International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 02 | Feb - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Advancements in Real-Time Disaster Management and Early warning Systems: A Comprehensive Review

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Abstract - Successful disaster management and early warning are essential in reducing the effects of natural and human-induced hazards. Advances in real-time monitoring, data analysis, and communication technologies have greatly enhanced the forecast, detection, and response to disasters. This review paper presents a critical evaluation of contemporary methods, such as, geospatial analysis, and artificial intelligence-based prediction models. It also brings to light the shortcomings of current systems and delves into possibilities of building better real-time decision-making, timely warnings, and synchronized response strategies, leading the way for more adaptive and anticipatory disaster management solutions.***Key Words***: Disaster Management, Disaster Response, Early Warning Systems, Machine Learning, Geospatial Analysis, Mobile Applications, Web-based Platforms, Emergency Preparedness, Predictive Modeling.

1.INTRODUCTION

Disasters, both natural and man-made, pose serious risks to infrastructure, human life, and socioeconomic well-being. A concerted effort is necessary for effective disaster management in order to lessen the impact of such calamities, guarantee prompt reaction, and facilitate a rapid recovery. The four primary phases of disaster management are preparedness, prevention/mitigation, response, and recovery [1]. The process is typically organized around a cyclical pattern.

The formulation of plans, early warning systems, and public education initiatives to lessen potential effects are all part of preparedness. In order to reduce the likelihood and severity of disasters, prevention and mitigation strategies focus on both structural and non-structural measures, such as zoning regulations, building rules, and vulnerability assessments. The immediate interventions of relief, medical assistance, and search and rescue for the impacted communities are included in the response stage. Last but not least, is the recovery stage focuses on restoring normalcy through infrastructure repair, medical care, and grants.

The discipline of disaster management has seen a transformation thanks to recent technical advancements including artificial intelligence, sensor networks, geospatial analysis, and real-time monitoring. Faster detection, improved prediction, and better coordinated responses are made possible by these improvements, which enhance the efficacy of early warning systems and ultimately reduce the overall impact of disasters. In addition to proposing present capabilities, limitations, and future trends, this paper provides a thorough analysis of recent advancements in real-time catastrophe management and early warning systems.

Fig -1: Disaster management cycle [1]

2. LITERATURE SURVEY

A. Hybrid Prediction Model Integrating Artificial Intelligence and Geospatial Analysis for Disaster Management

For improved accuracy and responsiveness of disaster management systems, Saleem et al. [3] presented a hybrid disaster forecasting framework that combines geospatial data analytics and artificial intelligence (AI). To analyze complex datasets with spatial, temporal, and environmental factors, the research combines Convolutional Neural Networks (CNNs), Gradient Boosting Machines (GBMs), and Support Vector Machines (SVMs). The model outperformed conventional approaches in terms of predicted reliability by merging these complementing algorithms, achieving 90\% accuracy for flood forecasting in Bangladesh and 92\% accuracy for earthquake damage assessment in Japan. The suggested hybrid prediction model, as shown in Fig. 2, shows how geospatial data and machine learning can work together to enhance situational awareness, real-time prediction, and adaptive early warning capabilities across a variety of disaster types.

The study's CNN-based damage estimation framework, which uses satellite imagery to quantify the impact of disasters using sophisticated image segmentation and object detection techniques, is one of its main contributions. The model's performance was validated by evaluation criteria such mean Average Precision (mAP) and Intersection over Union (IoU), which achieved 0.85 and 0.83, respectively. These outcomes demonstrate the framework's potential for real-time disaster assessment as well as its low latency processing of large image datasets. The system helps emergency decision-making, damage assessment, and prioritizing during disaster response operations by delivering fast, data-driven intelligence through the integration of remote sensing and geospatial mapping.

Additionally, the study created an optimization module that maximizes response efficiency while minimizing operational expenses for efficient resource deployment under realistic restrictions. In order to strategically distribute resources among impacted areas, this component combines geospatial logistics with predictive outputs. After being thoroughly tested in a variety of disaster situations, including floods, earthquakes, and wildfires, the hybrid model demonstrated excellent robustness, scalability, and flexibility. All things considered, the study offers a strong basis for the development of next-generation early warning and decision-support systems that use AI–geospatial integration to improve coordination, disaster response timeliness, and predictive accuracy.

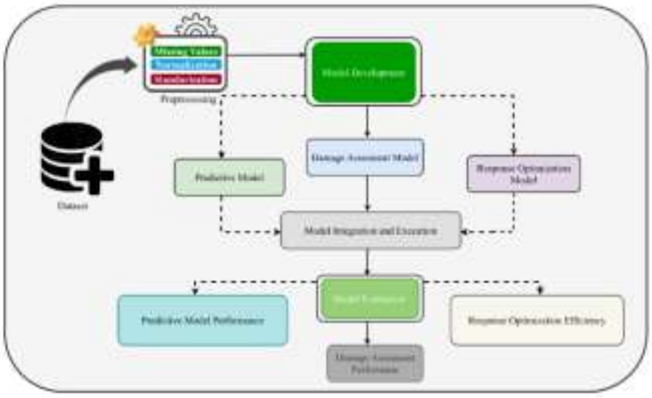

Fig -2: The working of the proposed model [3]

B. Disaster Guard for Disaster Management

With an emphasis on real-time environmental sensing and data transmission for the early detection of hazards, Fouzan et al. [2] have suggested a wireless sensor network (WSN) system for landslide monitoring in Nusa Tenggara Timur, Indonesia. The ideas of distributed data collecting, low-power transmission, and automated alerting are applicable to multi-hazard disaster management models, even though their research focused on a specific disaster category. WSN-based systems' resilience and adaptability have made it possible to create integrated disaster response platforms that can manage a range of emergency scenarios, including man-made and natural disasters.

Current research has moved toward reliable mobile-based disaster management systems that incorporate cloud computing, artificial intelligence (AI), and Internet of Things (IoT) devices based on such sensor-based infrastructures. An excellent illustration of this trend is the "Disaster Guard" architecture, which offers an integrated platform that makes it easier to manage resources, do predictive analytics, monitor in real time, and coordinate stakeholder communications. The technology enhances situational awareness and enables a more rapid and accurate emergency response to various disasters by integrating IoT sensors and AI-driven decision assistance.

Additionally, traditional reactive crisis management is transformed into a proactive, data-driven process with the addition of features like resource tracking, geofencing, and citizen reporting. The combination of mobile communication, smart analytics, and WSN concepts improves community resilience and early warning dissemination. This convergence shows that active, interoperable platforms meant for comprehensive catastrophe management and preparedness are replacing standalone monitoring systems.

C. A Web-Based Platform for Disaster Management

To maximize resource allocation in emergency response systems, Balogun et al. [4] proposed a progressive online platform built on data analytics and real-time coordination. By utilizing a Progressive Web App (PWA) that unifies resource data, people coordination, and user interactions through secure cloud databases and dynamic APIs, their research addresses the inefficiencies of conventional disaster management procedures. To increase situational awareness and facilitate evidence-based decision-making, the architecture leverages real-time data from both internal and external sources, such as population databases, open government APIs, and geospatial infrastructure maps. Fair and responsible use of technology in mission-critical scenarios was made possible by the implementation of ethical design principles, such as data protection, algorithm transparency, and privacy protection.

Furthermore, Balogun et al. examined earlier emergency logistics decision-support and optimization models and discovered that flexibility, computational complexity, and limited real-world adoption remain persistent problems. Their platform demonstrates how modern web technologies may offer low-latency, cross-platform, and user-focused solutions for emergency coordination by utilizing an architecture based on Next.js and interactive data visualization. Predictive analytics and automatic prioritizing were highlighted as being made easier by integrating AI and machine learning into future extensions. All things considered, this research provides a strong technological foundation for developing next-generation digital architectures that can enhance emergency management systems' operational effectiveness, responsiveness, and resilience.

D. IWARN: A People-Centered Approach for Early Warning

A citizen-centered strategy that improves early warning capabilities and real-time catastrophe management is put out by Sánchez-López et al. [5]. IWARN positions citizens as intelligent human sensors by integrating them into an active role in data collecting and event monitoring. An operator desktop interface and a mobile application are the two components of the system that work together to enable two-way contact between the public and the government. Operators use an integrated dashboard to dispatch jobs, verify information, and coordinate incident maps, while users use the mobile platform to submit geolocated photographs, SMS, and situation reports. This approach improves situational awareness, facilitates prompt decision-making, and promotes community participation in emergency situations.

The authors stress the need for trustworthy information, user confidence, and manageable operator workloads when integrating data supplied by citizens. Validation using real-world events showed that community involvement significantly improves data richness and spatial coverage, but at the expense of causing problems with privacy, misinformation, and sustained engagement. By combining structured coordination models with mobile crowdsensing, IWARN's gamified and interactive framework effectively enhances conventional sensor-based early warning systems. All things considered, the framework offers a clever and scalable way to create robust early warning and catastrophe management systems that are focused on the community.

E. Image4Act: Online Social Media Image Processing for Disaster Response

Alam et al. [6] present Image4Act, a modular architecture for disaster intelligence that leverages social media. It analyses crisis photos in real time to assist first responders in determining the scenario. There is a sequential pipeline in the system design. This consists of a CNN-based severity classifier that uses transfer learning with the VGG-16 model, an image extraction module, a relevance classifier, a duplicate detection unit that uses perceptual hashing (pHash), a crowd-annotation system for human validation, and a persistent storage layer for structured crisis intelligence. This design facilitates the conversion of unprocessed visual input created by the public into actionable severity-level insights for prompt decision support.

With an AUC (Area Under the Curve) of 0.98, extensive validation across a variety of crisis scenarios—such as the earthquakes in Nepal and Ecuador, Typhoon Ruby, and Hurricane Matthew—showed good relevance detection accuracy. With an AUC of 0.72, it also showed respectable damage severity classification ability. About 76,000 tweets were successfully handled by the system during Cyclone Debbie, its real-world deployment. By using visual analysis to highlight locations that were severely affected, it assisted responders. Alam et al. [6] provide Image4Act, a modular architecture for disaster intelligence that makes use of social media, inspite of the fact that it successfully extracts actionable insights from unstructured image data.It helps first responders identify the situation by analysing crisis photographs in real time. The system design includes a sequential pipeline. This includes an image extraction module, a relevance classifier, a CNN-based severity classifier that employs transfer learning with the VGG-16 model, a duplicate detection unit that employs perceptual hashing (pHash), a crowd-annotation system for human validation, a persistent storage layer for structured crisis intelligence, and more. For quick decision assistance, this design makes it easier to transform unprocessed visual input produced by the general public into actionable severity-level insights.layer of analysis. Dynamic resource prioritisation, field-level mobile reporting tool integration, and automatic alerts are not supported.

F. Acceptance of Mobile Application on Disaster Preparedness

Escolano et al. [7] offer a framework for data-driven mobile applications that uses artificial intelligence and simulation-based analytics to enhance decision-making in disaster management and preparedness. Within a layered system comprising an AI engine, simulation and prediction modules, and a secure cloud repository, the design integrates real-time data collecting, predictive modelling, and prescriptive analytics. Interactive disaster preparedness scenarios are made possible by the mobile application. By converting user behaviour and interaction into machine learning-usable data, these simulations improve individual preparedness as well as institutions' situational awareness. This combination of data-driven decision-making and human involvement demonstrates a move toward disaster management systems that are more intelligent and flexible.

In addition to the technical framework, a user-centred design and a comprehensive evaluation of the system's usability and acceptance among disaster experts are highlighted by Escolano et al. [7]. According to their findings, users have a high level of confidence in the application's dependability, accuracy, and use. This emphasises how crucial trust and cognitive participation are when implementing smart catastrophe technology. One innovative approach to addressing data scarcity in actual disaster scenarios is the training of predictive algorithms on simulation-generated datasets. It makes it possible to enhance the model without depending on erratic crisis data.

The study also emphasizes how important it is to integrate AI ethically and communicate securely in emergency scenarios. By including adaptive intelligence, cloud-edge interoperability, and privacy protection, the model continues to perform well even under constrained network settings. All things considered, the research provides a scalable approach that blends responsible system design, simulation-driven learning, and AI-based analytics. A significant step toward the realisation of robust and technologically enabled catastrophe management and early warning systems is marked by its adaptable, safe, and user-trusted structure.

G. Smart Disaster Detection and Response System for Smart Cities

A comprehensive smart system design is also recommended by Boukerche and Coutinho [8] to enhance catastrophe detection, response, and prediction in smart cities. For real-time situational awareness and responsive response, the architecture integrates mobile ad hoc networking, people-centric sensing, and the Internet of Things (IoT). The system's five primary parts are wireless ad hoc networking of everything, smart sensing, smart processing, smart response, and privacy & security. While intelligent processing employs machine learning and data analytics to identify and forecast disasters, the intelligent sensing layer gathers environmental, social, and sensor data through IoT-focused and participatory sensing. Layered design reduces delays and improves response accuracy by enabling continuous information flow between responders, sensors, and decision-makers.

In order to optimise communication, monitoring, and security, the intelligent response module focuses on search and rescue (SAR) operations using wearable sensors, drones, and autonomous devices. The technology maintains continuous contact between rescue teams and IoT devices by adjusting to wireless ad hoc networks in the event that traditional infrastructures collapse. Drones can be used as mobile base stations to expand coverage and facilitate data relay in areas with inadequate communication. For dependability even in emergency scenarios, the model also emphasises user privacy, data integrity, and secure communication. The model establishes a strong basis for scalable and adaptable disaster-management systems by combining distributed fog computing, supervised learning, and IoT-based cooperation.

All things considered, the smart system outlined in [8] is a complete and future-proof solution that embodies the idea of resilient, tech-enabled smart cities. It makes a significant contribution to current early warning and disaster response scholarship because of its ability to combine sensor data, human engagement, and intelligent analytics. Figure 3's communication model and system structure demonstrate how networked smart devices and interconnected networks can work together to enable efficient life rescue, coordination, and prediction in emergency situations,response timeliness, and predictive accuracy.

Fig -3: The proposed smart system for disaster prediction, discovery and response for smart cities [8]

H. IRespondPH: A Mobile and Web-based Application for Post Disaster Needs Assessment and Response

IRespondPH is a cross-platform mobile and web application developed by Montefalcon et al. [9] with the goal of simplifying Post-Disaster Needs Assessment (PDNA) through systematic data collection, grouping, and visualisation. Comprehensive damage and needs reports can be submitted by impacted individuals or the assessment teams using the system. These reports are then combined and presented to responders and local government units (LGUs) on a centralised web dashboard. By classifying reports into human needs categories like housing, food, healthcare, and infrastructure issues, the platform enhances situational transparency and facilitates access through its user-friendly mobile interface. IRespondPH's backend assessment module is a crucial component that facilitates decision-making by prioritising zones according to severity levels and combining localised data to improve response times and resource deployment.

Through user acceptability testing, the authors demonstrated the system's feasibility, and strong usability and perceived usefulness ratings validated the suitability of electronic PDNA tools in real-world crisis situations. The lack of real-time alerting features, automated severity grading, and AI-based prioritisation limits IRespondPH's usefulness from early warning or predictive disaster preparedness to post-event response, despite the fact that it makes coordinated data collection and response coordination easier. The study also highlights how citizen participation and online platforms can improve government responsiveness, which serves as a foundation for more sophisticated disaster management solutions that may eventually include risk assessment, early warning triggers, and adaptive decision-making intelligence.

I. 112.social: Design and Evaluation of a Mobile Crisis App for Bidirectional Communication between Emergency Services and Citizens

A mobile crisis communication app called 112.social was presented by Kaufhold et al. [10] with the goal of facilitating organised, two-way communication between emergency response personnel and the public. The study discussed the drawbacks of open social media platforms and traditional emergency hotlines, which frequently lack organised reporting procedures and trustworthy methods for receiving comments [10]. To make sure the application satisfied the needs of both professionals and citizens in emergency management, the authors methodically designed and assessed it using a Design Science Research (DSR) approach [10]. In order to improve data consistency and operational usefulness, the platform enables users to submit incident reports using predefined categories, geolocation tagging, written descriptions, and multimedia attachments [10].

The method improves communication transparency and confidence in crisis circumstances by allowing authorities to reply directly to users and distribute verified notifications in addition to citizen reporting [10]. In comparison to traditional social media channels, the evaluation's findings showed that organised data collecting enhances situational awareness and lowers disinformation [10]. Additionally, during emergencies, the use of geo-referenced data facilitates effective resource allocation and event prioritisation [10]. Overall, by offering a scalable system that connects official emergency response infrastructures with citizen-generated information, the study advances crisis informatics [10].

J. AI-based concepts for Crisis Propagation Forecasting and Early Warning in Urban Areas

An AI-based paradigm for early warning and crisis propagation forecasting in complex urban environments is put out by Tundis et al. [11]. The paper discusses the drawbacks of traditional crisis warning systems, which frequently rely on authoritative inputs that are delayed and do not incorporate predictive knowledge. The authors want to facilitate personalised warning distribution and short-term, context-aware forecasting by integrating machine learning, natural language processing, and diverse urban data sources. In order to enhance readiness and reduce response delays brought on by disjointed warning systems, the framework is made to simulate the spatial and temporal evolution of crises in urban environments.

Data imputation, spatiotemporal forecasting, and citizen-centric advising components are all connected via an integrated AI-centered pipeline in the suggested system. To overcome data sparsity and coverage limitations, spatial imputation algorithms are used to collect and interpret urban sensor data from vital infrastructures and real-time citizen reports. The early identification of high-risk areas is then made possible by a forecasting model that makes autoregressive predictions about the spread of crises throughout discretised metropolitan grids. In order to bridge the gap between communication and prediction, the system includes a crisis adviser that uses natural language generation based on validated government documents to provide personalised warnings and actionable advice, guaranteeing contextual relevance, compliance, and dependability.

A scenario-based case study on storm-related crisis events in the German city of Darmstadt serves as evidence of the approach's efficacy. The system can produce timely, situation-aware warnings that are in line with national crisis communication requirements, according to qualitative evaluation. The work in [11] provides a complete and forward-looking approach for intelligent urban early warning systems by combining predictive modelling with adaptive alarm generating and citizen-oriented communication. The study's overall findings demonstrate how distributed collective intelligence powered by AI has the potential to boost proactive emergency management techniques, increase urban resilience, and raise crisis awareness.

3. COMPARATIVE STUDY

Scalability, data dependability, and user adoption are some of the issues that face disaster management system advancements powered by web and mobile platforms, artificial intelligence, geospatial analysis, and multi-sensor integration. The research that focus on real-time monitoring, predictive modelling, people-centered early warning, social media image processing, and post-disaster needs assessment are highlighted in Table I along with their goal, methodology or technology employed, and sensors or data sources. The sensors and data sources that facilitate situational awareness, quick alerts, risk prediction, and effective resource allocation include environmental sensors, GPS, satellite imaging, GIS data, mobile sensors, social media posts, and Internet of Things devices. These technologies boost proactive decision-making, increase preparedness, and boost the effectiveness of catastrophe response. They open the door for more intelligent, flexible systems that can handle a range of catastrophic situations while striking a balance between practical limitations and technology improvements to guarantee accessibility and dependability.

Table -1: Comparative summary of disaster management systems

Paper / Year	**Purpose**	**Methodology /Technique Used**	**Sensors/Data Sources Used**
Fouzan et al., 2024 [2]	Disaster alert and coordination	IoT-based system with mobile alerts	Environmental and GPS sensors
Saleem et al., 2025 [3]	Disaster prediction model	AI+GIS hybrid model	Satellite and geospatial data n accuracy, RMSE
Balogun et al., 2025 [4]	Online disaster management platform	Web-based system	User and environ-mental data
Díaz et al., 2022 [5]	Earlywarning via citizen participation	Action research + gamified mobile EWS	Citizen-generated data (images, GPS)
Alam et al., 2017 [6]	Social media image analysis for disasters	Deep learning + image classification	Online social media images (Twitter)
Escolano et al., 2023 [7]	Mobile app acceptance in disaster preparedness	Decision intelligence and survey-based analysis	User survey data
Boukerche & Coutinho, 2018 [8]	Smart disaster detection and response	IoT + cloud-based system for smart cities	IoT sensors, cloud data
Monte-falcon et al., 2021 [9]	Post-disaster needs assessment	Mobile + web-based application	Field survey and user input data
Kaufhold et al., 2018 [10]	Bidirectional crisis communication between citizens and emergency services	Design Science Research (DSR) with mobile app prototype development and evaluation	Citizen-reported data (text, images, geolocation), mobile GPS data
Tundis et al., 2025 [11]	AI-based crisis propagation forecasting and early warning in urban areas	Grid-based spatio-temporal modeling with ML forecasting + RAG-based LLM crisis advisor	Urban critical infrastructure sensors, citizen reports, government crisis documents (BBK), geospatial grid data

4. CONCLUSION

Creating communities that are aware, engaged, and proactive is the first step in empowering disaster resilience. We can foster a culture where readiness and quick response are shared duties by utilising early warning systems, web-based and mobile platforms, and public involvement. Communities obtain real-time situational awareness through the integration of AI, geospatial analysis, and multi-sensor data, which facilitates prompt decision-making and efficient resource allocation. These systems aid in risk assessment, recovery from disasters, and ongoing learning from the past in addition to emergency response. Technology developments and public involvement guarantee that solutions are applicable, broadly accepted, and easily available. With improved data fusion, AI-driven decision support, smooth platform integration, and more intelligent predictive models, disaster management technology is expected to develop further in the future and become an essential component of public safety. Community exercises, awareness campaigns, and training will all help to strengthen readiness, and stakeholder cooperation and policy frameworks will guarantee successful execution. A future where readiness, efficiency, and resilience work together to protect people, infrastructure, and the environment is being shaped by these inventions and group efforts.

REFERENCES

1. W. Sun, et al., "Applications of artificial intelligence for disaster management," Natural Hazards, pp. 1–59, 2020.
2. M. Fouzan et al., “Disaster Guard for Disaster Management,” International Journal for Multidisciplinary Research, vol. 6, no. 1, 2024.
3. A. Saleem, M. Muhammad et al., “A Hybrid Prediction Model Integrating Artificial Intelligence and Geospatial Analysis for Disaster Management,” IEEE Access, vol. 13, pp. 43716–43727, 2025.
4. G. B. Balogun et al., “A web-based platform for disaster management,” Science World Journal, 2025.
5. P. Díaz, M. Sánchez-Francisco, T. Onorati, A. Montero, and I. Aedo, “IWARN: A people-centered approach for early warning,” in Proc. Hawaii International Conference on System Sciences, 2022.
6. F. Alam, M. Imran, and F. Ofli, “Image4Act: Online Social Media Image Processing for Disaster Response,” in Proc. 2017 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM), 2017, pp. 601–604.
7. V. J. C. Escolano et al., “Acceptance of Mobile Application on Disaster Preparedness: Towards Decision Intelligence in Disaster Management,” in Proc. 2023 8th International Conference on Business and Industrial Research (ICBIR), 2023, pp. 381–386.
8. A. F. M. Boukerche and R. W. L. Coutinho, “Smart Disaster Detection and Response System for Smart Cities,” in Proc. 2018 IEEE Symposium on Computers and Communications (ISCC), 2018.
9. M. D. Montefalcon et al., “IRespondPH: A Mobile and Web-based Application for Post Disaster Needs Assessment and Response in the Philippines,” in Proc. 2021 5th International Conference on E-Society, E-Education and E-Technology, 2021.
10. M.-A. Kaufhold, N. Rupp, C. Reuter, and C. Amelunxen, “112.social: Design and evaluation of a mobile crisis app for bidirectional communication between emergency services and citizens,” in Proc. 26th Eur. Conf. Inf. Syst. (ECIS), Portsmouth, UK, 2018, Research Paper 81.
11. A. Tundis, M. Hummel, J. Gunkel, and C. Savaglio, “AI-based concepts for crisis propagation forecasting and early warning in urban areas,” in Proc. IEEE International Conference on Smart Cities and Crisis Management, 2024.