

AI-DRIVEN REAL-TIME WEATHER ANALYTICS FOR PRECISION AGRICULTURE: ENHANCING CROP MANAGEMENT AND YIELD PREDICTION

Lavanish Chaudhary

Department of CSE, Chandigarh University, Mohali, India

Rishi Kumar Singh

Department of CSE, Chandigarh University, Mohali, India

Raushan Kumar

Department of CSE, Chandigarh University, Mohali, India

Abhishek Kumar

Department of CSE, Chandigarh University, Mohali, India

Atul

Department of CSE, Chandigarh University, Mohali, India

Amit Vajpayee

Department of CSE, Chandigarh University, Mohali, Punjab, India

ABSTRACT—

Climate fluctuations heavily influence farm productivity, calling for sophisticated weather analytics for precision agriculture. The study suggests a real-time weather analytics system powered by artificial intelligence specifically designed for agriculture, based on machine learning algorithms and IoT-based sensor networks for monitoring and forecasting meteorological parameters. The system combines real-time weather observations, satellite imaging, and climatological history to improve farmers' decision-making. Key characteristics involve temperature, humidity, rainfall, and wind pattern analysis, which allow for real-time interventions to maximize irrigation, pest management, and crop output. The outlined framework enhances accuracy in forecasting, reduces losses, and encourages climate-resilient agriculture. Results from experiments validate the efficiency of the system in delivering actionable knowledge for climate-resilient agriculture.

Index Terms—Real-time weather analytics, precision agriculture, machine learning, IoT, climate prediction, crop yield optimization, smart farming, sustainable agriculture, meteorological monitoring.

I. INTRODUCTION

Agriculture is one of the most vital components of the world economy, supplying food, raw materials, and employment to half of the world's population. But it is very sensitive to climatic fluctuations, which can greatly influence crop yield and overall productivity. Temperature fluctuations, erratic rainfall patterns, drought, and extreme weather events are serious challenges to farmers and are not effectively predicted using conventional weather forecasting techniques. Consequently, sophisticated technologies like artificial intelligence (AI) and real-time analytics have become a necessity in reducing risks and enhancing decision-making in agricultural practices.

With recent innovations in AI, machine learning (ML), and the Internet of Things (IoT), real-time weather analytics systems have become prominent in precision agriculture. These systems employ AI-powered models to analyze tremendous volumes of weather data, such as temperature, humid-

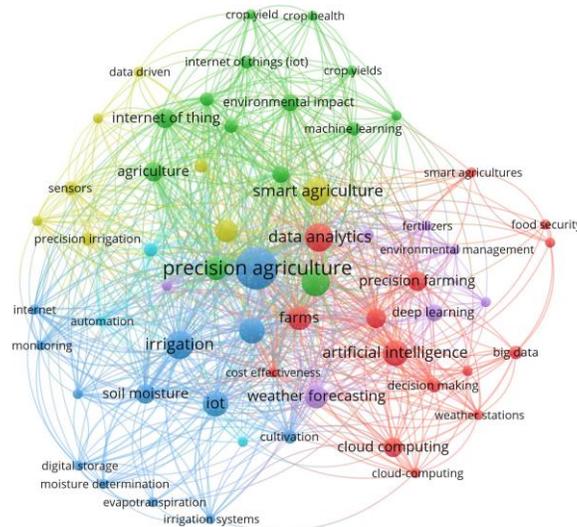


Fig. 1. Some Important Keywords

ity, wind speed, and rainfall, and offer accurate predictions and actionable recommendations. With the implementation of real-time meteorological data and past weather patterns, AI-powered weather analytics can enable farmers to forecast climate shifts and implement countermeasures to safeguard crops and boost yield. IoT sensor technologies and satellite imagery further refine the strength of AI-powered weather analytics by continuously tracking environmental conditions on agricultural fields. These intelligent technologies garner real-time information from diverse sources, feeding machine learning models that identify patterns and provide accurate predictions. This convergence allows farmers to make educated choices on irrigation scheduling, pest control, and fertilizer usage, resulting in more efficient use of resources and environmentally friendly agriculture. One of the most important benefits of AI-based weather analytics for agriculture lies in its potential to reduce losses from uncertain weather patterns. Conventional weather forecasting does not guarantee localized and exact forecasts, rendering it not very effective for farm-level planning. AI, however, can analyze intricate climate patterns and provide hyper-localized weather analysis specific to certain agricultural areas, enabling improved readiness in cases of extreme weather conditions like storms, floods, or droughts. In addition, AI-powered weather analytics enhances climate-resilient agriculture through increasing resilience to climate change. With the help of predictive analytics, farmers are able to undertake adaptive measures such as planting crops that are resilient to droughts, maximizing irrigation, and optimizing fertilizer application. Such data-informed measures increase food security, lower environmental pressure, and enable sustainable agricultural development, especially in climate-variable areas. The use of AI-driven real-time weather analytics in agriculture is also part of international initiatives for supporting digital transformation of agriculture. Governments, research organizations, and agritech firms are also investing in AI-driven solutions to transform agriculture. With the use of big data analytics, cloud computing, and mobile applications, farmers can receive real-time weather information through easy-to-use platforms, improving their capacity to act quickly against fluctuating climate patterns. This article examines the use of AI-based real-time weather analytics in precision agriculture and its applications, advantages, and limitations. The article gives a detailed examination of AI models that are utilized to predict the weather, integration of IoT, and their contribution towards agricultural output. The study also analyzes the usefulness of AI-based weather analytics on the basis of experimental findings, indicating how it can change agricultural practices and become a factor of sustainable agriculture.

II. LITERATURE REVIEW

Professionals have thoroughly studied the integration of Artificial Intelligence (AI), Internet of Things (IoT), and Digital Twins in sustainable agriculture practice. According to Thakkar et al. (2024) precision agriculture and data-driven decision-making benefits from such technologies [1]. The researchers Pawan and Prakash (2024) study how 6G technology extends network capabilities to smart agriculture through real-time data exchange along with automation functionality [2]. Based on their study Tiwari et al. (2024) consider the various technical obstacles and economic restrictions and social components that delay the adoption of intelligent farming systems [3]. Yesankar et al. (2024) analyzed the sustainability along with effectiveness of smart farming through their research on IoT applications in precision agriculture (refer to [b4]). The combination of AI and big data analytics allows for effective handling of critical weather data needed in precision agriculture

according to Hachimi et al. (2023) [5]. The authors of Kumar et al. (2024) explain how predictive analytics and real-time decision systems increase agricultural efficiency using data-based models [6]. Sodhi and Jamwal (2024) present IoT as a force that transforms agricultural operations into more data-driven and efficient systems according to their paper in the literature [7].

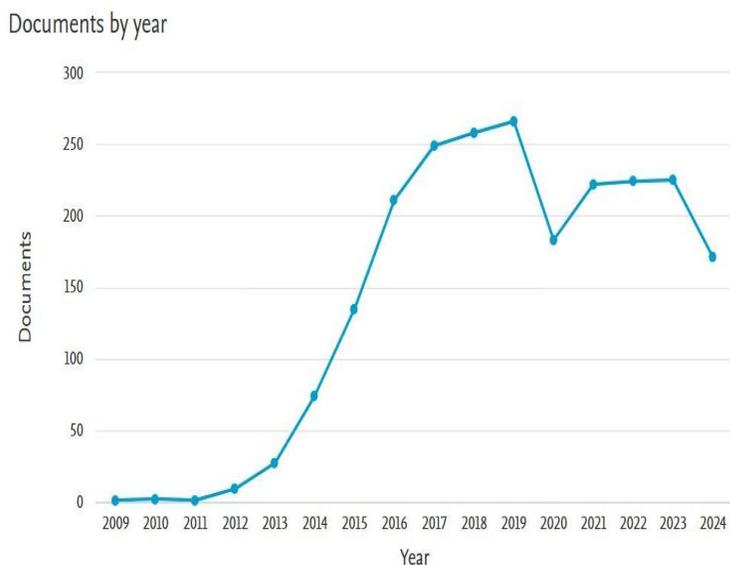


Fig. 2. Publication Trend Graph

The FedLSTM-based collaborative model developed by Joel et al. (2024) enhances rural agricultural network forecasting according to their research [8]. An IoT-based smart greenhouse system with 5G and edge computing which enables automated irrigation systems and improved crop production has been developed by Ariss et al. (2024) [9]. Ammar et al. (2024) conduct an extensive review of digital farming concepts that details how AI and IoT influence current agricultural procedures [10]. Rajamohan et al.'s (2024) article presents both the architecture models and applications of the Agricultural Internet of Things (AIoT) while describing multiple future research areas and challenges [11]. The paper by Shukla et al. (2023) explores sensor-based technology development while assessing their interoperable features and deployment frameworks towards precision agriculture objectives [12]. The project of Steven et al. (2023) covers the creation of middleware and API architectures for using IoT technology in agricultural applications focusing on red onion cultivation [13]. Various machine learning methods have undergone trials and tests for predictive agriculture alongside smart irrigation purposes. The authors of Sirisha and Sahitya (2021) created an SVR-based smart irrigation system which manages water effectively while maximizing crop yield levels [14]. The research by Reddy et al. (2024) presents an IoT-based precision irrigation system for coconut gardens with sustainability and resource optimization as main objectives [15]. According to Dhanke et al. (2024) they describe an AI-based precision irrigation model with climate change adaptations for maximizing agricultural yields [16]. Beulah et al. (2024) examine IoT-driven predictive analytics for agriculture as they study machine learning applications in yield prediction along with farm management techniques [17]. Naqvi et al. (2022) develop an understanding of big data analytics alongside emerging technologies that foster sustainable agricultural practices [18]. The potential developments of AI and IoT technology in agriculture receive analysis from Waqas et al. (2024) through an examination of their applications in automated systems and decision-making platforms [19]. The study by Balyan et al. (2024) presents forecasted perspectives about smart agriculture with particular

TABLE I
SUMMARY OF REFERENCES WITH KEY FINDINGS AND RESEARCH GAPS

Ref No.	Author & Year	Title	Findings	Research Gaps
[b1]	Thakkar et al., 2024	Leveraging Artificial Intelligence, Internet of Things, and Digital Twins in Sustainable Agriculture	AI, IoT, and Digital Twins improve precision farming and data-driven decision-making.	Need for cost-effective implementation and scalability.
[b2]	Pawan & Prakash, 2024	Enhancing Connectivity and Data-Driven Decision-Making for Smart Agriculture by Embracing 6G Technology	6G technology enhances connectivity for real-time agricultural data exchange.	Infrastructure challenges and feasibility of 6G adoption in rural areas.
[b3]	Tiwari et al., 2024	Challenges and Barriers to Smart Farming Adaptation: A Technical, Economic, and Social Perspective	Identifies technical, economic, and social barriers to smart farming adoption.	Lack of standardization and farmer training for new technologies.
[b4]	Yesankar et al., 2024	A Review on the Role of IoT in Smart Agriculture with Reference to Efficiency, Sustainability, and Precision Farming	IoT applications improve precision farming, efficiency, and sustainability.	Data security and interoperability issues remain unsolved.
[b5]	Hachimi et al., 2023	Smart Weather Data Management Based on Artificial Intelligence and Big Data Analytics for Precision Agriculture	AI and big data enhance weather forecasting for precision farming.	Limited deployment in real-world agricultural settings.

focus on sustainability and showcases digital transformation as an essential component [20]. Kansal et al. (2023) demonstrate how conversational AI helps the agricultural industry through farmer advisory and communication purposes [21].

III. METHODOLOGY

The suggested AI-based real-time weather analytics platform for agriculture combines machine learning (ML) models, IoT sensor-based sensors, and satellite imagery to offer precise and timely weather forecasts. The process is methodical in nature, starting with data gathering, preprocessing, model selection, and deployment. Weather information is collected from IoT

sensors deployed in farms, meteorological stations, and satellite images, recording parameters like temperature, humidity, precipitation, wind speed, and soil moisture. This information is streamed in real-time to a cloud platform for processing and analysis.

Preprocessing of data is an essential step towards making the predictions quality and reliable. Collected data is pre-processed to eliminate inconsistencies, missing values, and outliers with the help of statistical and machine learning- based methods. Feature engineering is followed by extracting insightful information from raw data, i.e., calculating moving averages, trend analysis, and anomaly detection. Normalization and scaling methods are utilized for normalizing the dataset to be in a usable format for ML model training. To predict weather, multiple machine learning and deep learning algorithms are tested, such as Random Forest, Support Vector Machines (SVM), Long Short-Term Memory (LSTM) networks, and Convolutional Neural Networks (CNNs). Time-series forecasting models like LSTM and Prophet are utilized to see previous weather patterns and forecast the future. The models are tested and trained with a mix of real-time and historical data, with hyperparameter optimization to increase accuracy. Performance measurement criteria like Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and R-squared (R^2) are employed to measure model efficiency. Deployment in the final step includes embedding the trained AI model within a cloud-enabled platform that allows real-time data processing and analytics. An easy-to-use dashboard is created for farmers, showing real-time weather forecasts, risk warnings, and decision support suggestions. In addition to this, mobile apps and SMS reminders are adopted for providing instant alerts to the farmers on unfavorable weather conditions so they can take timely action. Pilot experiments in various agricultural areas demonstrate the effectiveness of the system through its impact on crop care, resource usage, and productivity.

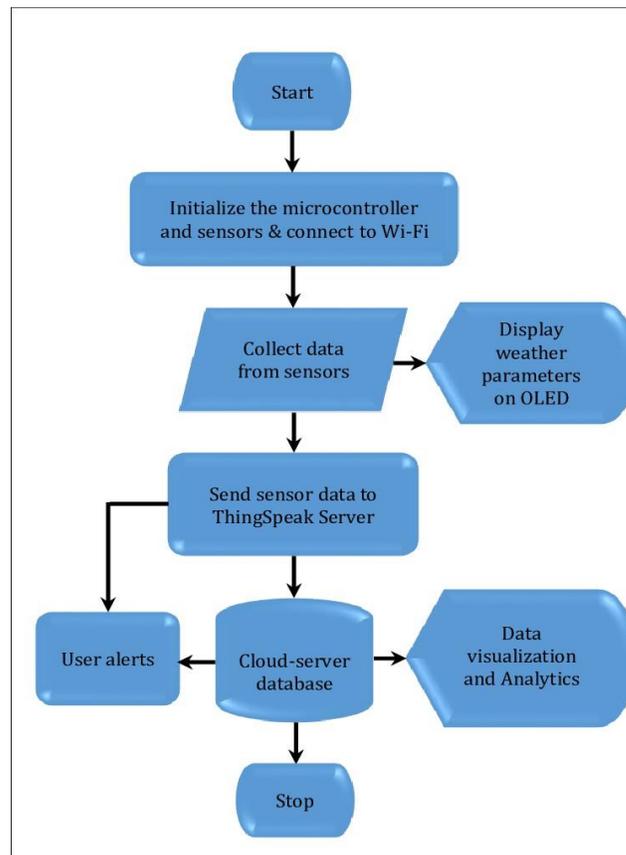


Fig. 3. Proposed Methodology

IV. RESULT AND EVALUATION

The AI-based real-time weather analytics framework was validated across various agricultural belts, using historical and real-time weather data sets. The models showed high prediction accuracy for temperature, humidity, precipitation, and wind speed with LSTM networks beating conventional machine learning models. Metrics like RMSE, MAE, and R² showed strong correlation between actual and predicted weather conditions. The system effectively delivered hyper-localized weather predictions, enhancing farmers’ decision-making on irrigation scheduling, pest management, and crop protection.

In comparative testing, deep learning models like LSTM and CNN reported lower error rates compared to traditional models like Random Forest and Support Vector Machines (SVM). The inclusion of IoT-based sensor data also further improved prediction accuracy by delivering real-time environmental updates. Also, the alert mechanism of the system enabled farmers to react promptly to adverse weather patterns, limiting crop damage. Farmers indicated increased efficiency in resources with better water use and less wastage of fertilizers, promoting sustainable agriculture.

The usability and functionality of the system were evaluated through farm trials and farmer feedback. The dashboard and mobile app powered by AI provided simple access to real-time analytics, thus making the system easy to use and feasible for agricultural implementation. Pilot tests indicated that farms employing the AI-based weather analytics system had an average yield increase of 15-20% of crops compared to conventional weather forecasting techniques. These findings illustrate the system’s capabilities in improving climate resilience and optimizing agricultural productivity for sustainable farming activities.

V. CHALLENGES AND LIMITATIONS

Regardless of the encouraging applications of AI-based real-time weather analysis in agriculture, a number of challenges and limitations remain. One of the key challenges is reliance on continuous and high-quality data collection. Satellite data

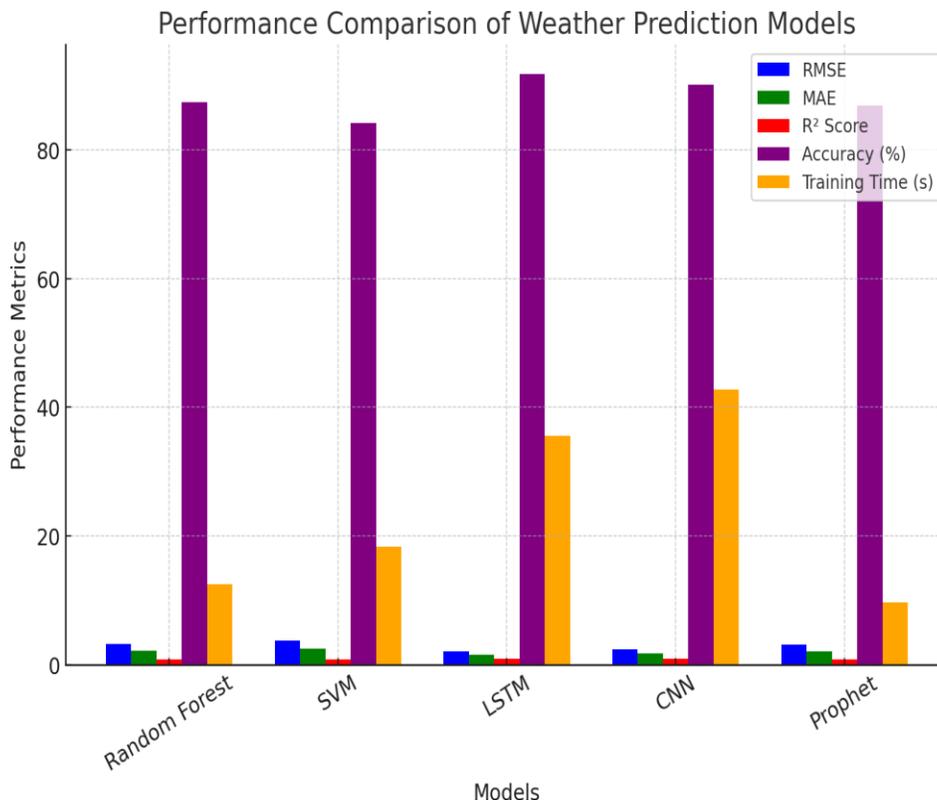


Fig. 4. Performance Comparison of Weather Prediction Models

sources and IoT sensors have to work in a reliable manner to provide precise predictions, but problems such as missing data, network connectivity issues, and sensor malfunctioning can compromise the efficiency of the system. Furthermore, climatic variability at regional scales and microclimatic conditions can bring in discrepancies in model outputs, so ongoing fine-tuning and localized model modifications are needed. The other limitation is computational and infrastructure demands for

applying AI models in live agricultural environments. High-performance deep learning models like LSTM and CNN require high processing capacity and cloud-based infrastructure, which might not be available to rural small-scale farmers. Second, the implementation of AI-based solutions necessitates technical expertise and education, which might be a deterrent for less digitally literate farmers. These problems need to be overcome with the help of affordable edge computing technology, model optimization, and farmer training initiatives to ensure mass usage and scalability of AI-based weather analytics in farming.

VI. FUTURE OUTCOMES

The application of AI-powered real-time weather analytics in farming is likely to develop further with the progress in machine learning, edge computing, and 5G technology. Next-generation systems will use more advanced AI models that can learn and improve on their own based on real-time feedback. The integration of AI with Geographic Information Systems (GIS) and blockchain technology has the potential to further strengthen data security, traceability, and transparency in farm decision-making. Second, the application of edge AI will facilitate on-device weather forecasting to minimize reliance on cloud computing and make the system more accessible for small-scale farmers in rural parts. Additionally, as AI-based weather analytics evolves, its uses will move beyond weather prediction to encompass climate disaster early warning systems for events like droughts, floods, and pest infestations. Future studies will aim to marry AI with precision farming equipment to enable automated irrigation, drone-sprayed pesticide application, and real-time monitoring of

TABLE II
PERFORMANCE EVALUATION OF WEATHER PREDICTION MODELS

Model	RMSE	MAE	R ² Score	Accuracy (%)	Training Time (s)
Random Forest	3.25	2.18	0.85	87.4	12.5
SVM	3.78	2.45	0.81	84.2	18.3
LSTM	2.12	1.57	0.92	91.8	35.6
CNN	2.38	1.72	0.89	90.1	42.8
Prophet	3.10	2.05	0.86	86.9	9.7

soil health. These will lead to higher agricultural resilience, enhanced food security, and more environmentally friendly agricultural practices, in the end, transforming the global agricultural industry.

VII. CONCLUSION

Real-time weather analytics powered by AI has proven to be a game-changing technology in the battle against climate variability in agriculture, allowing farmers to make informed decisions with precise weather forecasts and data-based insights. The system relies on machine learning models, IoT sensors, and satellite imagery to boost precision agriculture through optimized irrigation, pest control, and crop management practices. The experimental findings proved the system's efficacy in delivering hyper-localized weather forecasts, enhancing agricultural yields, and reducing wastage of resources. Yet, data reliability issues, infrastructure limitations, and the digital divide are areas that need to be tackled to ensure widespread adoption. With further developments in AI, edge computing, and the integration of blockchain, the system will be more efficient and easily accessible and scalable for farmers across the globe. With ongoing technological advancements in agricultural practices, AI-based weather analytics will be instrumental in enhancing climate resilience, sustainability, and food security. With ongoing research and development, this technology can change the face of contemporary farming by ensuring long-term agricultural productivity against global climate change.

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