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Review Article

IoT-Driven Disaster Management Systems: A Framework for Early Warning, Mitigation, and Resilient Recovery

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A B S T R A C T

The Internet of Things (IoT) has emerged as a transformative paradigm reshaping disaster management through intelligent connectivity, real-time sensing, and automated decision-making. This paper explores the evolution of IoT from early networked devices to its present role in enabling resilient, data-driven disaster response frameworks. It analyses traditional early warning mechanisms and contrasts them with IoT-enabled systems that integrate sensors, cloud platforms, and AI analytics for proactive mitigation and rapid recovery. Applications across domains, including floods, landslides, wildfires, earthquakes, and counter-terrorism, demonstrate how IoT enhances situational awareness, resource coordination, and risk reduction. Real-life case studies from Jakarta (2024) and Mogadishu (2025) exemplify IoT's practical potential in urban flood management and smart drainage infrastructure. The findings emphasise that integrating IoT into disaster management enhances preparedness, minimises response delays, and fosters sustainable resilience against natural and anthropogenic threats.

Keywords: Internet of Things (IoT), Disaster Management, Early Warning Systems, Smart Cities, Real-Time Monitoring

Introduction

The Internet has transformed telecommunications into a global connectivity platform, with innovations like VoIP enabling seamless voice communication over data networks. This evolution has given rise to the IoT, a paradigm that interconnects everyday devices and resources for remote monitoring and control via internet access. Conceptualised at MIT's Auto-ID Labs in the early 1990s, IoT's early milestones include the 1993 Trojan Room Coffee Pot at the University of Cambridge, an internet-connected webcam for monitoring coffee levels, often regarded as the first IoT device, and the 1990 internet-enabled toaster for remote operation. Over time, IoT research has proliferated, yielding varied definitions; the ITU defines it as "a global infrastructure for the information society, enabling advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies".[1] At its essence, IoT promotes device synchronisation with minimal human involvement, creating an ecosystem of intelligent objects. It has progressed through phases: the Internet of Content for multimedia transmission, the Internet of Services for user-centric data sharing, e.g., email attachments, and the current era of autonomous connectivity for billions of devices executing tasks via predefined algorithms.[2] IoT now drives Industry 4.0, enhancing profitability and efficiency in sectors like manufacturing and logistics through sensors, cloud computing, and edge processing. This integration unlocks novel business opportunities, particularly in disaster management, where real-time sensor data supports early warnings, resource allocation, and coordinated responses to save lives and reduce economic impacts. Figure 1 highlights the evolution of connectivity from traditional communication to IoT ecosystems.[3] This paper examines IoT's role in disaster management, underscoring its potential to mitigate risks and bolster resilience.

The reminder of this paper is as follows: Section 2 presents a detailed literature review outlining the historical evolution and foundational milestones of IoT systems. Section 3 classifies different types of disasters and highlights the key phases of disaster management. Section 4 discusses conventional early warning mechanisms and their limitations, while Section 5 explores IoT-enabled approaches for disaster mitigation. Section 6 categorises various IoT-based disaster recovery systems, and Section 7 provides real-life case studies demonstrating IoT's practical applications in disaster management. Finally, the paper concludes with key findings and future research directions in the Conclusion section.

Literature Review

The foundation of IoT-enabled disaster management systems traces back to the early innovations in networked devices, which laid the groundwork for interconnecting physical objects with digital networks. A seminal example occurred in 1982 when four Carnegie Mellon University students connected a vending machine to ARPANET, the precursor to the modern internet, to monitor the temperature and inventory of Coca-Cola cans. This system allowed users to remotely check if drinks were sufficiently chilled and estimate wait times before restocking, using a simple network interface to avoid unnecessary trips to the machine. This experiment sparked widespread interest among researchers, inspiring the development of connected appliances and foreshadowing the potential for real-time monitoring in critical applications, such as disaster response.[4]

Building on this momentum, the 1990s saw significant advancements in identification and tracking technologies. IBM researchers proposed and patented RFID systems using UHF tags, which enabled long-range, high-speed data transmission for asset management. Despite conducting promising pilot studies, IBM faced commercialisation challenges and auctioned the patents to Intermec, a barcode technology firm. Intermec's RFID implementations gained traction in supply chain logistics, though high costs and power limitations initially hindered widespread adoption.[5] To address these barriers, Professor David Brock and Sanjay Sarma at MIT's Auto-ID Center advocated for low-cost RFID tags integrated with barcodes, enhancing item tracking in distribution networks while reducing expenses and enabling scalable memory for complex data storage. These tags were linked to centralised databases accessible via the internet, forming an early blueprint for ubiquitous connectivity.[6]

The term "Internet of Things" was formally coined in 1999 by Kevin Ashton, Executive Director of MIT's Auto-ID Center, during a presentation on RFID's role in supply chains. Ashton envisioned IoT as a transformative force, capable of reshaping industries much like the internet itself. However, some sources credit Neil Gershenfeld, a physicist at MIT's Center for Bits and Atoms, with early conceptual contributions, as reflected in his 1999 book When Things Start to Think, which explored the implications of intelligent, networked objects. These developments marked the shift from isolated experiments to a cohesive IoT paradigm, emphasising seamless data exchange without human intervention.[7]

Table 1 outlines the key evolutionary milestones of IoT systems from 1982 to 2025, highlighting how these innovations have progressed toward applications in disaster management. In this domain, IoT's ability to provide real-time sensing, data aggregation, and automated alerts, rooted in these foundational technologies, enables proactive strategies for early warning, resource deployment, and post-event recovery, ultimately enhancing societal resilience against natural and man-made calamities.

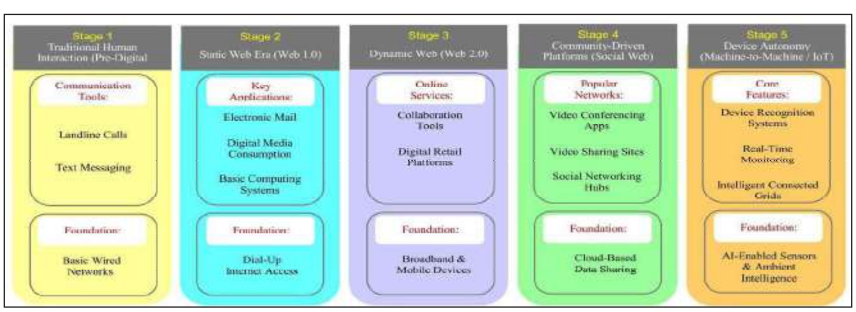

Figure 1.Evolution of Connectivity: From Traditional Communication to IoT Ecosystems

Table 1.IoT Framework Stages from 1982 to 2025

Year	Milestone
1982	Carnegie Mellon students built an ARPANET-linked Coke machine to monitor temperature and stock remotely.
1989	Tim Berners-Lee invented the World Wide Web, enabling foundational data sharing for IoT.
1990	John Romkey developed the first internet-connected toaster for remote appliance control.
1999	Neil Gershenfeld’s book When Things Start to Think outlined early IoT concepts for intelligent objects.
1999	Kevin Ashton coined “Internet of Things” at MIT, highlighting RFID for supply chain integration.
2000	LG launched the first internet-enabled refrigerator for inventory tracking and alerts.
2004	IoT gained popularity through widespread media and academic coverage on automation.
2005	Nabaztag Wi-Fi robot delivered weather, news, and stock updates via voice/LED.
2008	First International IoT Conference held in Zurich to standardize global applications.
2009	Google tested sensor-equipped self-driving Prius vehicles for hazard detection.
2010	China prioritized IoT as a national industry under Premier Wen Jiabao.
2011	IPv6 rollout addressed IoT’s growing address demands beyond IPv4.
2013	Google Glass introduced AR smart glasses with voice-activated internet connectivity.
2015	Mattel released Wi-Fi Barbie with interactive smart house features like voice lights.
2016	Apple HomeKit framework enabled secure smart home app development.
2016	Google Home smart speaker integrated services for home automation.
2017	Microsoft Azure IoT Edge supported local cloud analytics on remote devices.
2018	Global governments mandated IoT cyber security standards for manufacturers.
2019	Cisco projected ~50 billion connected IoT devices by 2020, reflecting ecosystem scale.
2021	BMW, Ford, and Volvo committed to autonomous vehicles using IoT sensors and V2X communication.
2022	Matter protocol launched for unified smart home interoperability across platforms.
2022	5G deployments boosted low-latency IoT for smart cities and disaster networks.
2023	IoT connections exceeded 15 billion; AIoT advanced edge computing for IIoT.
2023	EU Digital Decade promoted sustainable IoT for environmental and disaster monitoring.
2024	Over 20 billion devices projected; quantum encryption and satellite IoT, e.g., Starlink, expanded for remote areas.
2025	>25 billion connections via 6G prototypes; emphasis on ethical AI, resilient supply chains, and disaster standards like sensor networks for earthquakes and floods.

Analysis of Disaster Management Classification

Defining a Disaster

The WHO defines a disaster as any occurrence that disrupts the environment, leads to human fatalities, and impairs health services, necessitating urgent external support for the impacted community or region. Experts may differ in their interpretations, but many public health specialists view a catastrophe as an abrupt, severe event that endangers or harms public well-being. Broadly, disasters stem from natural or human-induced hazards causing substantial physical damage, deaths, and destruction. Examples include events like hurricanes, floods, massive accidents, fires, or explosions, which can devastate individuals’ lives, assets, economies, cultures, and societies. Key characteristics involve rapid onset, urgency, disarray, unforeseeability, risks, and losses to human and animal lives as well as property. While complete prevention isn’t always possible, various emergency response strategies aim to lessen impacts, such as early warning systems for floods, though droughts remain harder to avert, emphasising proactive policies to curb occurrences.[8] Table 2 mentions various disaster prevention and management policies, and Figure 2 depicts the key phases of disaster management.

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Categories of Catastrophes

The disasters can be separated into two main groups: those caused by natural forces and those resulting from human-made or technological failures. This particular domain is closely connected to the subcategory of calamities and the overall nature of the event. Figure 3 offers a broad overview of the different types of disasters.[9] Figures 4 and 5 highlight the comparative analysis of the top 10 countries most affected by natural disasters and technological disasters between 1990 and 2025, respectively.

Table 2.Disaster Prevention and Management Policies

Disaster Management Phase	Description / Key Activities
Preparedness	Pre-event measures like developing contingency plans, conducting drills and training, and implementing alert mechanisms.
Response	Immediate crisis actions, including public notifications, evacuation protocols, and search-and-rescue operations.
Recovery	Post-disaster efforts such as providing temporary housing, processing aid claims, offering long-term healthcare, and psychological support.
Mitigation	Ongoing risk-reduction activities like enforcing construction standards and land-use regulations, educating the public, and assessing vulnerabilities.

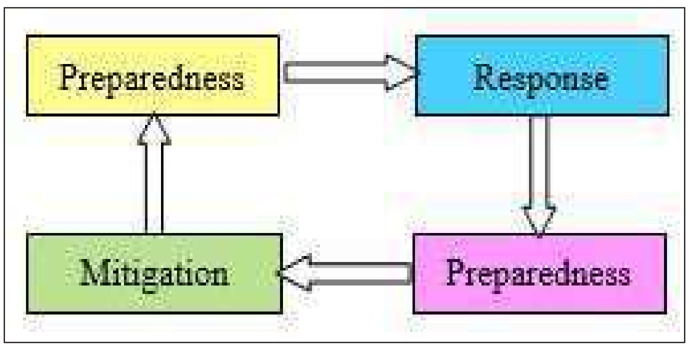

Figure 2.Key phases of disaster management

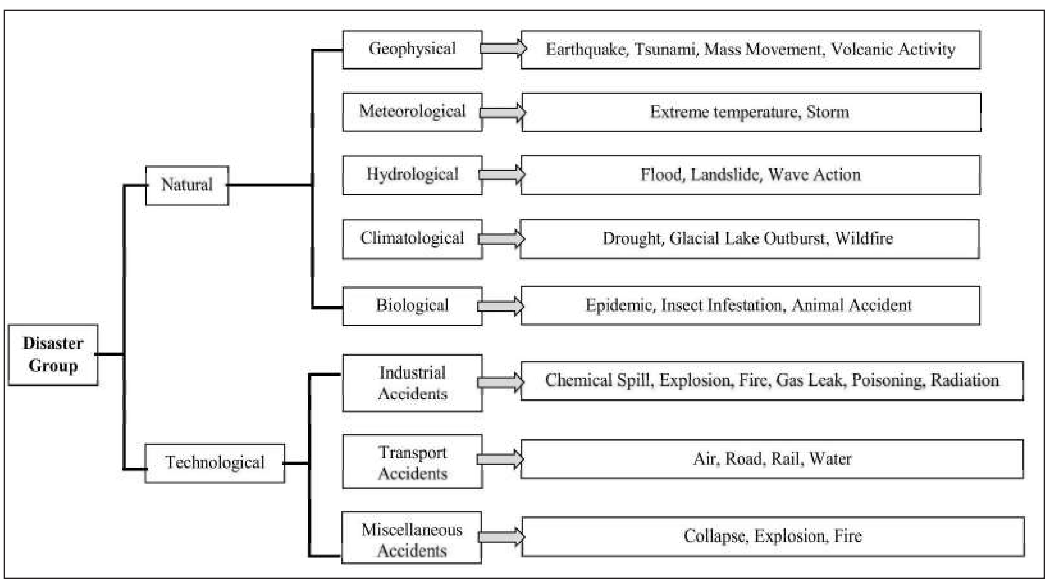

Figure 3.General Classification of Disasters

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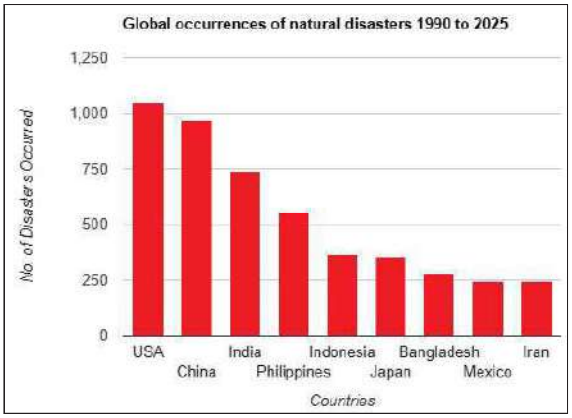

Figure 4.Global occurrences of Natural Disasters 1990 to 2025

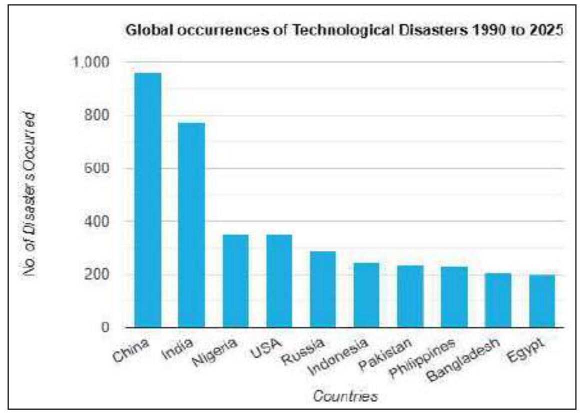

Figure 5.Global occurrences of Technological Disasters 1990 to 2025

Disaster Management Components: Conventional Early Warning Mechanisms

Broadcast Media (Radio and Television)

Radio and television remain essential, low-cost communication tools during disasters. Radio is especially effective for illiterate and remote populations, while television offers strong visual reach but higher costs. In regions like Karachi, radio serves as the main alert source for cyclones and floods.[10] Devices such as the Lifeline Pro radio, rugged and multi-band, enhance preparedness, as seen in Mozambique and Cuba, where fatalities dropped sharply due to timely alerts.[11] However, both media are limited by one-way communication and power outages.

Satellite-Based Radio

Satellite radio extends communication beyond terrestrial coverage, maintaining connectivity during infrastructure failure. Integrated with mobile or GPS devices, systems like AREA deliver real-time audio/text warnings in Asia. High setup costs and signal interference remain challenges.[12]

Landline and Cellular Telephony

Telephones enable direct alerts and community "telephone trees." Mobile phones have improved rural disaster monitoring, as in Vietnam's Mekong floods, through SMS-based water-level reporting and forecast dissemination.[13] SMS alerts are also used in Beijing for typhoon warnings.[14] Challenges include network congestion and limited access in low-income areas.

Cellular Broadcasting

This technology sends area-specific alerts to many users simultaneously without overloading networks. It supports multilingual, location-based messages but depends on user-enabled settings and carrier cooperation. In Sri Lanka and the Philippines, partnerships between governments and telecoms use this method for cyclone and flood warnings.[15]

Satellite Imagery and Emerging Tools

Remote sensing and GIS combine climatic, vegetation, and rainfall data for drought and disaster prediction. Programmes like FEWS NET monitor food security in Africa,[16] while India's Kalpana-1 and INSAT-3A satellites support cyclone alerts.[17] GIS-based vulnerability mapping and mobile-integrated fire and flood systems, such as Malaysia's Advanced Fire Information System, further strengthen preparedness.[18] However, traditional methods have limits; integrating IoT technologies, like drones for rescue and sensor networks, offers future-ready disaster management improvements, as discussed in Section 5.

IoT-Enabled Approaches to Disaster Mitigation

Recent advances in smart urban development across Asia, especially India, highlight the need for resilient systems. India faces major hazards: 57% of its land is seismically active (12% highly so), 68% is prone to drought, 12% of forests are degraded, and 8% is exposed to cyclones, while cities confront industrial and anthropogenic risks.[19] Disaster mitigation frameworks aim to reduce disruptions to societal functions; though full prevention is impossible, timely alerts and proactive strategies can greatly limit damage. Hazards include natural ones: earthquakes, landslides, floods, storms, tidal surges, and wildfires; and human-induced ones: radiological, toxic, mining, and biological. The Internet of Things provides a powerful platform for real-time sensing, communication, and coordinated response. By embedding sensors and transmitters into physical objects, IoT enables continuous data exchange, situational awareness, and actuator-based interventions during crises. However, poor connectivity and logistics can hinder rapid evacuation and coordination.[20] This study explores IoT's role in disaster preparedness and mitigation, covering utilities, floods, wildfires, earthquakes, landslides, and urban/agricultural impacts, along with victim tracking and counter-terrorism applications. Table 3 summarises

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IoT frameworks, cloud integrations, key technologies, and real-world deployments. Figure 6 illustrates an architecture for IoT-driven disaster recovery systems.[21]

IoT-Based Disaster Recovery Systems Classification

Mitigation of Volcanic Hazards

IoT aids volcano monitoring through cost-efficient LPWAN systems. The study used LoRa-based sensors at Tenerife's Teide volcano to measure thermal anomalies and water levels via eight low-energy units for real-time oversight.[31] Carrera-Villacres et al.[32] integrated fog harvesting with IoT for continuous environmental tracking and sustainable water generation.

Forest Fire Mitigation

IoT enhances wildfire detection and control. Kalatzis[33] proposed a UAV-supported Edge-Fog-Cloud model for early detection. Trinath Basu et al.[34] used ESP8266 and NodeMCU to send mobile/web alerts, reducing fire losses by up to 80%. Adam et al.[35] employed Raspberry Pi and neural networks for early alerts. The Smart Forest initiative applies IoT sensing for prediction, while Neumann et al.[36] developed edge-based Mobile Hubs using Context Net and EPAs for on-site fire tracking.

Flood Mitigation

IoT integrates with big data and HPC for predictive flood control. Sood et al.[37] designed an IoT framework validated for risk assessment. Big data-driven geoinformatics enables early warnings using GIS and GPS. Perumal et al.[38] created a real-time IoT water-level monitor issuing threshold alerts. IoT improves search and rescue, post-flood AI recovery, and victim rescue optimisation.

Landslide Mitigation

Landslides are monitored via IoT-WSN systems for early warning. Sofwan.[39] used Arduino ATmega2560 for sensor data aggregation and slope validation. Moulat et al.[40] employed statistical models to map susceptible zones and proposed automated IoT-based evacuation alerts. Reliability issues in WSNs are mitigated through energy-efficient smart grids. Viswanathan et al.[41] addressed these via photovoltaic-based community sharing and secure IoT-grid integration.

Seismic Hazard Mitigation

IoT supports early earthquake alerts and resilience systems. The study designed low-cost accelerometers with ML to distinguish seismic events from ambient vibrations. Rajput et al.[42] proposed an IoT–deep learning model for end-to-end quake management and recovery analytics. Alsaeh and Sezen.[43] emphasised that ontologies and semantic IoT enable interoperability by providing a shared understanding of IoT data and device interactions, allowing systems—such as those used in disaster response—to integrate, reason over, and reuse heterogeneous information for coordinated decision-making.

Urban Hazard Mitigation

IoT fortifies smart cities against floods, fires, and structural failures. Sensor networks transmit anomalies via Wi-Fi. China's infrastructure embeds IoT into both surface and subsurface systems. IoT-VANET integration aids urban incident tracking, traffic rerouting, and rapid emergency alerts using GPS-enabled vehicles.[44]

Counter-Terrorism Strategies

IoT-based reasoning frameworks use long-, medium-, and short-term modules with a technical reasoning kernel to forecast urban attacks via event analysis. Trust-as-a-Service (TaaS) strengthens security and anonymity. The ATDS system profiles behavioural patterns, comparing them with extremist models to alert authorities of potential threats.[45]

Survivor Tracking and Positioning

Accurate localisation saves lives during crises. MAVs detect victims using microphone arrays and particle filtering. The LoT approach employs TW-ToA and MLE for indoor tracking, while WILA uses gait and posture sensing. Advanced models include HOG-SVM, Fast SLAM, and DMR for human signal detection. The Mi-oT platform, RFID fusion, and energy spectrum sensing further enhance survivor identification.[46]

Table 4 highlights market-available IoT tools for disaster handling and compares them across architectural and technical dimensions, reflecting accessible smart, portable options for public use.

Table 3.IoT Frameworks for Disaster Management Systems

Study	IoT Used	Cloud Used	Key Features	Primary Application
[22]	Yes	Yes	Leverages big data analytics and high-performance computing (HPC) within IoT ecosystems	Flood prevention and monitoring
[23]	No	No	Employs IoT sensors, big data processing, and convolutional deep neural networks (CDNN); utilizes map-reduce functions to eliminate redundancies before classification	Flood detection and prediction

[24]	Yes	Yes	Integrates IoT with ThingSpeak cloud platform and image processing algorithms for real-time anomaly detection	Urban fire identification in smart cities
[25]	Yes	No	Incorporates machine learning (ML) into an early warning system (EWS) via a service-oriented IoT model	Emergency response planning and forecasting
[26]	Yes	No	Utilizes Hadoop, Spark, and big data tools to support IoT-driven urban infrastructure development	Smart city resilience against urban hazards
[27]	No	No	Deploys ZigBee-enabled PIC microcontrollers for seismic wave detection and public alerts	Earthquake early warning for P- and S-waves
[28]	Yes	Yes	Proposes a layered IoT framework (perception, network, and application layers); enables early detection, decision support, and real-time situational awareness	General disaster management including floods, earthquakes, and fire emergencies
[29]	Yes	Yes	Integrates IoT sensing with machine learning; features real-time data collection, early warning, risk prediction, and smart alerts	Natural disaster prediction and management, particularly floods, storms, and earthquakes
[30]	Yes	Partial	Combines IoT and blockchain; emphasizes data integrity, security, traceability, and decentralized coordination	Emergency and crisis management—focus on secure data sharing among response agencies

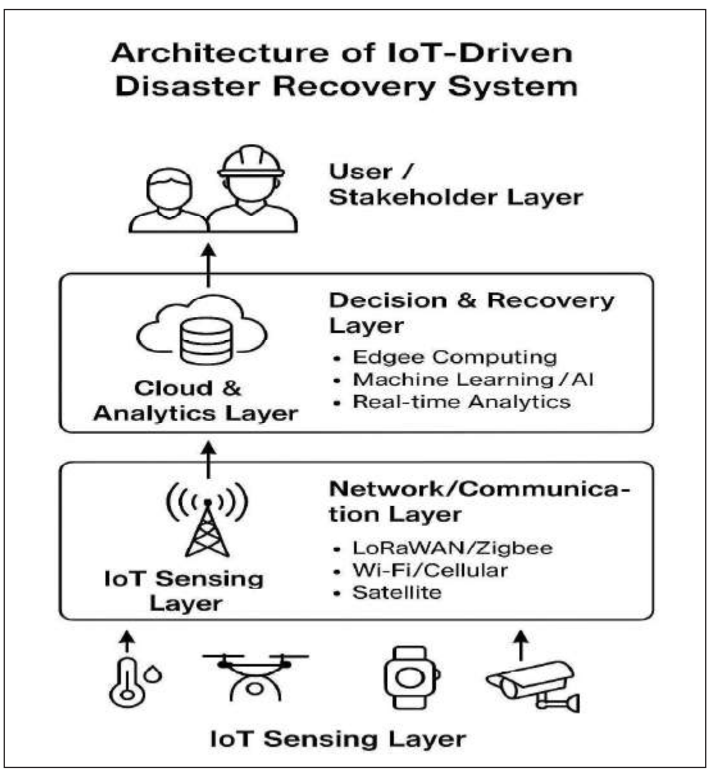

Figure 6.Architecture for IoT-driven disaster recovery systems

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Table 4.Comparative Overview of IoT-Integrated Disaster Response Technologies

System	Cloud Support	Mobile App Integration	Core Sensing Components	Connectivity Methods	Primary Hazard Focus
Brinco	Yes	Yes	Accelerometer	Bluetooth Low Energy (BLE) and Wi-Fi	Seismic events and tidal surges
Brck	Yes	No	Multifunctional sensors	Wi-Fi, GSM, and Ethernet	Diverse environmental threats
Grillo	Yes	Yes	Accelerometer	Wi-Fi and BLE	Seismic events and tidal surges
Flood Network	Yes	No	Ultrasonic distance sensor	GSM	Inundation events
Flood Beacon	Yes	Yes	Ultrasonic distance sensor	GSM and BLE	Inundation and tidal surges
Floating Sensor Array	Yes	Yes	Accelerometer and ultrasonic distance sensor	GSM and BLE	Inundation and tidal surges
Lightning Detection	Yes	No	Lightning strike detector	Radio frequencies	Electrical storm activity
Alarms	Yes	Yes	Accelerometer	Radio and BLE	Slope instability

Case Studies on IoT Driven Disaster Management

Case Study 1: Smart Flood Management in Jakarta, Indonesia (2024)

Jakarta has deployed an IoT & AI-driven flood management system as part of its Jakarta Smart City programme. Sensors monitor rainfall, river flow and water levels, feeding into predictive analytics that can forecast flood risk. When models indicate danger in specific districts, authorities send alerts to residents via the JAKI app. They also take proactive infrastructure measures: closing floodgates, activating pumps, and mobilising response teams. This has enabled warnings up to six hours ahead in some cases, improving readiness and reducing potential damage.[47]

Case Study 2: Smart Drainage & Flood Mitigation in Mogadishu, Somalia (2025)

In Mogadishu, the urban flooding problem has been tackled by building an IoT-based smart drainage system. Real-time monitoring of water levels and flow rates via sensors is integrated with automated control mechanisms for pumps and drainage channels. The system detects excess accumulation and redirects water from vulnerable points to avoid flooding in urban areas, helping increase city resilience. This has been published in 2025.[48]

Conclusion

The integration of IoT technologies into disaster management systems represents a paradigm shift from reactive responses to predictive and preventive strategies. Through intelligent sensing, data analytics, and cloud-enabled communication, IoT facilitates early detection, swift alerts, and coordinated responses that significantly reduce human and economic losses. The case studies of Jakarta and Mogadishu illustrate the tangible benefits of IoT-based flood management in improving urban resilience and preparedness. Despite challenges related to network reliability, data privacy, and implementation costs, ongoing advancements in AI, 5G, and edge computing continue to strengthen the reliability and scalability of IoT frameworks. Therefore, future disaster management systems must adopt IoT-driven, interoperable, and ethically governed architectures to ensure safety, sustainability, and adaptive recovery in the face of escalating global hazards.

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