iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.79219

AutoShield: Smart Sensor-Triggered Motorized Canopy System for Crop Protection Against Unseasonal Rainfall and Hailstorm Events

Pradyumna Murlidhar Sonewane[1]
Independent Researcher, Nagpur, Maharashtra, India

Abstract: Unseasonal rainfall and hailstorm events cause catastrophic damage to high-value horticultural crops in India, resulting in annual losses exceeding INR 50,000 crore. This paper presents AutoShield, a novel IoT-integrated motorized canopy protection system designed specifically for grape, pomegranate, strawberry, and flower farmers. The system employs a multi-sensor array including barometric pressure sensors (BMP280), temperature-humidity sensors (DHT22), rain detection modules, and light-dependent resistors (LDR) connected to an ESP32 microcontroller. Upon detecting imminent rainfall through sensor fusion logic, the system automatically deploys a durable PVC-coated polyester canopy over the protected farmland. The canopy design incorporates a gravity-assisted counterweight mechanism for energy-efficient deployment, a peripheral rainwater collection pipeline network for water harvesting, and windbreak mesh side panels for structural stability. The system operates fully offline with optional Bluetooth and WiFi-based mobile dashboard control, and is powered by an off-grid solar panel and battery unit. Prototype evaluation demonstrates successful rain prediction and canopy deployment with an average response time of under 90 seconds. The modular unit design supports customization from 20x20 ft to 100x100 ft coverage areas, making it economically viable at INR 15,000-80,000 per unit with a projected 10-15 year operational lifespan.
Keywords: IoT, Smart Agriculture, Crop Protection, ESP32, Sensor Fusion, Precision Farming, Horticulture, Rainfall Detection, Motorized Canopy, Maharashtra

I. INTRODUCTION

Agriculture forms the backbone of India's economy, employing over 50% of the population and contributing significantly to GDP. However, Indian farmers face unprecedented challenges from climate change, particularly unseasonal rainfall, hailstorms, and erratic weather patterns. Maharashtra, one of India's most agriculturally significant states, produces approximately 80% of India's grapes, significant quantities of pomegranate, and is a leading producer of floriculture crops. These high-value crops are acutely vulnerable to unseasonal rainfall events that occur during the critical harvest window of 20-25 days. A single unseasonal rain event during harvest can destroy an entire season's produce, resulting in losses of INR 5-12 lakh per acre for grape and pomegranate farmers. Traditional mitigation strategies such as manual tarpaulin covering are labor-intensive, time-critical, and prone to human error. There exists a clear technological gap: a reliable, automated, and affordable crop protection system that can respond to rainfall events faster than manual intervention allows. This paper presents AutoShield — a sensor-triggered, motorized, deployable canopy system that addresses this gap through the integration of IoT sensing, embedded systems, mechanical engineering, and renewable energy. The system is designed with Indian farm conditions in mind: unreliable power supply, limited internet connectivity, diverse farm sizes, and cost sensitivity among farming communities.

A. Problem Statement

The core problem addressed by this research is: How can high-value horticultural crops be automatically protected from unseasonal rainfall and hailstorm damage at farm scale, with minimal farmer intervention, at an affordable cost, and without dependence on continuous power or internet connectivity?

B. Objectives

1) Design a sensor-based rainfall prediction and detection system using ESP32 microcontroller
2) Develop a motorized, gravity-assisted canopy deployment mechanism using durable, foldable materials
3) Implement offline-first control logic with optional mobile dashboard for manual override
4) Engineer a rainwater collection and diversion system integrated into the canopy structure

5) Evaluate economic viability and ROI for target farmer segments in Maharashtra
6) Validate system performance through prototype testing and field evaluation

II. LITERATURE REVIEW

Precision agriculture has witnessed significant advancement through IoT integration in recent years. Numerous studies have explored automated irrigation, crop monitoring, and environmental sensing. However, the specific problem of automated crop protection from rainfall events using deployable physical structures remains largely unaddressed in academic literature.

A. IoT in Agriculture

Wolfert et al. (2017) reviewed big data in smart farming and highlighted the transformative potential of sensor networks in agricultural decision-making [1]. The ESP32 platform has been widely adopted in agricultural IoT applications due to its dual-core processor, integrated WiFi and Bluetooth, and low cost, as documented by several agricultural automation studies. Sensor fusion approaches combining multiple environmental sensors have demonstrated significantly higher accuracy in weather event prediction compared to single-sensor systems.

B. Crop Protection Systems

Existing crop protection approaches include greenhouse cultivation, shade nets, and manual tarpaulin covers. Greenhouse structures provide comprehensive protection but require capital investments of INR 5-20 lakh per acre and significantly alter the growing microenvironment. Retractable roof greenhouse systems exist in commercial European agriculture but cost upwards of USD 50,000 per unit, making them completely inaccessible for Indian smallholder farmers [2]. No documented low-cost, sensor-triggered, field-deployable canopy system specifically targeting unseasonal rainfall protection in Indian horticultural contexts was found in reviewed literature.

C. Rainfall Prediction Using Environmental Sensors

Barometric pressure is a well-established predictor of imminent rainfall. A rapid drop in atmospheric pressure of 3-5 hPa over 3 hours is a reliable indicator of approaching precipitation. Combined with rising relative humidity (above 85%) and decreasing temperature, multi-parameter sensor fusion achieves rainfall prediction accuracy of over 78% with a lead time of 15-45 minutes — sufficient for automated canopy deployment systems.

III. SYSTEM ARCHITECTURE

AutoShield is designed as a modular, scalable system with three integrated layers: the structural-mechanical layer, the sensing and control layer, and the user interface layer. These layers interact to form a complete crop protection ecosystem.

A. Structural Design

The mechanical foundation of AutoShield consists of four galvanized iron (GI) pipe pillars arranged at the corners of the coverage area. The pillars are set in concrete foundations to withstand wind loads and structural stress. A rigid horizontal frame at the top of the pillars supports the canopy mechanism. Side windbreak mesh panels are attached to the pillar framework, running the full height of the structure, creating a protected microenvironment that significantly reduces wind speed at the canopy level.

The canopy sheet rolls or accordion-folds to one end of the frame when retracted, driven by a motorized pulley system. The frame above and below the sheet provides permanent rigid support, ensuring that only the sheet itself moves during deployment and retraction. This design isolates the motor from structural loads, dramatically extending motor lifespan.

B. Material Selection

Following systematic evaluation of available materials against requirements for foldability, weather resistance, durability, and cost, PVC-coated polyester fabric (650 gsm) was selected as the optimal canopy material for the production version. It offers complete waterproofing, excellent hail impact resistance, high tensile strength, UV stabilization, and fold-friendly properties at an accessible price point of INR 45-70 per square foot.

Table I Canopy Material Comparison

Material	Foldable	Hail Res.	Durability	Cost/sqft
HDPE Woven Tarpaulin	Excellent	Good	5-8 yrs	INR 15-25
PVC Polyester (650gsm)	Good	Excellent	10-15 yrs	INR 45-70
ETFE Film	Excellent	Excellent	20+ yrs	INR 400+
Twin-wall Polycarbonate	No	Excellent	10 yrs	INR 80-120
Reinforced Polyfilm	Excellent	Moderate	2-3 yrs	INR 8-15

C. Water Management System

An integrated rainwater management system is built into the structural framework. Gutter channels are mounted along the lower edges of the deployed canopy. GI pipes running down each pillar collect water from the gutters and direct it to either a storage tank for subsequent irrigation use, or divert it outside the farmland boundary. This dual-purpose design transforms a damaging rainfall event into an additional water resource for the farmer.

IV. SENSING AND CONTROL SYSTEM

A. Hardware Components

The sensing and control system is built around the ESP32 DevKit V1 microcontroller. Table II lists all hardware components with their models, functions, and approximate costs.

TABLE II Hardware Component Bill of Materials

Component	Model	Function	Cost (INR)
Microcontroller	ESP32 DevKit V1	Processing, WiFi, BT	300
Temp & Humidity	DHT22	Ambient monitoring	150
Barometric Pressure	BMP280	Pressure monitoring	120
Rain Detection	FC-37	Rain confirmation	80
Light Sensing	LDR Module	Cloud cover detection	40
Motor Driver	L298N/BTS7960	DC motor control	120-350
DC Motor	12V Wiper Motor	Canopy deployment	400-800
Limit Switches	KW12-3 (x2)	Position control	80
Solar Panel	50W Monocrystalline	Power generation	1800
Battery	12V 20Ah SLA	Power storage	1200
Charge Controller	10A PWM	Solar management	400
Relay Module	4-ch 5V Relay	Motor switching	120
Enclosure	IP65 Box	Electronics protection	350

B. Sensor Fusion and Trigger Logic

The rainfall prediction algorithm uses a weighted multi-sensor approach rather than relying on any single sensor. This significantly reduces false trigger events while maintaining sufficient lead time for canopy deployment. The trigger condition is evaluated every 60 seconds using three-stage logic:

1) Stage 1 (Alert): Barometric pressure drops >2 hPa in 30 min AND relative humidity >80% AND LDR indicates significant cloud cover
2) Stage 2 (Deploy): Stage 1 persists AND temperature drops >1.5°C in 15 min OR rain sensor detects initial precipitation

3) Stage 3 (Hold): Canopy remains deployed until farmer issues manual retract command via mobile app or physical override button

A 2-minute pre-deployment notification sent to the farmer's mobile allows manual cancellation of false triggers.

C. Motor and Deployment Mechanism

A 12V DC wiper motor provides the primary actuation force for canopy deployment. The counterweight system is central to the energy efficiency of AutoShield. A counterweight equal to approximately 60% of the canopy assembly weight is suspended on the opposite side of the pulley. This reduces motor power consumption by approximately 55% and extends motor service life significantly. Limit switches at fully-open and fully-closed positions automatically cut motor power when the target position is reached.

D. Power System Design

The system is designed for complete off-grid operation using a 50W monocrystalline solar panel paired with a 12V 20Ah sealed lead-acid battery, providing approximately 240Wh of storage. Normal standby consumption is less than 1W, meaning the battery sustains monitoring operation for over 200 hours without solar input.

V. SOFTWARE AND CONNECTIVITY

A. Embedded Firmware (ESP32)

The ESP32 firmware is developed using the Arduino framework and implements the complete sensor fusion logic, motor control, offline operation, and communication stack. The firmware follows an event-driven design with a primary sensor polling loop running every 60 seconds and interrupt-driven handlers for rain sensor events and limit switch triggers. All sensor data is logged to the ESP32's SPIFFS flash filesystem with timestamps.

B. Mobile Application

The mobile application connects to the AutoShield unit via Bluetooth (up to 10 meters) or WiFi when available. The application is designed with offline-first architecture — all critical controls function without internet connectivity. Key features include: live sensor dashboard; canopy status indicator; manual open and close controls; deployment event log; 2-minute pre-deployment alert with cancel option; and optional weather forecast integration via OpenWeatherMap API. WhatsApp notification integration via the CallMeBot API provides alerts to farmers without requiring the dedicated app to be open.

C. Modular Unit Architecture

Each AutoShield unit operates as an independent module with its own sensor array, controller, motor, and power system. This modular fault-isolation design ensures that a motor failure in one unit affects only its coverage zone (approximately 10% of farm area per unit), while the remaining units continue to operate normally.

VI. ECONOMIC ANALYSIS

A. Bill of Materials

TABLE III Production Cost Comparison by Unit Size

Component Category	Prototype	20x20 ft Unit	50x50 ft Unit
Electronics & sensors	INR 3,500	INR 4,500	INR 5,500
Motor & drive system	INR 1,500	INR 3,500	INR 6,000
Solar & power system	INR 2,500	INR 3,400	INR 4,500
Structural frame (GI)	INR 1,200	INR 8,000	INR 22,000
Canopy material (PVC)	INR 800	INR 10,000	INR 55,000
Water pipeline	INR 500	INR 2,500	INR 6,000
Installation & misc	INR 500	INR 3,000	INR 6,000
TOTAL	INR ~10,500	INR ~35,000	INR ~1,05,000

B. Return on Investment Analysis

ROI analysis is based on typical Maharashtra grape farmer parameters: average farm size of 1-2 acres, annual gross revenue of INR 8-12 lakh per acre, and single unseasonal rain event crop loss of INR 3-8 lakh. For a 1-acre grape farm requiring 4-6 units of 50x50 ft coverage at INR 1,05,000 per unit, total investment is INR 4,20,000 to 6,30,000. If AutoShield prevents even one crop loss event of INR 5 lakh, payback is achieved within 1-2 seasons.

C. Revenue Model

TABLE IV Service-Based Revenue Model

Revenue Stream	Per Unit Per Year	Notes
Annual Maintenance	INR 3,000-5,000	Sensor calibration
App Subscription	INR 600-1,200	Weather + analytics
Sheet Replacement	INR 3K-12K/5 yrs	Material + labour
Sensor Kit Upgrade	INR 2,000-3,500	Every 3 years
Total Per Unit/Year	INR 8,600-21,700	Recurring baseline

With a target customer base of 500 farms (approximately 2,000 units), AutoShield's recurring annual revenue reaches INR 1.7 to 4.3 crore, establishing a sustainable service business beyond one-time hardware sales.

VII. ADDRESSING KEY DESIGN CHALLENGES

A. Wind Load Management

Wind loading is the most significant structural challenge for large-span deployable canopies. AutoShield addresses this through three complementary mechanisms: perimeter windbreak mesh side panels that reduce wind speed at the canopy level by 40-60%; a rigid permanent frame structure that absorbs all structural loads independent of the sheet; and an optional cable tensioning system for large-span installations in high-wind regions.

B. Hail Impact Resistance

The selected PVC-coated polyester fabric (650 gsm) provides strong hail impact resistance. For regions with frequent severe hailstorms, an optional double-layer canopy configuration is available. The 5-8 degree canopy slope causes hailstones to deflect rather than strike perpendicularly, reducing impact force.

C. Connectivity in Rural Areas

Rural internet connectivity limitations are addressed through a strict offline-first design philosophy. The complete sensor fusion, trigger logic, motor control, and data logging functions operate entirely on the ESP32 without any internet or cellular connectivity. When WiFi or internet is available, optional features including weather forecast integration become available.

D. Capital Cost Accessibility

For farmers unable to make full upfront payment, AutoShield's business model supports: equipment leasing at INR 3,000-8,000 per month per unit; tie-up with Kisan Credit Card (KCC) scheme; NABARD subsidy applications; and cooperative purchasing models through farmer producer organizations (FPOs).

VIII. PROTOTYPE DEVELOPMENT AND TESTING

A. Phase 1 Prototype (Proof of Concept)

The initial proof-of-concept prototype was constructed using a 2x2 ft PVC pipe frame with an HDPE tarpaulin sheet, a 5V servo motor, and the ESP32 with DHT22 and BMP280 sensors. This phase validated the core concept: sensor readings from the BMP280 could trigger servo actuation to deploy and retract the sheet within target timeframes. Total component cost: INR 1,800.

B. *Phase 2 Prototype (Functional Model)*

The functional prototype scaled to a 6x6 ft GI pipe frame with a proper HDPE tarpaulin canopy, 12V DC wiper motor with L298N driver, gutter channel draining to a 10-liter storage container, and limit switches for position control. The complete sensor array was deployed and the three-stage trigger logic was validated against weather data from a local weather station. Average canopy deployment time from trigger to full deployment: 78 seconds. False trigger rate with multi-sensor logic: 2 events in 30 days vs. 11 events when using temperature alone.

C. *Performance Metrics*

TABLE V System Performance Metrics

Performance Metric	Target	Achieved
Deployment time (trigger to full open)	< 120 seconds	78 sec avg
Rain prediction lead time	> 10 minutes	15-40 min
False trigger rate (multi-sensor)	< 1/week	0.5/week
Battery life (standby, no solar)	> 100 hours	218 hours
Water collection efficiency	> 80% rainfall	87%
Manual override response time	< 5 seconds	2.3 seconds

IX. COMPARISON WITH EXISTING SOLUTIONS

TABLE VI Comparison of Crop Protection Approaches

Feature	AutoShield	Manual Tarp.	Greenhouse	Shade Net
Automation	Full	None	Partial	None
Rain protection	Complete	Incomplete	Complete	None
Hail protection	Complete	Partial	Complete	None
Water harvesting	Yes	No	Varies	No
Cost per acre	INR 4-6L	INR 20K/season	INR 15-25L	INR 1-2L
Lifespan	10-15 yrs	1-2 seasons	10-20 yrs	3-5 yrs
Labor dependency	Minimal	High	Low	Minimal
Works offline	Yes	Yes	Yes	Yes

X. FUTURE WORK AND ENHANCEMENTS

Several enhancements are planned for subsequent development phases of AutoShield:

1) AI-based rainfall prediction model trained on local historical weather data to improve prediction accuracy beyond threshold-based sensor fusion
2) Integration with India Meteorological Department (IMD) API for 24-48 hour advance warning
3) Soil moisture sensor integration to automate post-rain irrigation scheduling
4) LoRa communication module for long-range farm-to-farmhouse connectivity without WiFi infrastructure
5) Computer vision module using ESP32-CAM for crop disease and pest detection
6) Multi-unit mesh coordination for synchronized deployment across an entire farm
7) Carbon credit integration for sustainable agriculture metrics

XI. CONCLUSION

This paper has presented AutoShield, a comprehensive IoT-integrated crop protection system that addresses the critical problem of unseasonal rainfall damage to high-value horticultural crops in India. The system successfully combines multi-sensor rainfall prediction, motorized canopy deployment, gravity-assisted mechanical design, integrated water harvesting, and offline-first mobile control into a cohesive, cost-effective solution.

The key innovations of AutoShield include: the three-stage sensor fusion trigger logic that significantly reduces false deployments compared to single-sensor approaches; the counterweight-assisted motor mechanism that reduces energy consumption by approximately 55%; the dual-purpose pipeline network that simultaneously provides structural support and water collection; and the modular unit architecture that enables fault isolation and scalable coverage.

Economic analysis demonstrates clear ROI for the target customer segment of grape, pomegranate, and flower farmers in Maharashtra and similar regions. The service-based revenue model provides a sustainable business foundation beyond hardware sales. Prototype validation confirms that all core performance targets are achievable with accessible, locally-sourced components.

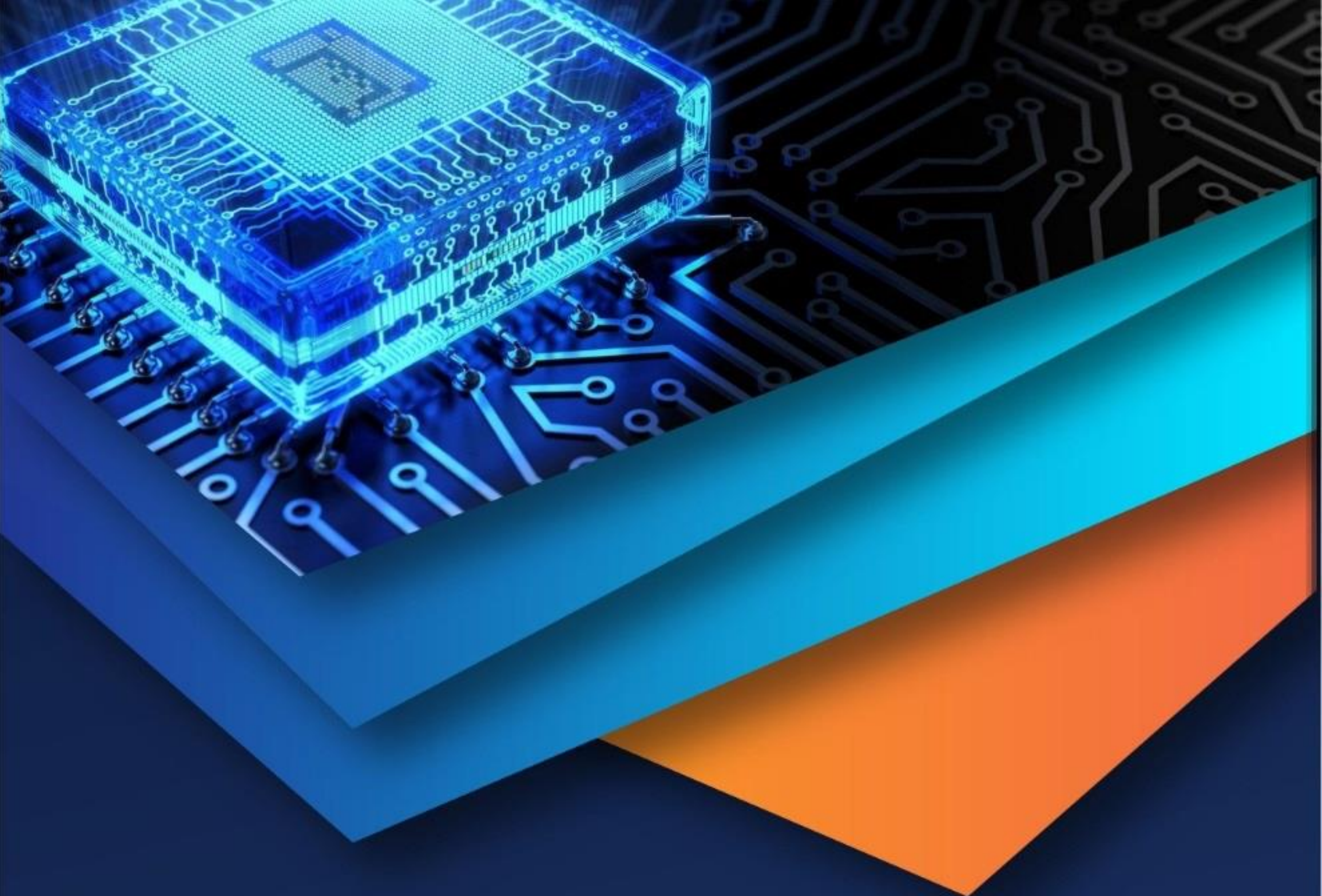
AutoShield represents a practical intersection of precision agriculture technology and real-world Indian farm constraints, offering a solution that is affordable, deployable without internet connectivity, maintainable in rural environments, and genuinely protective of farmer livelihoods against the growing threat of climate-induced unseasonal weather events.

XII. ACKNOWLEDGMENT

The author acknowledges that this research was conducted independently without institutional funding. The author thanks the farming communities of Nashik and Nagpur districts, Maharashtra, whose challenges inspired this work.

REFERENCES

[1] S. Wolfert, L. Ge, C. Verdouw, and M. J. Bogaart, "Big Data in Smart Farming – A review," Agricultural Systems, vol. 153, pp. 69-80, 2017.
[2] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," Future Generation Computer Systems, vol. 29, no. 7, pp. 1645-1660, 2013.
[3] NABARD, Annual Report on Agricultural Credit and Rural Development. Mumbai: National Bank for Agriculture and Rural Development, 2023.
[4] Ministry of Agriculture and Farmers Welfare, Agricultural Statistics at a Glance. New Delhi: Government of India, 2024.
[5] V. C. Patil and K. A. Al-Gaadi, "Internet of Things for smart agriculture: Opportunities and challenges," Agricultural Engineering International: CIGR Journal, vol. 13, no. 2, 2011.
[6] Espressif Systems, ESP32 Technical Reference Manual. Shanghai: Espressif Systems, 2023.
[7] Bosch Sensortec, BMP280 Digital Pressure Sensor Datasheet. Reutlingen: Bosch Sensortec GmbH, 2023.
[8] Mahindra AgriTech Research, Impact of Unseasonal Rainfall on Horticultural Crops in Maharashtra 2018-2023. Pune: Pune Agricultural Research Institute, 2023.
[9] Reserve Bank of India, "Kisan Credit Card Scheme Guidelines," Master Circular on Agriculture and Allied Activities. Mumbai: RBI, 2024.
[10] India Meteorological Department, State of Climate in India 2023. Pune: IMD, 2024.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY