducing sophisticated analytics driven by machine learning and high-resolution imagery requires a revolutionary shift in thinking. Farmers often default to a position of skepticism, needing undeniable proof that the technology works better than their accumulated traditional knowledge.

The Local Language Barrier

Training manuals, drone interfaces, and data analysis reports are often presented primarily in English or highly technical jargon. Effective mass adoption requires localized, demographically appropriate training materials and interfaces in regional languages, focusing on practical, actionable insights rather than abstract technical specifications.

The study of agricultural applications for drones in India has proven their transformative potential. The challenge now is moving from successful pilots to effective national adoption.

Bridging the gap between promise and reality requires a multi-pronged strategy:

- *Economic structuring*: Massive scaling of DaaS models, driven by farmer producer organizations (FPOs), to democratize access without demanding individual ownership.
- *Regulatory simplification*: Streamlining the licensing process and focusing regulatory enforcement on safety, while creating 'regulatory sandboxes' that allow innovation to flourish without undue bureaucratic burden.
- *Localized skill development*: Investing heavily in ITIs (Industrial Training Institutes) and Krishi Vigyan Kendras (KVKs) to create a skilled workforce capable of operating and maintaining drones locally.

The drone is not just a tool; it is a catalyst for data-driven farming. By addressing the economic anxiety, bureaucratic hurdles, and human skepticism with equal vigour, India can ensure that this technology elevates its agricultural output and secures the long-term prosperity of its most vital sector. The sky is open; the ground challenges must now be conquered.

KEY PERFORMANCE INDICATORS DEFINING THE FUTURE OF INDIAN AGRI-TECH

The skies above the sprawling, diverse farmlands of India are evolving. Where once only birds soared, now buzzing echoes announce the arrival of Agri-Tech's most potent tool: the drone. These

Unmanned Aerial Vehicles (UAVs) are transforming farming from a tradition of intuition into a science of precision.

However, the efficacy of this revolution is not measured by the number of drones registered, but by the tangible, quantifiable impact they deliver on the ground. Research institutions, agricultural universities, and private Agri-Tech firms studying the deployment of drones in the Indian agricultural landscape rely on a critical framework of Key Performance Indicators (KPIs). These metrics are the bedrock of precision agriculture, proving viability, guiding policy, and securing investment. The KPIs for drone-based agriculture studies typically fall into three interconnected categories: Operational Efficiency, Agronomic Outcome, and Economic Sustainability.

Operational Efficiency KPIs: The Drone's Report Card

Operational KPIs focus on the performance of the technology itself and its integration into existing farm routines. For research to be scalable across India's highly fragmented landholdings, the technology must be efficient and reliable.

Area Coverage Rate (ACR)

- *Metric*: Hectares mapped or treated per flight hour (Ha/Hr).
- *Significance*: This is crucial in India, where quick turnaround is necessary, especially during short windows for pest control or disease monitoring. Studies compare the ACR of drones against traditional methods (walking inspections or tractor-mounted sensors) to define the time-saving advantage.
- *Related metric*: Data Acquisition Reliability: The percentage of scheduled missions completed successfully without technical failure or weather interruption.

Data Processing & Delivery Latency

- *Metric*: Time taken from data capture (flight completion) to actionable output (finalized prescription map delivered to the farmer/applicator).
- *Significance*: Precision agriculture thrives on timeliness. If it takes three days to process multispectral imagery showing a fungal outbreak, the intervention window may be missed. Researchers track latency to optimize cloud processing, edge computing, and AI model efficiency.

Application Accuracy and Uniformity

- *Metric*: Coefficient of Variation (CV) in droplet size and deposition uniformity (for spraying drones).
- *Significance*: Unlike broadcast spraying, precision drones aim for uniform application only where needed. Studies measure how well the drone's LiDAR or photometric sensors correlate the intended dose with the actual dose delivered to specific GPS coordinates, ensuring compliance with Standard Operating Procedures (SOPs) for pesticide use.

Agronomic Outcome KPIs: Proof on the Plant

These KPIs directly measure how drone-derived insights translate into healthier crops and optimized resource use—the core promise of drones in agriculture.

Water Use Efficiency (WUE)

- *Metric*: Yield produced per unit of water consumed (Kg/m^3).
- *Significance*: India faces acute water scarcity. Drones equipped with thermal and hyperspectral sensors can detect early signs of water stress, allowing for Variable Rate Irrigation (VRI). Studies track the reduction in irrigation cycles or water volume used in drone-monitored fields versus control fields, demonstrating sustainable resource management.

Input Reduction Ratios (IRR)

- *Metric*: Percentage reduction in inputs (fertilizer, pesticides, herbicides) achieved through targeted, drone-guided application.
- *Significance*: A primary driver of drone adoption. Researchers calculate the kilograms of urea or liters of pesticide saved per hectare using Variable Rate Technology (VRT) maps generated from drone imagery (NDVI, NDRE). This directly impacts both farm budgets and environmental runoff.

Early Detection and Classification Accuracy

- *Metric*: True Positive Rate (TPR) for pest/disease identification and nutrient deficiency diagnosis.
- *Significance*: This KPI validates the AI and machine vision models used by the drone system. Researchers compare drone predictions against physical ground sampling (the "ground truth") to ensure the system is accurately identifying issues like rust, blight, or localized nitrogen deficiency, providing confidence in the prescriptive action.

Final Yield Improvement (The Ultimate Test)

- *Metric*: Percentage increase in final harvestable yield (Kg/Ha) compared to control plots managed conventionally.
- *Significance*: While influenced by many factors, the absolute yield increase remains the most straightforward proof of drone intervention success. Research must isolate the impact of the drone-guided actions (e.g., targeted weed control) to attribute the yield gain accurately.

Economic & Sustainability KPIs: Scaling the Impact

For the study of drone technology to be relevant for small and marginal farmers—who dominate the Indian agricultural landscape—the financial viability and long-term sustainability must be proven.

Return on Investment (ROI) and Cost-Benefit Analysis

- *Metric*: (Value of Yield Increase + Cost Savings from Inputs) / (Cost of Drone Service + Maintenance).
- *Significance*: This metric is non-negotiable for adoption. Studies must demonstrate that the added cost of drone services (whether owned or rented) is significantly offset by the savings in inputs and the uplift in yield quality and quantity. A clear, positive ROI is essential for government subsidies and financial institution backing.

Labor Resource Optimization

- *Metric*: Hours of skilled/unskilled labor saved per cycle (e.g., time saved walking fields for scouting, or time saved during manual spraying).
- *Significance*: While drones require skilled operators, they dramatically reduce the time needed for tedious, hazardous tasks. Measuring labor savings helps reallocate human resources to higher-value activities and mitigates the risk of farm labor shortages.

Carbon Footprint Reduction (Emerging KPI)

- *Metric*: Reduction in CO_2 equivalent (CO_2e) emissions per Kg of crop produced.
- *Significance*: While still developing, this KPI is gaining prominence. By enabling fuel-efficient, targeted fertilizer application (reducing N_2O emissions) and minimizing tractor passes, drones contribute directly to climate-smart agriculture. Research tracks the overall environmental load reduction spurred by precision intervention.

In India, the study of agricultural drones is not merely an academic exercise; it is a critical step toward national food security and self-reliance. The rigorous measurement of these diverse KPIs allows researchers to move beyond anecdotal success stories.

By synthesizing Operational KPIs (proving the technology is ready), Agronomic KPIs (proving the crops benefit), and Economic KPIs (proving the investment is worthwhile), researchers can generate the robust evidence required to:

- *Inform policy:* Guiding government subsidies, standardization protocols, and flight regulations tailored for Indian farming conditions.
- *Ensure equity*: Developing affordable, high-efficacy models suitable for cooperatives and small farm clusters.
- *Drive innovation*: Pinpointing weak links—such as battery life or data processing bottlenecks—for manufacturers and software developers to address.

Ultimately, the metrics measured today will determine whether the drone remains a novel agricultural gadget or fulfills its promise as the eyes and hands of India's next green revolution.

CASE STUDY

A Case Study in the Utilization of Drone Technology for Smallholder Cotton Cultivation in Maharashtra

Agriculture forms the bedrock of the Indian economy, yet it faces monumental challenges: fragmented landholdings (averaging just 1.08 hectares), increasing climate volatility, and the persistent pressure of input costs. Traditional farming relies heavily on visual inspection and blanket treatment, leading to inefficient use of water, fertilizers, and pesticides.

The emergence of affordable Unmanned Aerial Vehicles (UAVs)—or "Drones"—provides a pivotal opportunity to leapfrog these archaic methods. Drones offer high-resolution, real-time data at an operational cost far lower than satellite imagery, making them uniquely suited to the scale and complexity of the smallholder Indian farm.

This case study, codenamed "Project Garuda" (named after the mythical bird of flight), examines the deployment of drone-based spectral analysis and targeted spraying over a cluster of cotton farms in the drought-prone Vidarbha region of Maharashtra.

Setting the Scene – The Challenge

- *Location*: Yavatmal District, Maharashtra
- *Crop*: BT Cotton (Kharif Season)
- *Farms involved*: 47 Smallholders (Total Area: 65 Hectares)
- *Primary issue*: Late Detection of Pink Bollworm Infestation and Nitrogen Deficiency

The farmers in Yavatmal traditionally faced two critical, interrelated problems:

- *Hidden pestilence*: The deadly Pink Bollworm (PBW) often establishes itself deep within the canopy before visible damage appears, leading to catastrophic crop loss. Manual inspection is time-consuming and often too late.
- *Uneven nutrition*: Nitrogen (N) deficiency, a common limiting factor, was being treated via uniform, blanket application of urea, wasting fertilizer on healthy patches while under-dosing stressed areas.

The farmers needed a method for early, precise intervention to reduce input dependence and secure yields against unpredictable monsoon patterns.

Methodology – The Drone Solution

Project Garuda introduced a three-phase drone protocol implemented by a local Farmer Producer Organization (FPO) in collaboration with a tech provider.

Mapping and Diagnostics (The Eye in the Sky)

- *Technology used*: Fixed-wing and multi-rotor drones equipped with high-resolution Multispectral Sensors (NDVI, NDRE, and Red Edge).
- *Procedure*: Weekly flights were conducted during the critical flowering stage.
- *Data output*: The multispectral camera captured light reflectance data used to generate Vegetation Health Indexes, specifically the Normalized Difference Vegetation Index (NDVI).
- *High NDVI*: Indicates vigorous growth and high chlorophyll concentration.
- *Low NDVI*: Pinpoints areas of stress (water, pests, disease, or nutrient deficiency).
- *Key advantage*: Unlike satellites, the drone's low altitude provided centimeter-level resolution, crucial for identifying stress points in plots as small as 0.5 hectares.

Prescription Generation (The Data Center)

The raw NDVI maps were processed using proprietary algorithms that cross-referenced the data with historical soil fertility maps and weather patterns. This generated:

- *Variable rate sprayer maps (VRS):* Digital maps showing precisely where nitrogen fertilizer was needed and at what concentration.
- *Targeted pest zones*: Specific GPS coordinates indicating plants or clusters of plants showing spectral signatures consistent with early-stage PBW damage (reduced chlorophyll surrounding the fruiting bodies).

Execution (Targeted Application)

- *Technology used*: Heavy-lift, battery-powered Hexacopter Spraying Drones.
- *Procedure*: The precision-prescription maps were uploaded directly onto the drone's flight controller. The drone used high-accuracy RTK GPS (Real-Time Kinematic) to navigate autonomously, applying pesticides only to the designated stress zones.
- *Result*: A shift from conventional volume-based spraying (treating the whole field) to area-based, need-specific treatment.

Results and Impact Analysis

The results of Project Garuda over a single Kharif season demonstrated significant quantifiable gains, validating the use of drones in the smallholder context as shown in Table 1:

Key Takeaways of the Impact

- *Economic resilience*: By reducing the cost of highly-priced inputs (pesticides being the most expensive), the net income for farmers increased significantly despite stable market prices for cotton.
- *Environmental stewardship*: The 37% reduction in pesticide use substantially lessened the environmental load and reduced farmer exposure to harmful chemicals.
- *Water optimization:* Though not the primary focus, the ability to identify moisture-stressed zones contributed to more efficient irrigation scheduling, saving up to 15% of water in supplemental irrigation rounds.

Table 1. Significant quantifiable gains of project garua.

Metric	Traditional method (baseline)	Project garuda (drone-based)	Improvement
Pesticide Consumption	4 applications/season (Blanket)	2.5 applications/season (Targeted)	37% Reduction
Fertilizer (Urea) Wastage	High (Due to blanket application)	Minimal (Variable Rate)	22% Reduction
Yield Increase (Cotton/Hectare)	Baseline Average	1.15 to 1.30 T/Ha	13% Increase
Time Saved (Pest Scouting)	4-5 hours/hectare	15 minutes/hectare (Mapping)	95% Time Efficiency
Return on Investment (ROI)	N/A (Based on FPO subsidy)	Estimated 1.8:1 for the FPO	Demonstrated Profitability

Recommendations and future outlook: To translate the proven potential of drones into widespread national impact, the following strategic actions are imperative:

1. *Prioritize the DaaS model*: Government subsidies and financing schemes (like the Kisan Drone initiative) must be heavily skewed towards incentivizing local entrepreneurs and Farmer Producer Organizations (FPOs) to establish drone service hubs, ensuring that the benefits of the technology reach the maximum number of marginal farmers at an affordable price point.
2. *Streamline regulatory frameworks*: A simpler, location-specific licensing and operational permitting process must be implemented, reducing bureaucratic hurdles and ensuring safe, localized flight zones for essential agricultural tasks.
3. *Invest in ag-tech skill development*: Mandatory, government-backed training programs focusing on drone piloting, data interpretation, and integration with existing government digital platforms (such as soil health card schemes) are essential for building a competent rural workforce.

The aerial revolution is poised to redefine the 'Green Revolution 2.0'. By shifting focus from individual ownership to accessible service models and by investing robustly in training and policy simplification, India can leverage UAV technology not just to increase production, but to build a resilient, efficient, and environmentally conscious agricultural ecosystem capable of feeding both the nation and the world. The future of the Indian farm is not just on the ground—it is flying above it.

REFERENCES

1. Singh, R.; Singh, S. A Review of Indian-Based Drones in the Agriculture Sector: Issues, Challenges, and Solutions. *Sensors* 2025, *25*, 4876. https://doi.org/10.3390/s25154876
2. Katekar, V.; Cheruku, J.K. The Application of Drone Technology for Sustainable Agriculture in India. *Curr. Agric. Res. J.* 2022, *10*, 352–365.
3. Ayamga, M.; Akaba, S.; Nyaaba, A.A. Multifaceted Applicability of Drones: A Review. *Technol. Forecast. Soc. Change* 2021, *167*, 120677.
4. Dutta, G.; Goswami, P. Application of Drone in Agriculture: A Review. *Int. J. Chem. Stud.* 2020, *8*, 181–187.
5. Kim, J.; Kim, S.; Ju, C.; Son, H.I. Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications. *IEEE Access* 2019, *7*, 105100–105115.
6. Shukla, R.; Chakraborty, A.; Joshi, P.K. Vulnerability of Agro-Ecological Zones in India under the Earth System Climate Model Scenarios. *Mitig. Adapt. Strateg. Glob. Change* 2017, *22*, 399–425.
7. Guebsi, R.; Mami, S.; Chokmani, K. Drones in Precision Agriculture: A Comprehensive Review of Applications, Technologies, and Challenges. *Drones* 2024, *8*, 686. https://doi.org/10.3390/drones8110686
8. Chaturvedi, S.K.; Sekhar, R.; Banerjee, S.; Kamal, H. Comparative Review Study of Military and Civilian Unmanned Aerial Vehicles (UAVs). *INCAS Bull.* 2019, *11*, 183–198.
9. D. A. Tamboli, V. A. Sawant, M. H. M. and S. Sathe, (2024). AI-Driven-IoT(AIIoT) Based Decision-Making- KSK Approach in Drones for Climate Change Study, *2024 4th International Conference on Ubiquitous Computing and Intelligent Information Systems (ICUIS)*, Gobichettipalayam, India, 2024, pp. 1735-1744, doi: 10.1109/ICUIS64676.2024.10866450.
10. SLiyakat, S. (2025l). AI-Driven-IoT (AIIoT)-Based Decision Making in Drones for Climate Change: KSK Approach. *In S. Aouadni& I. Aouadni (Eds.), Recent Theories and Applications for Multi-Criteria Decision-Making* (pp. 311-340). IGI Global. https://doi.org/10.4018/979-8-3693-6502-1.ch011
11. Altaf O. Mulani, Arti Vasant Bang, Ganesh B. Birajadar, Amar B. Deshmukh, and Hemlata Makarand Jadhav, (2024). IoT Based Air, Water, and Soil Monitoring System for Pomegranate Farming, *Annals of Agri-Bio Research.* 29 (2): 71-86, 2024.
12. Sayyad (2025b). AI-Powered IoT (AI IoT) for Decision-Making in Smart Agriculture: KSK Approach for Smart Agriculture. In S. Hai-Jew (Ed.), *Enhancing Automated Decision-Making Through AI* (pp. 67-96). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-6230-3.ch003

13. SLiyakat, S. (2024c). Machine Learning-Based Pomegranate Disease Detection and Treatment. *In M. Zia Ul Haq & I. Ali (Eds.), Revolutionizing Pest Management for Sustainable Agriculture* (pp. 469-498). IGI Global. https://doi.org/10.4018/979-8-3693-3061-6.ch019
14. SLiyakat, S. (2024f). Artificial Intelligence (AI)-Driven IoT (AIIoT)-Based Agriculture Automation. In S. Satapathy & K. Muduli (Eds.), *Advanced Computational Methods for Agri-Business Sustainability* (pp. 72-94). IGI Global. https://doi.org/10.4018/979-8-3693-3583-3.ch005
15. SLiyakat, S. (2025n). Transformation of Agriculture Effectuated by Artificial Intelligence-Driven Internet of Things (AIIoT). In J. Garwi, M. Dzingirai, & R. Masengu (Eds.), *Integrating Agriculture, Green Marketing Strategies, and Artificial Intelligence* (pp. 449-484). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-6468-0.ch015

