The Social Impact of IoT in Disasters

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***Abstract*—Disasters, both natural and man-made, pose significant global threats, causing loss of life, economic damage, and social disruption. The rising frequency and severity of such events highlight the urgent need for effective disaster management. The Internet of Things (IoT) offers transformative potential to meet these challenges, particularly by improving early warning systems, enhancing emergency responses, and facilitating post-disaster recovery. This paper explores the role of the IoT in disaster management, highlighting its architecture and applications. It covers benefits such as improved response times, enhanced resource allocation, and reduced casualties, while also discussing challenges namely communication reliability in harsh environments, data security, and standardization issues. Additionally, the paper emphasizes the need for region-specific solutions, particularly in areas like Chongqing and Sichuan in China, which confront unique geological and meteorological risks, suggesting approaches for future research.**

***Keywords*—Disaster Management (DM), Internet of Things (IoT), Early Warning System (EWS), IoT-based Applications.**

I. INTRODUCTION

The occurrence of disasters represents a significant global concern, as they present a considerable risk to human life and socio-economic stability. The United Nations Office for Disaster Risk Reduction [1] defines a disaster as 'a serious disruption of the functioning of a community or society on any scale resulting from the interaction of hazardous events with exposure conditions, vulnerabilities and coping capacities, causing loss and impact on one or more aspects of human, material, economic and environmental well-being. In general, disasters can be classified into two main categories: natural disasters and man-made disasters [2]. Natural disasters, such as earthquakes, typhoons and floods, are caused by natural causes and are inherently difficult to control. In contrast, man-made disasters have their origins in human activities, including military conflicts, terrorism, political unrest and industrial accidents. Although this categorization is somewhat superficial, it provides a basic framework for understanding the different natures of disasters.

Over the past 10 years, the International Federation of Red Cross and Red Crescent Society's (IFRC) 2018 World Disasters Report [3] identified 3,751 natural disasters, such as floods, earthquakes, landslides, tsunamis, etc. The economic losses associated with these disasters are estimated to be around $165.8 million, and human casualties are estimated to be around 2 billion. By 2023, the situation is expected to have worsened. According to the Global Natural Disaster Assessment Report 2023 [4] and EM-DAT 2024 reports [5], the frequency of natural disasters globally in 2023 will be 326, a decrease of 3 % compared to the average of the last 30 years, but the number of deaths will be 86,437, exceeding the 20 year average of 64,148 deaths and the median value of 19,290 deaths 3 for the same period. Despite a 53% decrease in the number of people affected, direct economic losses have increased by 32% to around $202 billion. Turkey suffered particularly severe economic and population losses because of the earthquake, while the United States, China and India were the top three regions at risk of disasters. Disasters not only bring about economic losses, but also have an immediate impact on public health, humanitarian and the environment, as well as long-term negative effects. Particularly in densely populated urban and coastal areas, developing countries are more vulnerable to disasters owing to a lack of adequate data and resources. In recent news, the British Broadcasting Corporation (BBC) reported [6], [7] that on November 5, 2024, Spain experienced a year's worth of rainfall within just eight hours, leading to catastrophic flooding. Due to the absence of a timely and effective early warning system, the disaster caused significant economic losses and casualties, with over 200 confirmed deaths. Similarly, on January 8, 2025, the Los Angeles region faced a series of devastating wildfires. These fires led to at least 10 deaths, the destruction of thousands of buildings, and the displacement of approximately 150,000 residents.

In light of this, reducing disaster risks effectively presents a serious challenge for researchers, scientists, and authorities, while finding a suitable solution to efficiently handle and process the flow of information is crucial. Recent advancements in technologies, particularly the Internet of Things, have shown great potential in disaster management, which has become one of the key buzzwords. This paper projects on how IoT can play a transformative role in disaster management by mitigating risks and reducing the social impact of disasters. Additionally, it also explores the main challenges associated with IoT implementation in this field, including ensuring reliable communication, maintaining data security, and managing energy efficiency in resource-constrained environments [8]– [11].

II. Internet of Things and Disaster management (DM)

A. Architecture

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it [12]. IoT is the extension of Internet connectivity into physical devices and everyday objects. The functions and characteristics of IoT systems can be described starting from their architectural configuration. A three-layers architecture can be used to describe a generic IoT-based electronic system [8], as shown in Fig.1, a common IoT architecture basically consists of a perception layer, a communication layer and an application layer [8], [12]–[15].

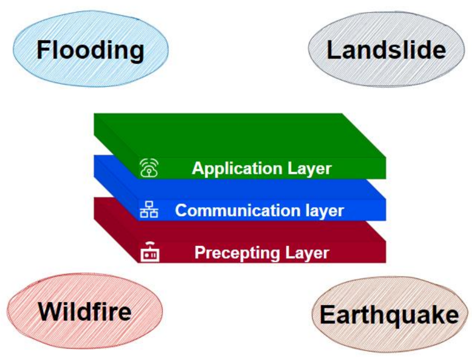

Fig. 1. Architecture of IoT (replot by Haoming Xiang from [8]).

The perception layer is responsible for sensing and collecting environmental data via a network of heterogeneous sensors, forming a Wireless Sensor Network (WSN). These networks are widely used in disaster monitoring and consist of nodes equipped with sensing and communication units that collect data and forward it to gateway nodes for further processing. Fan Zeng et al. [16] discuss various sensors, including accelerometers and triaxial gyroscopes for seismic monitoring to detect earthquake activities and crustal movements. Landslide monitoring uses inertial sensors, in combination with accelerometers, extensometers, borehole inclinometer, rainfall sensors, and displacement sensors to detect geological shifts and tilting. Flooding monitoring employs a variety of sensors, including rain sensors (e.g., tipping bucket rain gauges), water level sensors (e.g., radar liquid level sensors and ultrasonic sensors like MaxBotix MB7066, HC-SR04), water pressure sensors, soil moisture sensors, temperature sensors, and water presence sensors (e.g., conductive metal fork probes). Furthermore, meteorological sensors monitor environmental parameters such as temperature, humidity, rainfall, and wind speed, providing critical meteorological data for disaster prediction like landslides and floods. The combination and collaboration of these sensors form a robust Wireless Sensor Network for data collection.

The communication layer transmits data from the perception layer to servers, cloud services, or applications, handling routing, communication between heterogeneous networks, and ensuring reliable data transfer through various communication technologies. Studies [8], [16] have shown that different communication technologies serve distinct purposes. Modern communication technologies include short-range and long-range types. Short-range technologies, namely Bluetooth, Wi-Fi, ZigBee, and IEEE 802.15.4 offer low power consumption and cost advantages for short-range transmission but have limited distance. Long-range technologies like LoRaWAN, NB- IoT, Sigfox, and cellular networks (GSM, GPRS, 3G) provide extensive coverage, with cellular networks being reliable but more affected by environmental disasters.

At the top of the IoT architecture, the application layer utilizes this data to provide services by combining it with historical records, satellite data, or weather forecasts. It analyzes data and implements algorithms to generate and disseminate timely warnings for impending disasters, enabling effective prediction and response. For instance, research [17] demonstrates the use of IoT technology to create a low-cost, sustainable environmental monitoring system. The system collects CO, CO2, temperature, humidity, and PM2.5 data via low-power sensor arrays connected by LoRaWAN, powered by solar energy. The data is processed and visualized through Node-RED, triggering real-time alerts, and is uploaded to the cloud for remote monitoring and early earthquake prediction. Another example is [18], where an IoT system based on the LoRaWAN network, leveraging AWS cloud services, offers high scalability and security, enabling real-time data processing and fire detection.

B. IoT applications in Disaster management

Disaster management is a structured process that involves planning, managing, and applying strategies at any stage of a disaster, that are mitigation, rescue, response, and recovery [19]. The field has undergone significant transformation with the integration of IoT techniques, which can be leveraged at every stage of disaster management.

1) Early warning system (EWS): One of the most significant applications of IoT technology in disaster management is the development of early warning systems [19]. By deploying sensors in critical locations—such as humidity sensors, water-flow sensors, and water level monitors—IoT enables the real-time collection of environmental data. This data can be processed using traditional physical models or AI techniques to predict imminent disasters, allowing for timely alerts to relevant authorities and the public. For instance, Hanifah Yulia et al. [20] designed a prototype that integrates IoT technology to monitor water levels and ground movement, using components including an Arduino microcontroller, ESP32, ultrasonic sensors, water level sensors, MPU6050, and soil moisture sensors. This system is capable of triggering alerts when specific thresholds are crossed, offering early warnings for landslides and floods. Similarly, Mohammed Siddique et al. [21] proposed an advanced flood monitoring and early warning system that combines Synthetic Aperture Radar imagery with IoT sensors and hybrid machine learning techniques, resulting in more precise flood predictions and timely alerts. The

European Flood Awareness System [22] uses rainfall detection and forecasts to predict floods, while Zahir et al. [23] highlight a web-based system that provides the public with access to real-time flood information. In another example, as reported by [24] introduced an IoT-based dam monitoring system that uses real-time data to classify alarms, thereby enhancing dam safety and supporting disaster prevention efforts, particularly in managing droughts. Moreover, research by [25] investigated the use of an IoT-driven ground sensor system for wildfire detection, which deploys sensors to monitor environmental parameters like fuel moisture levels. This system also incorporates advanced visual sensing technologies such as Visible Light Range Cameras, Infrared Range Cameras, and Ultraviolet Range Cameras, significantly improving the accuracy and speed of fire detection. Additionally, Pascador [26] demonstrates the use of industrial IoT to develop a sensor system for monitoring volcanic activity, employing over 80 IoT sensors within a volcano's crater to predict eruptions.

2) Emergency Response and Rescue: In the aftermath of disasters, IoT devices have become essential in enhancing emergency response and rescue operations, with drones or UAVS recognized as integral components of the evolving IoT ecosystem. Research by [27] highlights the use of FANET (Flying Ad Hoc Network) technology, enabling drones to function as mobile interconnected sensors. These drones form infrastructure-free, self-organizing networks capable of real-time transmission of rescue information, significantly improving the success rates of disaster response missions. Similarly, [28] discusses AI-powered drones that integrate advanced sensor technologies, image recognition algorithms, and autonomous navigation. These capabilities optimize task planning, enhance response speed and situational awareness, and improve safety for both rescue personnel and victims. Moreover, [29] proposes an SOA-based algorithm leveraging 5G networks, enabling drones to collect and process large-scale heterogeneous data from disaster zones. This data facilitates the analysis of affected area boundaries, blocked infrastructure, and residents' health conditions, contributing to risk mitigation in disaster scenarios. Furthermore, IoT- based automated ambulance rescue systems and advanced device localization technologies have demonstrated remarkable potential in enhancing emergency response efficiency. As demonstrated by [30], IoT systems that employ accelerometers to detect traffic accidents and instantly relay location data to rescue teams via Wi-Fi modules, enabling faster response times, While Study [31] proposes a cloud-based IoT system integrating an Android application, IoT toolkits, and cloud middleware to process real-time data. Additionally, Social IoT networks can identify relationships between devices and users without human intervention, providing key information for positioning and response. Despite the computational demands of deep learning models, localization using anchor nodes with known locations demonstrates high precision in Wi-Fi (0.54 meters), LoRa (0.62 meters), and Bluetooth (0.82 meters) positioning, all of which provide accurate support for rescue operations [32].

3) Post-disaster recovery and reconstruction: The application of IoT in post-disaster scenarios holds significant academic and practical value. By enhancing information exchange and system connectivity, IoT technologies can greatly improve the efficiency of recovery efforts, thereby mitigating the adverse impacts of natural disasters. For instance, one proposed approach is to incorporate a disaster mode into mobile phones [33]. When traditional cellular networks fail, devices would automatically switch to a Device-to-Device (D2D) communication mode, forming an ad hoc WSN. In these networks, specific devices act as relays or gateways to maintain connectivity during outages. Another example is the use of UAV equipped with sensors, which have been proposed as a means to restore communication links in disaster-affected regions [28], [29]. These UAVs can provide wireless coverage to ground users, effectively bridging communication gaps across diverse environments. In post-disaster contexts, a drone-based communication coverage strategy has been introduced, tailored for complex user distributions in cruise communication systems. This approach integrates UAVs with cruise communication modes, leveraging drone patrols and dividing the target area into units to ensure that users' minimum communication needs are met [34]. Additionally, satellite communication systems serve as a robust alternative. For example, Elon Musk's Starlink initiative restored internet connectivity to the Kingdom of Tonga following a tsunami- induced network failure [35].

C. Challenges and social impacts of technology

1) Technology Challenges: IoT holds tremendous potential in disaster management, but its practical implementation endures numerous technical challenges, one of the most significant being fault tolerance [8], [10]–[12], [36]. The requirements of disaster monitoring systems are long-term operation in harsh environments, including remote mountainous areas with complex terrains, where maintenance costs are prohibitively high. WSN has become increasingly prevalent. Consisting of a variety of intelligent sensor nodes, these networks are responsible for data collection and routing with distributed, auto-organized and energy-constrained characteristics. Each sensor node is capable of collecting data from the environment required for a particular application and can act as a data transponder to ensure that the data eventually reaches its intended destination. However, in harsh environments (e.g., strong magnetic fields or heavy rain, etc.), the communication quality of the sensor nodes may significantly degrade, resulting in impaired data quality and increased energy consumption, which in turn prevents the system from functioning properly in some cases. In addition, these nodes have limited hardware and computational resources, and once the equipment is damaged, part of the WSN's functionality will be lost. As the disaster continues, the functionality decreases until the end of the disaster. In disaster management, failures can be classified into two categories based on node behaviors [37] hard failures are usually due to module failures that render the device completely inoperative, while soft failures are those where the sensor nodes are still functioning, but the data provided may be incorrect or incomplete. For instance, ambient noise may interfere with sensor readings, leading to erroneous disaster predictions (e.g., flood levels or seismic vibration data) or errors may occur during data processing or transmission, leading to false or missed alarms. Additionally, at the network level, failures may occur, such as path disruption (e.g., communication disruption due to infrastructure damage from floods or earthquakes), wireless signal interference (data loss due to weather or other factors), network congestion (communication blockage due to many sensor nodes sending data at the same time during a disaster), and routing algorithms or applications. Several strategies can be employed to enhance system reliability and minimize the impact of faults, as demonstrated by existing research [8], [11], [38]. Increasing node density improves fault tolerance by reducing the impact of faulty nodes, while robust sensor enclosures can help mitigate damage caused by natural disasters. Additionally, employing mesh topologies and self-healing/self- organizing networks, along with communication redundancy or non-terrestrial satellite backhaul, strengthens network resilience. Fault-tolerant mechanisms can be categorized into centralized, decentralized, and hybrid approaches. Centralized methods rely on a central base station for fault detection and handling, while decentralized methods distribute tasks across nodes for autonomous fault management. Hybrid approaches combine both, using multi-layer or neighborhood statistical methods for fault detection and recovery, optimizing energy consumption and delay, and enhancing system robustness and response efficiency, especially in disaster scenarios.

In IoT-based disaster management, ensuring data security and privacy is one of the key challenges. In disaster scenarios, IoT devices play a crucial role in collecting and transmitting data related to environmental monitoring, personal identity information, health conditions, and infrastructure status, thereby supporting rescue and recovery efforts. However, due to the resource-constrained nature of IoT devices and their deployment in diverse environments, they are highly vulnerable to various security threats. Common issues include weak or default passwords, insecure communication protocols, and delayed firmware updates, which can be exploited by attackers through eavesdropping, data interception, denial-of-service attacks, and more, leading to device control breaches or system instability [36]. Furthermore, the integration of heterogeneous devices within IoT networks, which actively share data, exacerbates the risks posed by communication and device vulnerabilities [36]. Supply chain risks further amplify these challenges, potentially enabling malicious actors to compromise the integrity and reliability of collected and shared data [36], [39], [40]. Research [41] has shown that implementing encryption mechanisms, adopting secure communication protocols (such as Transport Layer Security (TLS) and Secure Sockets Layer (SSL)), introducing data anonymization techniques, and enhancing physical security measures (e.g., tamper-proof enclosures and physical access controls) can significantly improve data security and privacy protection in IoT systems and applications. The application of federated learning-based distributed methods in Software-Defined Networks (SDN) has also demonstrated its potential [42]. By deploying traffic regulators to effectively intercept malicious traffic, a detection accuracy of 79.47% was achieved. Future plans include the integration of differential privacy techniques to further optimize data privacy protection in disaster scenarios. In addition, a distributed health- care system based on the blockchain Hyperledger provides a robust solution for securing critical data during disasters [43]. This system effectively addresses challenges such as user verification, identity authentication, and privacy protection, while overcoming obstacles like cross-chain interoperability, high computational costs, and data lifecycle management. It offers a novel approach to constructing an efficient and secure IoT-based electronic healthcare environment for disaster scenarios.

Differences in IoT technology standards and disaster management policies across countries and regions can hinder international cooperation and slow the adoption of these technologies. Therefore, establishing a globally unified IoT standard and disaster management framework is essential [16], [36], [44]. Currently, IoT-based disaster monitoring and early warning systems lack unified technical standards in key areas namely sensor selection and production for field environments, data acquisition instruments and their interfaces, communication networks, and gateway manufacturing. Although some research has explored post-disaster applications, there are no specific standards in this domain. In addition, disaster management requires a range of sensors for both pre- and post-disaster phases, each designed according to different manufacturer and application-specific requirements. This heterogeneity impedes data integration and sharing. Additionally, initial disasters can trigger secondary events, and analyzing data from related sensors can help predict these cascading hazards. Future research should focus on sensor integration, data visualization, and the dissemination of multi-hazard alerts.

2) Impact: The integration of Internet of Things technology into disaster management has significantly reduced casualties, enhanced response capabilities and promoted social equity. A prominent example is the advancement of earthquake early warning systems, a concept dating back to 1868, which represents an early form of IoT application [45]. Modern systems, such as ShakeAlert in the United States, have further refined this technology and tested its effectiveness among pilot users in California, Oregon, and Washington [46]. Similarly, Mexico's SASMEX system has expanded its reach, covering multiple states and cities. Alerts in Mexico are disseminated through dedicated radio receivers in schools and government offices, as well as 12,000 city-wide sirens in Mexico City, ensuring comprehensive public notification [46].

In addition to earthquake warnings, IoT-powered flood early warning systems have shown the potential to reduce annual economic losses due to flooding by up to 35% [47]. These systems must provide tailored warnings to effectively reach vulnerable populations, particularly in multilingual or remote areas. For instance, in Pakistan, uneducated Punjabi-speaking women struggled to comprehend formal Urdu alerts that included technical terms such as rainfall millimeters and flood probabilities, underscoring the importance of delivering alerts in native languages and simple terminology [48]. Similarly, in Florida, the integration of Geographic Information Systems

(GIS) data into flood management systems facilitated efficient traffic control, ensuring safer and more organized evacuations during emergencies [49].

Regarding this, IoT plays a significant role in promoting social equity by improving resource allocation. Its widespread adoption ensures that remote areas have access to the same monitoring and early warning services as urban regions, bridging the gap in disaster management capabilities. This ensures that all social groups, including vulnerable populations, receive timely warnings and equitable access to emergency resources, reducing risks and losses during disasters and fostering overall social fairness.

III. Conclusion

Frequent global disasters pose severe threats to life and property. While the Internet of Things cannot prevent disasters, it can help identify hazards early, alert authorities, and assist in rescue operations, thereby saving lives, resources, and funds. IoT technology enhances emergency management, improves disaster response efficiency, and reduces casualties and economic losses. Early warning systems, emergency response tools, and post-disaster recovery frameworks have already demonstrated their significant potential in disaster management. Despite its advantages, IoT encounters challenges in dis- aster management, including ensuring reliable communication in harsh environments, maintaining data security. Additionally, IoT can extend its reach to remote and vulnerable communities, promoting equitable resource distribution and fostering social equity. As the frequency and severity of global disasters increases, leveraging IoT to build disaster resilient communities and mitigate disaster impacts is crucial.

IV. Future Work

The rapid advancement of information technology has significantly transformed daily life, with the Internet of Things emerging as a key enabler in addressing critical global challenges, including disaster management. While extensive re- search on related technologies has been conducted globally, there remains a notable gap in studies tailored to the unique disaster contexts of Chongqing and Sichuan in China. Chongqing, with its mountainous landscape, faces significant risks from landslides, mudslides, and floods, especially during the rainy season when water levels in the Yangtze and Jialing Rivers can rise, leading to flood hazards [50]. Sichuan, located in an earthquake zone, experiences frequent seismic activity, particularly in the western and northern parts of the province. Additionally, the mountainous regions of Sichuan are susceptible to landslides and mudslides, especially during heavy rains [51]. These factors highlight the urgency of establishing robust, region-specific disaster warning and management systems in these areas. The remote locations, complex terrain, and frequent disasters provide an ideal testing ground for IoT technologies. To improve the system's fault tolerance, the integration of IoT with satellite communication is crucial. Additionally, the widespread adoption of low-power wide-area network (LPWAN) technologies, such as ZigBee and LoRa, enhances the system's robustness, while narrowband IoT enables low-power, high-stability wireless monitoring. Future research will focus on developing advanced solutions tailored to the specific needs of these regions, aiming to build a comprehensive and reliable disaster management system.

References

[1] United Nations Office for Disaster Risk Reduction (UNDRR), "Terminology: Disaster," UNDRR Official Website, 2022, https://www.undrr.org/terminology/disaster.

[2] I. M. Shaluf, F. Ahmadun, and A. M. Said, "A review of disaster and crisis," *Disaster Prevention and Management: An International Journal*, vol. 12, no. 1, pp. 24–32, 2003.

[3] International Federation of Red Cross and Red Crescent Societies (IFRC), "World disasters report 2018: Leaving no one behind," IFRC Official Website, 2018, https://www.ifrc.org/document/world-disasters-report-2018.

[4] ReliefWeb, "2023 global natural disaster assessment report," ReliefWeb Official Website, 2024, https://reliefweb.int/report/world/2023-global-natural-disaster-assessment-report.

[5] C. for Research on the Epidemiology of Disasters, "2023 dis- asters in numbers: A significant year of disaster impact," 2024, https://www.emdat.be/categories/adsr/.

[6] B. Bell and K. Armstrong, "Search for spain flooding survivors continues as torrential rain hits another region," BBC News Website, 2024, https://www.bbc.co.uk/news/articles/cx27exg5g33o.

[7] BBC News Visual Journalism Team. (2025) Maps and images reveal scale of la wildfire devastation. https://www.bbc.co.uk/news/articles/cg525q2ggl4o.

[8] M. Esposito, L. Palma, A. Belli, L. Sabbatini, and P. Pierleoni, "Recent advances in internet of things solutions for early warning systems: A review," *Sensors*, vol. 22, no. 6, 2022.

[9] Y. Ai, M. Peng, and K. Zhang, "Edge computing technologies for internet of things: a primer," *Digital Communications and Networks*, vol. 4, no. 2, pp. 77–86, 2018.

[10] S. M. Khan, I. Shafi, W. H. Butt, I. d. l. T. Diez, M. A. L. Flores, J. C. Gala´n, and I. Ashraf, "A systematic review of disaster management systems: approaches, challenges, and future directions," *Land*, vol. 12, no. 8, p. 1514, 2023.

[11] M. Centenaro, C. E. Costa, F. Granelli, C. Sacchi, and L. Vangelista, "A survey on technologies, standards and open challenges in satellite iot," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 3, pp. 1693–1720, 2021.

[12] M. Somayya, R. Ramaswamy, and S. Tripathi, "Internet of things (iot): A literature review," *Journal of Computer and Communications*, vol. 3, no. 5, pp. 164–173, 2015.

[13] P. Gokhale, O. Bhat, and S. Bhat, "Introduction to iot," *International Advanced Research Journal in Science, Engineering and Technology*, vol. 5, no. 1, pp. 41–44, 2018.

[14] A. A. Laghari, K. Wu, R. A. Laghari, M. Ali, and A. A. Khan, "A review and state of art of internet of things (iot)," *Archives of Computational Methods in Engineering*, vol. 29, pp. 1395 – 1413, 2021.

[15] S. Nizˇetic´, P. Sˇolic´, D. Lo´pez-de-Ipin˜a Gonza´lez-de-Artaza, and L. Patrono, "Internet of things (iot): Opportunities, issues and challenges towards a smart and sustainable future," *Journal of cleaner production*, vol. 274, p. 122877, 2020.

[16] F. Zeng, C. Pang, and H. Tang, "Sensors on the internet of things systems for urban disaster management: A systematic literature review," *Sensors*, vol. 23, no. 17, p. 7475, 2023.

[17] V. Koushik, N. Sasipreetham, M. Nithya, and M. P. V, "Early detection and warning system for earthquakes using internet of things," in *2024 3rd International Conference on Sentiment Analysis and Deep Learning (ICSADL)*, 2024, pp. 529–533.

[18] M. N. Ramadan, T. Basmaji, A. Gad, H. Hamdan, B. T. Akgu¨n, M. A. Ali, M. Alkhedher, and M. Ghazal, "Towards early forest fire detection and prevention using ai-powered drones and the iot," *Internet of Things*, vol. 27, p. 101248, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2542660524001896

[19] R. de Franc¸a Bail, J. L. Kovaleski, V. L. da Silva, R. N. Pagani, and D. M. de Genaro Chiroli, "Internet of things in disaster management:

Technologies and uses," *Environmental Hazards*, vol. 20, no. 5, pp. 493–513, 2021.

[20] T. L. C. Miranda, H. J. R. Herrera, J. B. M. Coaquira, W. E. S. Villanueva, and M. A. M. Aguilar, "Sistema de alerta temprana de deslizamiento de tierra por lluvias basado en red inalámbrica de sensores en la ciudad de tacna," *INGENIERÍA INVESTIGA*, vol. 5, 2023.

[21] M. Siddique, T. Ahmed, and M. S. Husain, "Flood monitoring and early warning systems–an iot based perspective," *EAI Endorsed Transactions on Internet of Things*, vol. 9, no. 2, 2023.

[22] C. Corral, M. Berenguer, D. Sempere-Torres, L. Poletti, F. Silvestro, and N. Rebora, "Comparison of two early warning systems for regional flash flood hazard forecasting," *Journal of Hydrology*, vol. 572, pp. 603–619, 2019.

[23] S. B. Zahir, P. Ehkan, T. Sabapathy, M. Jusoh, M. N. Osman, M. N. Yasin, Y. A. Wahab, N. Hambali, N. Ali, A. Bakhit, F. Husin, M. Kamil, and R. Jamaludin, "Smart iot flood monitoring system," in *journal of physics: conference series*, vol. 1339, no. 1. IOP Publishing, 2019, p. 012043.

[24] D. Dhinakaran, S. U. Sankar, B. C. Latha, A. E. J. Anns, and V. K. Sri, "Dam management and disaster monitoring system using iot," in *2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS)*. IEEE, 2023, pp. 1197–1201.

[25] C. C. Chan, S. A. Alvi, X. Zhou, S. Durrani, N. Wilson, and M. Yebra, "A survey on iot ground sensing systems for early wildfire detection: Technologies, challenges, and opportunities," *IEEE Access*, vol. 12, pp. 172 785–172 819, 2024.

[26] Padtronics, "Lunatic volcano explorer deploys industrial iot sensors to predict eruptions," Padtronics Official Website, 2024, https://padtronics.com/lunatic-volcano-explorer-deploys-industrial-iot-sensors-to-predict-eruptions/.

[27] Y.-W. Kao, H. Samani, S.-C. Tasi, B. Jalaian, N. Suri, and M. Lee, "Intelligent search, rescue, and disaster recovery via internet of things," in *2019 Global IoT Summit (GIoTS)*, 2019, pp. 1–7.

[28] K. Rashida Farsath, K. Jitha, V. Mohammed Marwan, A. Muhammed Ali Jouhar, K. Muhammed Farseen, and K. Musrifa, "Ai-enhanced unmanned aerial vehicles for search and rescue operations," in *2024 5th International Conference on Innovative Trends in Information Technology (ICITIIT)*, 2024, pp. 1–10.

[29] W. Alawad, N. B. Halima, and L. Aziz, "An unmanned aerial vehicle (uav) system for disaster and crisis management in smart cities," *Electronics*, vol. 12, no. 4, p. 1051, 2023.

[30] P. Karmokar, S. Bairagi, A. Mondal, F. N. Nur, N. N. Moon, A. Karim, and K. C. Yeo, "A novel iot based accident detection and rescue system," in *2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT)*, 2020, pp. 322–327.

[31] T. Khan, S. Ghosh, M. Iqbal, G. Ubakanma, and T. Dagiuklas, "Rescue: A resilient cloud based iot system for emergency and disaster recovery," in *2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, 2018, pp. 1043–1047.

[32] A. Alnoman, A. S. Khwaja, A. Anpalagan, and I. Woungang, "Emerging ai and 6g-based user localization technologies for emergencies and disasters," *IEEE Access*, 2024.

[33] M. Kamruzzaman, N. I. Sarkar, J. Gutiérrez, and S. K. Ray, "A study of iot-based post-disaster management," *2017 International Conference on Information Networking (ICOIN)*, pp. 406–410, 2017.

[34] B. Yang, X. Xiong, H. Liu, Y. Jia, Y. Gao, A. Tolba, and X. Zhang, "Unmanned aerial vehicle assisted post-disaster communication coverage optimization based on internet of things big data analysis," *Sensors*, vol. 23, no. 15, p. 6795, 2023.

[35] K. Needham, "Musk's starlink connects remote tonga villages still cut off after tsunami," Reuters Official Website, 2022, https://www.reuters.com/world/asia-pacific/musks-starlink-connects-remote-tonga-villages-still-cut-off-after-tsunami-2022-02-23/.

[36] K. Sharma, D. Anand, M. Sabharwal, P. K. Tiwari, O. Cheikhrouhou, and T. Frikha, "A disaster management framework using internet of things-based interconnected devices," *Mathematical Problems in Engineering*, vol. 2021, no. 1, p. 9916440, 2021.

[37] G. H. Adday, S. K. Subramaniam, Z. A. Zukarnain, and N. Samian, "Fault tolerance structures in wireless sensor networks (wsns): Survey, classification, and future directions," *Sensors*, vol. 22, no. 16, p. 6041, 2022.

[38] M. Aalim, S. Kumar, and B. Bhushan, "Internet of things (iot) based interconnected systems for effective disaster management," in *2023 IEEE 15th International Conference on Computational Intelligence and Communication Networks (CICN)*. IEEE, 2023, pp. 1–7.

[39] U. A. Usmani, A. Happonen, and J. Watada, "Secure integration of iot-enabled sensors and technologies: Engineering applications for humanitarian impact," in *2023 5th International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, 2023, pp. 1–10.

[40] E. Schiller, A. Aidoo, J. Fuhrer, J. Stahl, M. Ziörjen, and B. Stiller, "Landscape of iot security," *Computer Science Review*, vol. 44, p. 100467, 2022.

[41] R. Uddin and S. A. P. Kumar, "Sdn-based federated learning approach for satellite-iot framework to enhance data security and privacy in space communication," *IEEE Journal of Radio Frequency Identification*, vol. 7, pp. 424–440, 2023.

[42] A. Khadidos, S. Shitharth, A. Khadidos, K. Sangeetha, and K. Alyoubi, "Healthcare data security using iot sensors based on random hashing mechanism. j sens 2022: 17," 2022.

[43] A. A. Khan, S. Bourouis, M. M. Kamruzzaman, M. Hadjouni, Z. A. Shaikh, A. A. Laghari, H. Elmannai, and S. Dhahbi, "Data security in healthcare industrial internet of things with blockchain," *IEEE Sensors Journal*, vol. 23, no. 20, pp. 25 144–25 151, 2023.

[44] G. Mei, N. Xu, J. Qin, B. Wang, and P. Qi, "A survey of internet of things (iot) for geohazard prevention: Applications, technologies, and challenges," *IEEE Internet of Things Journal*, vol. 7, no. 5, pp. 4371–4386, 2020.

[45] J. D. Cooper, "Earthquake indicator," *San Francisco Bulletin*, vol. 3, 1868.

[46] R. M. Allen and D. Melgar, "Earthquake early warning: Advances, scientific challenges, and societal needs," *Annual Review of Earth and Planetary Sciences*, vol. 47, no. Volume 47, 2019, pp. 361–388, 2019.

[47] D. Rogers and V. Tsirkunov, "Costs and benefits of early warning systems," *Global assessment rep*, 2011.

[48] D. Perera, J. Agnihotri, O. Seidou, and R. Djalante, "Identifying societal challenges in flood early warning systems," *International Journal of Disaster Risk Reduction*, vol. 51, p. 101794, 2020.

[49] K. Feng and N. Lin, "Reconstructing and analyzing the traffic flow during evacuation in hurricane irma (2017)," *Transportation research part D: transport and environment*, vol. 94, p. 102788, 2021.

[50] Y. Li, J. Gao, J. Yin, L. Liu, C. Zhang, and S. Wu, "Flood risk assessment of areas under urbanization in chongqing, china, by integrating multi-models," *Remote Sensing*, vol. 16, no. 2, p. 219, 2024.

[51] K. Xue, S. Cao, Y. Liu, D. Xu, and S. Liu, "Disaster-risk communication, perceptions and relocation decisions of rural residents in a multi-disaster environment: Evidence from sichuan, china," Habitat International, vol. 127, p. 102646, 2022