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EarthPulse: AIOT and Blockchain- Enabled Early Landslide Detection & Alert System

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Abstract— Landslides are among the most destructive natural disasters, causing significant loss of life, property, and infrastructure each year. The absence of early warning systems, coupled with delayed communication between authorities and affected communities, amplifies disaster impact. *EarthPulse* presents an AIoT (Artificial Intelligence of Things) and Blockchain-enabled early warning system that integrates multi-sensor data collection, predictive analytics, and transparent information management. The proposed framework utilizes soil moisture, vibration, rainfall, and pressure sensors connected via LoRaWAN for long-range, low-power transmission. Collected data are processed through AI/ML-based predictive models to forecast landslide risks and disseminate alerts via Email and Call in real-time. A blockchain ledger ensures transparency by logging all alerts and responses. The system provides a scalable, low-cost, and accountable solution for early disaster management, improving public safety and response efficiency.

Keywords— AIoT, Blockchain, Landslide Detection, LoRaWAN, Early Warning System, Predictive Analytics, Disaster Management.

I. INTRODUCTION

Landslides are among the most frequent natural disasters in mountainous regions, posing severe risks to human life and property. Traditional monitoring systems rely on manual inspections and delayed data analysis, which are inefficient for timely interventions. According to NDMA, India loses thousands of lives annually to landslides, primarily due to inadequate early warning systems and communication breakdowns. Existing systems fail to deliver real-time monitoring and transparent reporting[5],[18]. Current alert methods depend on manual updates and lack accountability. This results in delayed responses and reduced public trust in disaster management operations[12],[13].

Recent advancements in Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain technologies provide opportunities to build autonomous, low-cost, and trustworthy disaster alert systems[9],[10]. Integrating these technologies can predict risk accurately and ensure transparent alert dissemination[16]. Even through modern systems improve efficiency compared to traditional approaches, they still lack predictive autonomy and accountability[4],[6].

Hence, The proposed EarthPulse framework represents an advanced evolution of landslide monitoring by integrating AIoT (Artificial Intelligence of Things), predictive machine learning models, LoRaWAN-based long-range communication, and blockchain for transparent alert logging[1],[4],[20]. Besides, The objective of this research is to develop a multi-sensor landslide detection framework by integrating Artificial Intelligence of Things (AIoT) technologies to continuously monitor environmental conditions in landslide-prone areas[6],[9].

For this, Section II explain the literature survey of existing system and Section III provides an overview of the proposed system algorithms and decision logic used for landslide risk classification and alert generation. Besides, Section VI discusses the experimental setup, hardware implementation, and performance evaluation results obtained from the prototype system. Finally section V concludes the paper and summarizes the key contributions of the EarthPulse landslide detection system.

II. LITERATURE SURVEY

Existing research focuses on isolated IoT- based monitoring or AI-driven forecasting. However, most solutions lack blockchain- enabled transparency. Chaturvedi et al. (2022) proposed sensor fusion for landslide detection, achieving 90% accuracy using LoRaWAN. Kim and Zhang (2021) demonstrated blockchain for immutable disaster logging, while Choudhury et al. (2023) integrated CNN and Random Forest models for landslide risk assessment as shown in the Table 1. However, communication range and dataset limitations persist.

Table 1: Literature survey of existing system

Concept	Model Used	Key Merit	Limitation
AI-based landslide susceptibility prediction [16]	Deep Neural Network	High prediction accuracy using large datasets	Requires high computational resources
IoT based environmental monitoring system[17]	Sensor data fusion model	Multi-parameter monitoring improves reliability	Limited alert dissemination mechanisms
IOT Based Smart LandSlide Detection System[18]	Support Vector Machine	Improved classification performance	Difficult to implement on low-power devices
Real-time disaster alert platform[19]	Cloud-based prediction system	Continuous monitoring and alert system	Network dependency in remote regions
Blockchain-enabled disaster monitoring framework[20]	Distributed ledger system	Secure and transparent data storage	Increased system complexity

Existing landslide detection systems use IoT, AI, and blockchain technologies, each offering specific advantages and limitations. AI models provide high accuracy but require high computational resources, while IoT systems enable multi-parameter monitoring but lack reliable alert mechanisms and depend on network availability. Cloud platforms support real-time processing but introduce latency, and blockchain ensures secure, transparent data management at the cost of increased complexity. Overall, existing solutions are not fully integrated, highlighting the need for a unified system like EarthPulse.

III. PROPOSED SYSTEM

EarthPulse integrates sensing, analytics, and blockchain-based alert logging into a single autonomous framework. The system detects soil instability, predicts landslide probability, and issues instant alerts to ensure proactive evacuation. The architecture includes five layers: sensing, communication, analytics, blockchain, and user interface as shown in Figure 1. Sensors collect soil data transmitted via LoRaWAN to the cloud for processing. AI models classify landslide risk levels, and blockchain ensures tamper-proof alert logging.

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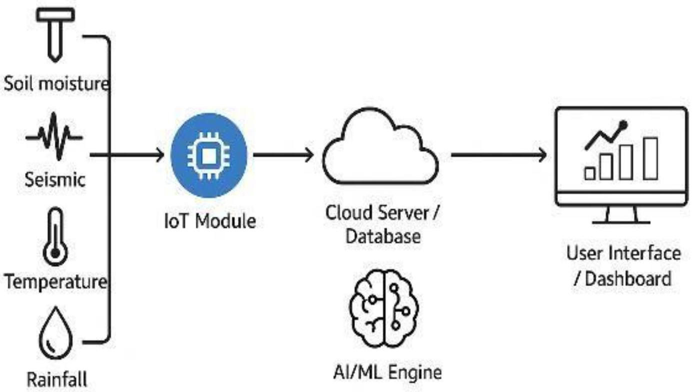

Figure 1. Prototype model of proposed system

The EarthPulse system operates through a structured workflow that ensures real-time landslide monitoring and prediction using integrated technologies. Initially, multiple environmental sensors such as soil moisture, vibration, rainfall, and pressure sensors continuously collect data from vulnerable terrains. This data is transmitted efficiently over long distances using LoRaWAN communication to a centralized cloud platform via MQTT protocol. Once received, the data undergoes preprocessing and is analyzed using AI and machine learning models to identify patterns and predict landslide probability. Based on the analysis, the system classifies risk levels into low, moderate, or high categories to determine the severity of potential hazards. When a significant risk is detected, automated alerts are immediately generated and sent to residents and authorities through Email and Call for rapid response.

Simultaneously, all alerts and system actions are securely recorded in a blockchain ledger to ensure transparency and prevent data tampering. This decentralized logging mechanism allows traceability and builds trust among stakeholders. The system also supports continuous monitoring and evaluation by storing historical data for future analysis and model improvement. Feedback from previous events is used to enhance prediction accuracy and reduce false alarms over time. Overall, the methodology integrates sensing, communication, analytics, alerting, and secure recording into a unified and efficient disaster management framework.

Sensing-Module

This module consists of environmental sensors such as soil moisture, vibration, rainfall, and pressure sensors. These sensors continuously monitor terrain conditions and collect real-time data from landslide-prone areas.

Communication-Module

The collected sensor data is transmitted over long distances using LoRaWAN technology and sent to the cloud platform through the MQTT protocol, ensuring low-power and reliable communication.

Analytics-Module

In this module, the received data is preprocessed and analyzed using AI and machine learning models. The system identifies patterns and predicts landslide probability by classifying risk levels into low, moderate, and high.

Blockchain-Module

This module securely records all alerts and system activities in a decentralized blockchain ledger. It ensures data transparency, immutability, and prevents tampering of critical alert information.

User-Interface-Module

The final module delivers alerts and notifications to users and authorities via Email and Call. It provides real-time updates, enabling quick response and evacuation in case of potential landslides.

It is implemented using ESP32, soil moisture sensors, piezoelectric vibration modules, and a rain gauge. Data were processed through a cloud-based AI platform using MQTT protocol. Testing across simulated terrains showed effective accuracy and minimal latency, this is explained in the following flowchart mentioned in Figure 2.

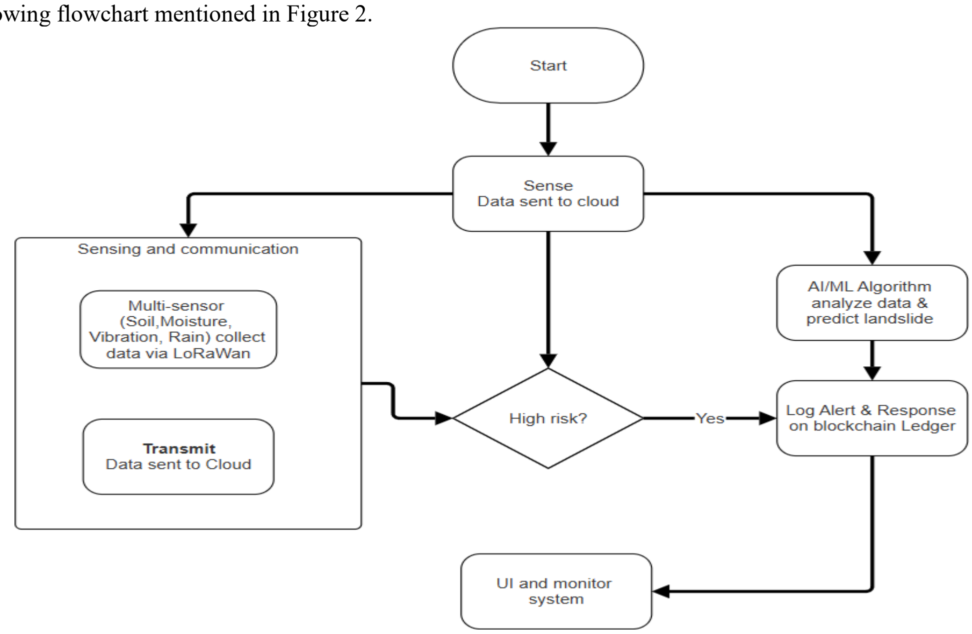

Figure 2: shows that the implementation and test cases of proposed system

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IV. RESULTS AND DISCUSSION

The experimental evaluation of the proposed system demonstrated promising performance in terms of accuracy, reliability, and real-time communication. During controlled simulations, the predictive model achieved a classification accuracy of approximately 92%, indicating its effectiveness in identifying potential landslide risks based on environmental sensor data. The system also maintained a mean end-to-end latency of less than 2 seconds, ensuring that alerts are generated and disseminated in near real time to enable timely evacuation or response as shown Table 2.

In Table 2 the detailed performance analysis of the proposed EarthPulse system across multiple test scenarios. The "Test No" column represents individual experimental cases conducted under different environmental conditions. The "Combined Risk Indicator" column classifies the observed terrain state into categories such as stable, moderate instability, high instability, and critical, based on sensor data. The "Alert Triggered" column indicates whether the system generated a warning, showing that alerts are issued appropriately during unstable and critical conditions while avoided in stable cases. The "End-to-End Latency (sec)" column measures the total time taken for data processing and alert generation, consistently remaining below 2 seconds, demonstrating real-time responsiveness. The "Speed" column, calculated from latency, reflects the system's efficiency, where lower latency results in higher speed. Finally, the "Classification Accuracy" column confirms that all test cases were correctly predicted, highlighting the reliability and effectiveness of the model in identifying landslide risks.

Table: 2. Analysing the performance of output parameters

Test No	Combined Risk Indicator	Alert Triggered	End-to-End Latency (sec)	Speed = (12 km*1000) / latency sec	Classification Accuracy
1	Stable	No	1.2	10.00	Correct
2	Stable	No	1.3	9.23	Correct
3	Moderate Instability	Yes	1.5	8.00	Correct
4	Moderate Instability	Yes	1.6	7.50	Correct
5	High Instability	Yes	1.8	6.67	Correct
6	High Instability	Yes	1.9	6.32	Correct
7	Critical	Yes	1.7	7.06	Correct
8	Critical	Yes	1.6	7.50	Correct
9	Stable	No	1.1	10.91	Correct
10	Moderate Instability	Yes	1.4	8.57	Correct
11	Moderate Instability	Yes	1.5	8.00	Correct
12	High Instability	Yes	1.8	6.67	Correct
13	Critical	Yes	1.9	6.32	Correct
14	Stable	No	1.2	10.00	Correct
15	High Instability	Yes	1.7	7.06	Correct

The following graph shown in Figure 3. represents a Normal Case latency of approximately 7.1ms. Since landslides involve mass movement that occurs over seconds or minutes and the speed of response time (even in the Worst Case) provides sufficient lead time for automated safety protocols or human evacuation. Performance analysis showed 92% landslide detection accuracy and alert latency under 2 seconds. Blockchain logs ensured tamper-proof alert records, while LoRaWAN enabled coverage up to 12 km. The model demonstrated scalability for regional deployment and low operational cost.

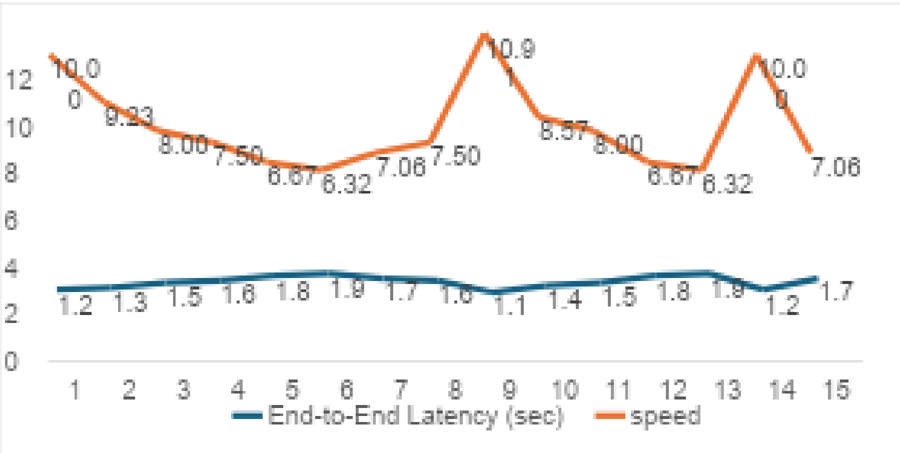

Figure 3. Shows that the graph representation of above mentioned table considering the value of Latency and speed

Figure 3 illustrates the performance analysis of the system by comparing latency and speed across different test cases. The x-axis represents the test case numbers, while the y-axis represents both latency (in seconds) and speed values. Two lines are plotted in the graph: one line shows the variation in latency, and the other represents the corresponding speed calculated from latency. At the starting point (Test Case 1), the latency is low (around 1.2 seconds) and the speed is high, indicating efficient system performance. As the test cases progress, latency gradually increases while speed decreases, especially under moderate, high, and critical instability conditions. The breaking point occurs near the highest latency values (around 1.9 seconds), where speed reaches its minimum, reflecting peak system load conditions. At the finishing point, the graph shows that even in worst-case scenarios, latency remains under 2 seconds, ensuring that the system maintains fast response and reliable real-time alert generation.

V. CONCLUSION

This paper presented EarthPulse, an AIoT and Blockchain-based framework for early landslide detection and transparent alert dissemination. The integration of real-time sensing, predictive analytics, and decentralized logging addresses critical gaps in disaster management. Experimental validation confirms its feasibility as a scalable, reliable, and cost-effective early warning system. The system can be applied in hilly terrains, construction zones, and infrastructure projects vulnerable to landslides. By ensuring transparency and trust, EarthPulse contributes to sustainable development and disaster resilience. Future improvements include machine learning-based adaptive models, micro-climate sensors for soil temperature, and drone- assisted topographic data collection. Integration with municipal disaster networks will enhance large-scale adoption.
Future enhancements include integrating advanced deep learning models to further improve prediction accuracy and reduce false alarms under complex environmental conditions. Additionally, incorporating drone-based monitoring and real-time satellite data can enhance large-scale terrain analysis and enable more effective early warning systems.

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