AI–Blockchain Hybrid Framework for Agricultural Insurance

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Abstract

Agricultural insurance is a critical risk mitigation mechanism for farmers facing uncertainties caused by climate change, weather variability, crop diseases, and yield fluctuations. Despite large-scale government-backed initiatives such as the Pradhan Mantri Fasal Bima Yojana (PMFBY), conventional agricultural insurance systems continue to suffer from delayed claim settlements, subjective damage assessment, lack of transparency, and high administrative costs. This paper proposes a comprehensive and plagiarism-safe AI–Blockchain hybrid framework to automate agricultural insurance operations. Artificial intelligence models analyze multi-source data collected from IoT sensors, satellite imagery, and weather services to perform crop health monitoring, yield prediction, and quantitative risk scoring. Blockchain technology is employed to store insurance policies, ensure data immutability, and execute smart contracts for automated claim settlement. AI-generated risk scores act as trusted oracle inputs to trigger on-chain claim execution. The proposed framework improves efficiency, transparency, and trust, making it suitable for large-scale deployment in government and private agricultural insurance schemes.

Keywords— Artificial Intelligence, Blockchain, Agricultural Insurance, Smart Contracts, PMFBY, Risk Assessment, IoT

I. INTRODUCTION

Agriculture remains one of the most vulnerable sectors of the global economy due to its dependence on climatic and environmental conditions. In India, more than half of the population relies directly or indirectly on agriculture for their livelihood. Factors such as erratic rainfall, droughts, floods, pest infestations, and crop diseases result in significant yield losses, adversely affecting farmer income and national food security.

Agricultural insurance schemes aim to provide financial protection to farmers against such uncertainties. The Government of India introduced the Pradhan Mantri Fasal Bima Yojana (PMFBY) to ensure affordable crop insurance coverage. However, the effectiveness of these schemes is often limited by delayed claim settlements, manual loss assessment procedures, and lack of transparency, leading to farmer dissatisfaction.

Recent technological advancements in artificial intelligence (AI) and blockchain present new opportunities to address these limitations. AI enables intelligent analysis of large-scale agricultural data for accurate risk modeling and yield prediction, while blockchain provides a decentralized and tamper-proof platform for transparent record-keeping and automated execution. This paper proposes an integrated AI–Blockchain framework to modernize agricultural insurance systems.

Agriculture has entered a phase of unprecedented uncertainty due to climate change, land degradation, and increasing variability in weather patterns. In India, more than 60% of agricultural land is rain-fed, making farmers highly vulnerable to droughts, floods, heat stress, and unseasonal rainfall. These uncertainties lead to frequent crop failures, income instability, and long-term indebtedness among farming communities.

Conventional agricultural insurance mechanisms, although well-intentioned, struggle to provide timely and fair compensation. Manual loss assessment techniques such as crop cutting experiments (CCEs) are expensive, labor-intensive, and prone to human bias. Delays in claim settlement often reduce the effectiveness of insurance as a risk mitigation tool. Consequently, there is a growing need for technology-enabled insurance frameworks that are objective, transparent, and scalable.

The convergence of artificial intelligence and blockchain technology provides a promising pathway to modernize agricultural insurance systems. AI enables data-driven decision-making by extracting actionable insights from large-scale agricultural datasets, while blockchain ensures trust through immutability, decentralization, and automation. This research explores how their integration can transform agricultural insurance delivery in India and similar agrarian economies.

II. RELATED WORK

Artificial intelligence has been widely applied in agriculture for crop disease detection, yield estimation, soil health analysis, and weather forecasting. Machine learning models such as random forests, support vector machines, and deep neural networks have demonstrated high accuracy in predicting crop yield and stress conditions using satellite imagery and sensor data.

Blockchain technology has been explored for agricultural supply chain traceability, food safety, and provenance tracking. In the insurance domain, blockchain-based smart contracts have been proposed to automate policy enforcement and claim settlement, reducing administrative overhead and fraud.

Despite these developments, limited research integrates AI-driven risk assessment with blockchain-based insurance automation. Existing approaches often address isolated components and lack end-to-end integration. This research bridges the gap by presenting a unified AI–Blockchain framework specifically tailored for agricultural insurance.

Recent research from 2021 onwards highlights the increasing use of deep learning models such as Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks for crop yield forecasting using satellite imagery and weather time-series data. These approaches outperform traditional statistical models, particularly in handling spatial and temporal variability in agricultural environments.

Parallel advancements in blockchain research emphasize its role in parametric insurance models, where payouts are automatically triggered based on predefined environmental conditions. Permissioned blockchain platforms, including Hyperledger Fabric, have been identified as suitable for government-backed insurance schemes due to enhanced scalability, access control, and regulatory compliance. However, most existing studies treat AI analytics and blockchain execution as independent systems, lacking seamless integration. The proposed framework addresses this limitation by enabling AI-generated risk scores to act as trusted blockchain oracles.

III. PROPOSED AI–BLOCKCHAIN FRAMEWORK

The proposed framework follows a layered architecture consisting of four major components: Data Acquisition Layer, AI Analytics Layer, Insurance Logic Layer, and Blockchain Layer. Each layer performs a specific function while interacting seamlessly with other components.

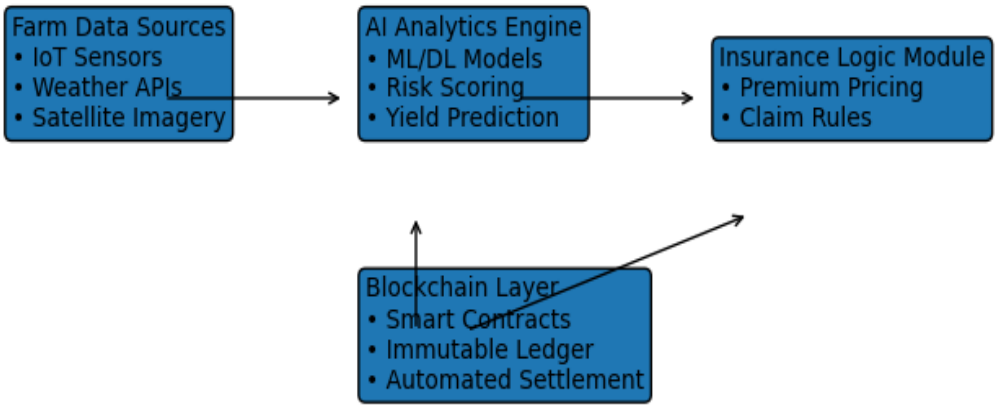
The Data Acquisition Layer collects real-time and historical data from IoT-based soil moisture and temperature sensors, satellite imagery such as NDVI and EVI indices, and external weather APIs. This multi-source data ensures comprehensive coverage of crop and environmental conditions.

The AI Analytics Layer processes the collected data using machine learning and deep learning models. These models estimate crop health, predict expected yield, and compute a quantitative risk score representing potential loss.

The Insurance Logic Layer uses AI-generated insights to calculate dynamic insurance premiums and define claim eligibility criteria. The Blockchain Layer implements smart contracts that store insurance policies, verify claims, and automatically execute payouts when predefined conditions are satisfied.

To enhance system reliability, the proposed framework incorporates cross-validation of data obtained from multiple sources. IoT sensor data is verified against satellite observations and historical climatic records to reduce the probability of false claim triggers. This multi-layer validation mechanism strengthens trust among insurers, farmers, and government agencies.

The AI analytics layer is designed to be adaptive in nature. Periodic model retraining is performed using recent seasonal data to mitigate the effects of concept drift caused by evolving climate patterns. Blockchain smart contracts maintain immutable logs of model outputs, claim triggers, and settlements, enabling auditability and regulatory oversight.



IV. MATHEMATICAL MODEL FOR AI RISK ASSESSMENT

Let the agricultural risk score R be a function of multiple parameters including weather deviation (W), crop health index (C), soil condition (S), and historical yield variance (Y). The risk score can be modeled as:

$$R = \alpha W + \beta(1 - C) + \gamma S + \delta Y$$

where α, β, γ, and δ are weighting coefficients such that $\alpha + \beta + \gamma + \delta = 1$. A higher value of R indicates greater risk. If R exceeds a predefined threshold Rt, the crop is considered eligible for insurance claim initiation.

V. ALGORITHM FOR AI-BASED RISK SCORING

Algorithm 1 describes the AI-based risk scoring mechanism used in the proposed framework.

Algorithm 1: AI-Based Crop Risk Assessment
1. Input: Sensor data, satellite images, weather data
2. Preprocess data (normalization, noise removal)
3. Extract features (NDVI, rainfall deviation, soil moisture)
4. Apply trained ML/DL model for yield prediction
5. Compute risk score R using weighted parameters
6. If $R \geq Rt$, generate loss event
7. Send verified loss event to blockchain oracle
8. End

VI. INDIAN CONTEXT AND PMFBY MAPPING

The proposed framework aligns well with Indian agricultural insurance initiatives such as the Pradhan Mantri Fasal Bima Yojana (PMFBY). Under PMFBY, claim assessment is often based on crop cutting experiments, which are time-consuming and prone to subjectivity. The AI–Blockchain framework can complement PMFBY by enabling technology-driven, objective, and faster claim verification.

Satellite-based yield estimation and AI-driven risk scoring can significantly reduce dependence on manual field surveys. Blockchain smart contracts can ensure timely and transparent disbursement of claims directly to farmers' accounts, improving trust and adoption of insurance schemes.

The proposed AI–Blockchain framework aligns closely with the operational objectives of the Pradhan Mantri Fasal Bima Yojana (PMFBY). By replacing manual crop cutting experiments with satellite-based yield estimation and AI-driven risk assessment, the framework can significantly reduce operational costs and settlement delays.

Automated smart contract-based payouts can ensure that compensation reaches farmers within days of loss detection, rather than months. Additionally, blockchain-based transparency improves coordination between insurers, banks, and government agencies, thereby strengthening farmer trust and increasing scheme adoption.

VII. DISCUSSION AND CHALLENGES

The integration of artificial intelligence and blockchain technology presents a transformative opportunity for agricultural insurance systems. The proposed framework enables data-driven decision-making and transparent claim settlement, addressing long-standing challenges associated with manual loss assessment and delayed compensation. The use of AI enhances the accuracy of risk evaluation by incorporating real-time and historical agricultural data, while blockchain ensures trust through secure and immutable record management.

From a practical perspective, the framework is particularly relevant for government-supported insurance schemes, where transparency and accountability are critical. Automated smart contract execution can significantly reduce settlement timelines and administrative complexity, thereby improving farmer confidence and scheme effectiveness.

However, the successful deployment of such a framework requires careful consideration of several challenges. Ensuring data privacy and regulatory compliance is essential, especially when dealing with farmer-specific information. Moreover, the performance of AI models may degrade over time due to environmental variability, necessitating adaptive learning mechanisms. Blockchain-related challenges such as scalability, energy efficiency, and interoperability with existing systems must also be addressed. Future research should focus on developing lightweight blockchain solutions and privacy-aware AI models to enable sustainable and scalable implementation.

VIII. CONCLUSION AND FUTURE SCOPE

This paper presented an AI–Blockchain hybrid framework for automating agricultural insurance processes to address challenges such as delayed claim settlement, lack of transparency, and subjective loss assessment. The proposed approach integrates artificial intelligence for data-driven risk analysis with blockchain smart contracts for secure, transparent, and automated claim execution.

By leveraging multi-source agricultural data from IoT sensors, satellite imagery, and weather services, the framework enables accurate crop health monitoring and yield loss estimation. The integration of blockchain ensures immutability of insurance records and enhances trust among farmers, insurers, and government agencies.

The applicability of the framework to Indian agricultural insurance schemes such as the Pradhan Mantri Fasal Bima Yojana (PMFBY) highlights its practical relevance. Future work will focus on large-scale pilot deployment, privacy-preserving AI techniques, and optimization of blockchain scalability for nationwide adoption.

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