Secure Federated AI for Multi-Hazard Detection – A Review

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Abstract

In the last few years, many researchers have been working in the field of disaster prediction. The use of IoT together with artificial intelligence is one major area which supports the development of early warning systems. Here, devices like rainfall gauges, water level monitors, smoke alarms, and earthquake sensors are used to provide real-time information.When all this data is handled only through a central system, problems like privacy loss, less security, and lack of trust may happen. Federated Learning (FL) helps in reducing this issue because the training is done locally, and instead of sending the full raw data, only the updates are passed.. Even then, FL alone is not fully safe because it may face harmful updates and wrong results. Blockchain can be applied here, since it stores the updates in a secure and transparent way, which protects the data and improves trust. The early prediction of disasters and proper analysis are needed to reduce loss and damage. In this paper, the study discuss a review of the methods and techniques suggested by researchers by combining Blockchain and FL in the field of disaster prediction.

Index Terms: Federated Learning, Blockchain, IoT, Disaster Prediction, Early Warning

1.Introduction:

Natural disasters like floods, earthquakes, wildfires, and landslides are becoming more frequent and severe, making early prediction and effective management critical. Modern disaster management relies on IoT sensors—such as rainfall monitors, water-level gauges, seismic detectors, and smoke sensors—to collect real-time environmental data. However, sending all this sensitive data to a central server can create privacy issues and communication bottlenecks.

To overcome this limitation, the concept of Federated AI (Federated Learning) is introduced. Federated AI allows models to be trained locally on distributed sensors or devices, and only the learned updates are shared—not the raw data. This way, different regions can contribute to a shared disaster prediction model without exposing sensitive environmental information. , Federated AI helps IoT sensors collaborate effectively, reduces network load, and supports real-time, region-specific disaster predictions.

Despite its advantages, Federated AI faces challenges including insecure model updates, malicious interference, and organizational trust deficits. Integrating Blockchain technology provides a robust solution. Blockchain is a decentralized, immutable ledger that securely records model updates, ensuring transparency, preventing tampering, and building trust among participating agencies. Smart contracts further enhance security by automating validation, enforcing rules, and rewarding reliable participants.

The proposed system integrates Federated AI with Blockchain, creating a secure, privacy-preserving, and collaborative framework for disaster early warning. IoT sensors can train models locally, share updates safely via blockchain, and collectively improve prediction accuracy. This approach ensures trustworthy communication, tamper-proof aggregation of models, and efficient multi-hazard detection, making disaster management systems more reliable and effective.

Recent studies highlight the practical benefits of this integration. Tehseen et al. [19] proposed a federated learning framework for distributed earthquake prediction. Their privacy-preserving algorithms process extensive seismic datasets with high accuracy while keeping local data confidential. Similarly, Begam [20] introduced a system combining Federated AI and Blockchain for multi-hazard early warning, showing that this integration improves prediction accuracy and enables trustworthy data sharing across multiple agencies. Together, these studies demonstrate that Federated AI and Blockchain form a robust framework for resilient and trustworthy disaster management systems.

2. Literature Review

Disaster prediction and early warning systems have progressed considerably in recent years, propelled by advancements in Artificial Intelligence (AI), the Internet of Things (IoT), Federated Learning (FL), and Blockchain. Researchers worldwide have investigated both individual and combined applications of these technologies to improve the accuracy, responsiveness, and

reliability of disaster management. This section reviews key studies in these domains, examining achievements, persistent challenges, and prospects for integrated, resilient frameworks.

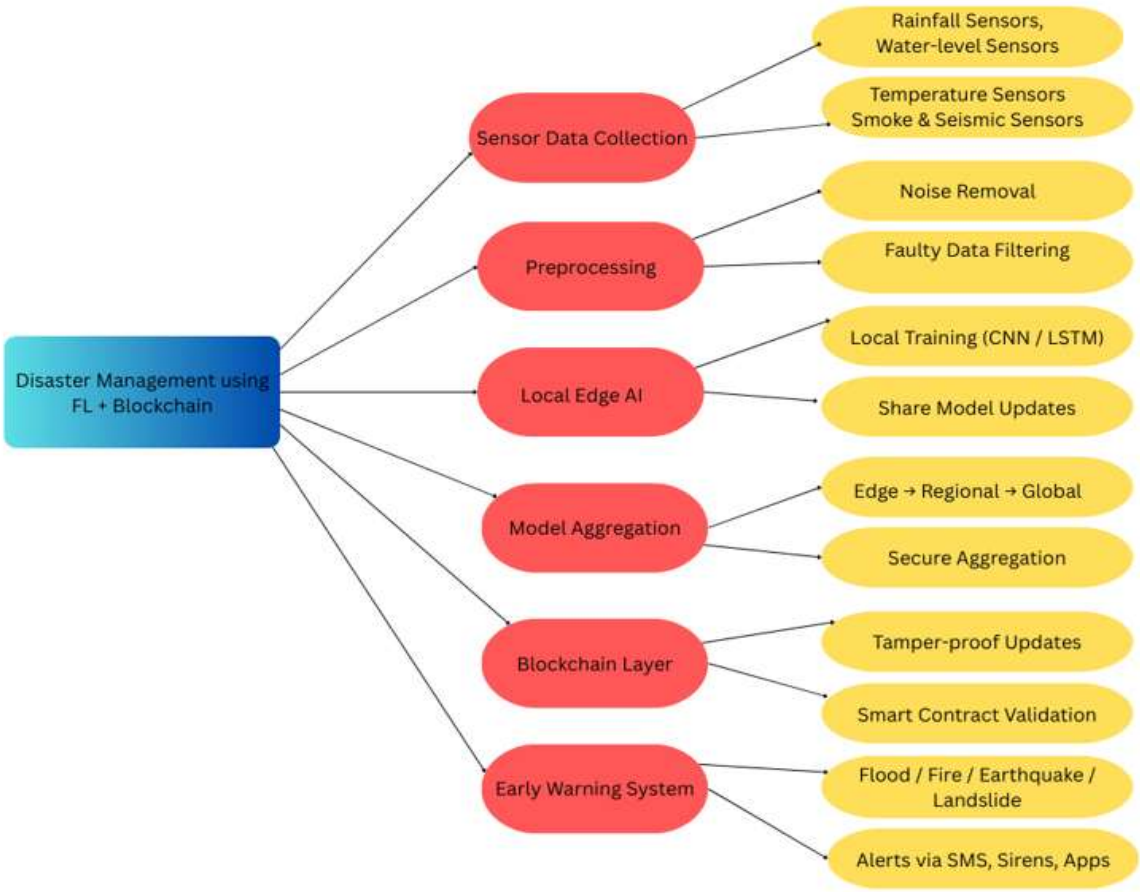

Fig. 1: Layout of Research Contributions for Disaster Early Warning Systems (DEWS)

The entire workflow of the literature review is shown in Figure 1. There exists many promising researches in the domain of detecting the disaster using FL and Blockchain.

2.1 AI and Machine Learning in Disaster Prediction

Artificial Intelligence is an essential tool for forecasting natural disasters. Hassan Rehan [1] demonstrated that combining machine learning models with IoT sensor data significantly improves the accuracy of flood and earthquake predictions. The study reported 85% prediction accuracy and substantially reduced response times, forming a robust framework for AI-driven early warning systems.

Building on this, Murali Krishna Pasupulet [3] investigated advanced AI techniques, including neural networks, ensemble models, and natural language processing. The study showed that AI not only improves hazard prediction but also enables real-time visualization, decision-making, and integration with technologies such as blockchain and augmented reality.

Md. Asif et al. [5] further analyzed how machine learning and deep learning enhance assessments of wildfires, earthquakes, and floods. Their work demonstrated that integrating AI with IoT and remote sensing facilitates real-time monitoring while also highlighting challenges related to data quality, model transferability, and infrastructure limitations in developing regions.

2.2 IoT-Enabled Early Warning Systems

Alongside AI, IoT has become central to disaster monitoring by enabling real-time data collection across diverse environments. Han Zhang et al. [10] developed a public safety alert system using heterogeneous sensors—including gas, flame, vibration, and biometric detectors—integrated with cloud and edge platforms such as AWS IoT and Firebase. Their prototype achieved 95% accuracy with low latency, demonstrating IoT's effectiveness in real-time monitoring, although energy consumption and limited predictive capabilities remained challenges.

Marco Esposito et al. [11] conducted a broader review of IoT-based early warning systems for floods, landslides, and earthquakes. Their analysis highlighted scalability, fault tolerance, and real-time data handling, while identifying barriers such as interoperability issues and the lack of standardized protocols.

Favour Olaoye and Axel Egon [8] approached early warning systems from a socio-technical perspective. They demonstrated that even advanced IoT setups are ineffective without proper communication, community preparedness, and trust, emphasizing that technical accuracy must be complemented by effective dissemination and citizen engagement for systems to save lives.

2.3 Federated Learning for Disaster Prediction

As privacy and data-sharing concerns increased, Federated Learning (FL) emerged as a promising solution. Sharma et al. [2] demonstrated the integration of FL into the Cognitive Internet of Vehicles (CIoV), turning vehicles into distributed data collectors. By collaboratively training models without centralizing data, their approach achieved 90% accuracy in disaster detection while preserving user privacy.

Juncen Zhu [12] further explored blockchain-empowered FL, or BlockFed, showing how blockchain can enhance federated learning by ensuring model integrity, secure data sharing, and fair incentive mechanisms.

Jianwei Huang et al. [15] extended these concepts to drone-based IoT systems combined with FL, blockchain, and 6G edge networks. Their model enabled drones to gather environmental data and collaboratively train models in real time, with blockchain providing trust and 6G ensuring ultra-low-latency communication. This study highlighted FL's scalability and adaptability for next-generation disaster management.

2.4 Blockchain in Data Security and Trust

Blockchain is essential for ensuring data integrity in disaster management systems. Zhu [12] and Huang et al. [15] showed that blockchain provides tamper-proof records of model updates in federated learning, promoting trust among agencies. Pasupulet [3] emphasized its role in securing IoT data streams, thereby enhancing the reliability of forecasting systems. Although blockchain increases transparency and accountability, challenges such as high computational requirements and energy consumption remain significant for real-time applications.

2.5 Hybrid AI–IoT–FL–Blockchain Approaches

Recent research emphasizes hybrid solutions integrating AI, IoT, FL, and blockchain. Fuzel Ahamed Shaik et al. [7] developed a holistic disaster ecosystem in Nordic countries by combining the INFORM risk framework with AI tools such as NLP, AutoML, and anomaly detection, covering prediction, risk communication, citizen trust, and psychological preparedness.

Singh et al. [4] showed that federated learning can function in privacy-sensitive environments while ensuring GDPR and HIPAA compliance. Secure aggregation and differential privacy allow multiple stakeholders to collaborate without exposing sensitive disaster-related data.

Esposito et al. [11] recommended integrating AI and FL into IoT architectures to enhance scalability and prediction. These studies demonstrate that hybrid ecosystems combining AI, IoT, FL, and blockchain are vital for resilient, ethical, and scalable disaster management systems.

3. Comparative Analysis of the Literature review

This section portrays the comparative view of the various research contributions related to the disaster early warning systems and also the assisting technologies that aids to provide a better lifestyle to the society.

Table 1 Comparative Review of Disaster Early Warning Techniques

S. No	Research Title	Year	Research Contribution	Techniques / Features	Key Results
1	Enhancing Disaster Response with AI	2020	Predictive modeling for floods & earthquakes	ML, IoT sensors, predictive simulation	85% accuracy; reduced response time
2	Disaster Identification with FL & CIoV	2021	Federated learning for vehicular IoT disaster detection	FL, Random Forest, Deep Learning	90% accuracy; privacy-preserving

3	AI-Driven Prediction & Early Warning	2021	Systematic review of AI applications in disaster forecasting	ML, DL, IoT, remote sensing	AI improves hazard forecasting but data issues persist
4	Federated Learning for Decentralized Prediction	2022	Privacy-sensitive disaster prediction	FL, secure aggregation, differential privacy	GDPR-compliant FL; improved privacy
5	AI-Based EWS in Nordic Countries	2022	Holistic disaster ecosystem with AI and citizen engagement	INFORM framework, NLP, AutoML, anomaly detection	Strengthened communication & resilience
6	Early Warning Systems Review	2020	Social & technical analysis of EWS	Surveys, case studies	Identified gaps in communication & citizen preparedness
7	AI-Powered Disaster Forecasting	2021	AI-enhanced forecasting with hybrid tech	DL, NLP, IoT, blockchain, AR	Improved accuracy; ethical & transferability issues
8	IoT Public Safety Alert	2019	IoT-based multi-sensor safety alerts	IoT sensors, edge computing, AWS IoT, Firebase	95% accuracy; 450 ms latency
9	IoT Solutions for EWS Review	2022	Generic IoT architecture for EWS	IoT, scalability/fault tolerance analysis	Identified interoperability & energy gaps
10	Blockchain-FL Integration	2020	BlockFed challenges and solutions	Blockchain, FL, consensus algorithms	Improved security & integrity
11	Drone-based, FL, Blockchain and 6G	2021	Drone-enabled decentralized prediction	FL, Blockchain, 6G edge computing	Scalable, low-latency, collaborative learning
12	AI for Risk Communication	2021	Citizen participation & trust in EWS	NLP, risk perception modeling	Better communication during crises
13	IoT-FL Hybrid Approaches	2022	Integration of AI/FL with IoT	IoT ,FL	Improved scalability & privacy
14	Blockchain for Integrity in Disaster Forecasting	2021	Securing IoT and AI data pipelines	Blockchain, cryptography	Transparency & trust but energy-intensive
15	Drone-Based Disaster Detection with FL, Blockchain, and 6G Networks	2021	Drone-enabled decentralized prediction	FL, Blockchain, 6G edge computing	Scalable, low-latency, collaborative learning
16	AI-driven disaster forecasting with IoT sensor data	2022	Demonstrated ML + IoT data integration for disaster prediction (floods & earthquakes)	Machine Learning models, IoT sensor data	85% prediction accuracy; reduced response time
17	Advanced AI for hazard prediction and visualization	2023	Explored neural networks, ensemble models, NLP for hazard forecasting & visualization	Neural networks, Ensemble, NLP, Blockchain & AR integration	Improved hazard prediction and support for decision-making
18	Toward Reliable Disaster Data Sharing With Blockchain and Zero-Knowledge Proofs	2025	Secure and privacy-preserving disaster data sharing	Blockchain, Decentralized Identity (DID), Zero-Knowledge Proofs (ZKP), DS4H prototype	Prototype shows feasibility; improves trust & privacy; scalability challenges

19	A Framework for the Prediction of Earthquake Using Federated Learning	2024	Developed FedQuake algorithm for distributed earthquake prediction with privacy-preserving FL	Federated Learning, FedQuake aggregation, Meta-classifier, Random Forest	88.87% accuracy on 35 years of seismic data (Western Himalayas); reduced data loss; privacy preserved
20	Federated AI with Blockchain for Disaster Early Warning	2025	Combines Federated AI and Blockchain to achieve both accurate prediction and trustworthy data sharing	Federated Learning, Blockchain integration, Secure aggregation, Privacy-preserving collaboration	Framework ensures accurate prediction (via FL) and secure, tamper-proof disaster data sharing (via Blockchain)

Thus the table 1 provides a comparative view of the techniques used in the recognition of various kinds of disaster and the technologies employed to improve the early detection of disaster. The Figure 2 shows the bar chart representation of the works contributed towards the research of disaster early warning systems using blockchain.

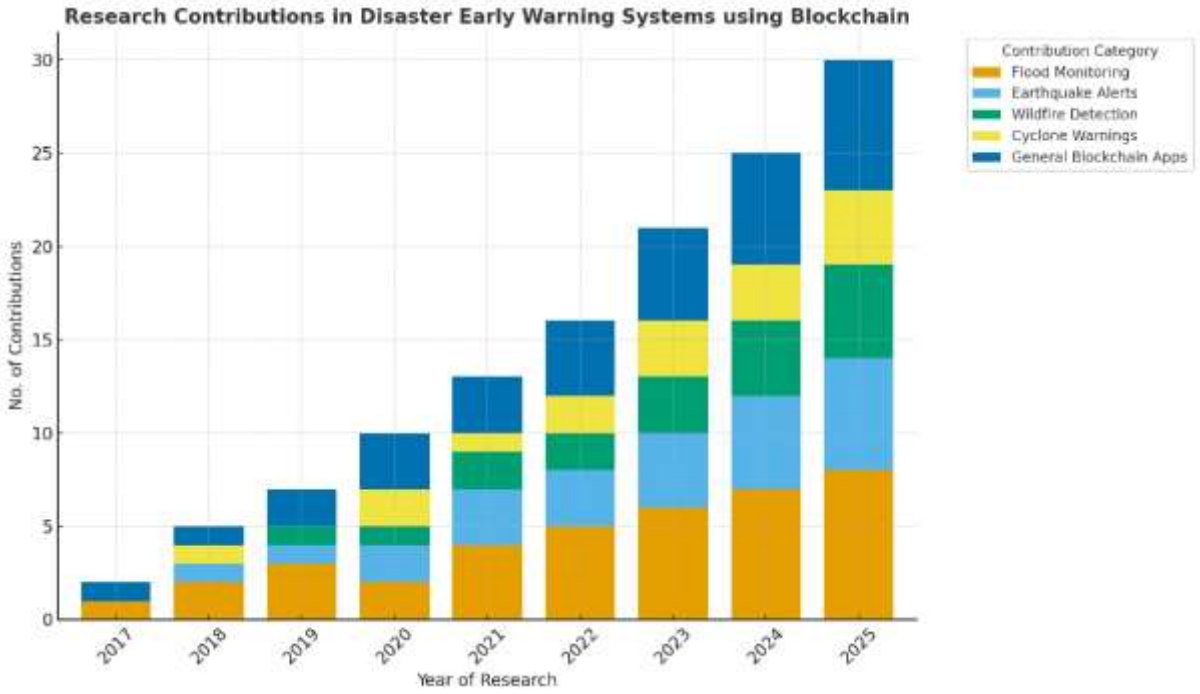

Fig. 2 Representation of research contributions

4.Conclusion

The review of research on secure federated AI for multi-hazard detection indicates that integrating AI, IoT, Federated Learning (FL), and Blockchain is transforming disaster early warning systems. Centralized systems often face limitations in privacy, trust, and scalability, while FL allows local model training on distributed devices, preserving sensitive data. Blockchain complements this by providing transparency, security, fostering inter-agency trust, and preventing tampering. AI-based predictive models achieve up to 95% accuracy in disaster alerts, and blockchain-enabled federated frameworks maintain integrity and fairness, demonstrating progress toward reliable, ethical, and collaborative disaster management. Despite these advances, challenges such as energy consumption, interoperability gaps, and the computational demands of blockchain remain. Future hybrid frameworks that combine AI, IoT, FL, and blockchain while incorporating social and community engagement will be crucial for resilient, effective, and future-ready disaster early warning systems capable of protecting lives and resources.

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