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Digital Transformation and Disaster Management in the Technological Society: A Review of Emerging Innovations, Governance Challenges, and Community Resilience Strategies

Muazu Muhammad Adam[1]*, Christopher Onosemuode[2], Sunday Akin Dare[3], Musa Lawal Falke[4], Hadi Sani Dangulbi[5]

[1,2,4,5]Center for Emergency, Crises and Disaster Risk Management, Federal University of Petroleum Resources, Effurun, Nigeria
[3]Department of International Studies, Baze University, Abuja, Nigeria

Email: muazumuhammad03@gmail.com, onosemuode.cris.@fupre.edu.ng, sundaydare@thetraffic.ng, abbafalke@gmail.com, hadisangulbi@gmail.com

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****Corresponding Author:***

ABSTRACT

Digital transformation (DT) is increasingly reshaping disaster management by enabling a transition from predominantly reactive approaches to predictive, data-driven, and resilience-oriented systems. However, the benefits of emerging digital technologies are often constrained by institutional, infrastructural, ethical, and socioeconomic challenges. This review examines the role of DT in enhancing disaster resilience and proposes an Integrated Digital Disaster Resilience Framework (IDDRF) that connects technological, governance, social, and resilience outcomes for sustainable disaster management. A comprehensive review of recent scientific literature was undertaken, focusing on Artificial Intelligence (AI), Internet of Things (IoT), Geographic Information Systems (GIS), remote sensing, big data analytics, blockchain, digital communication, and intelligent decision-support systems. The reviewed evidence was thematically analysed according to applications in disaster prediction, early warning, risk assessment, emergency response, recovery, and climate adaptation. The findings demonstrate that DT enhances disaster resilience through real-time hazard monitoring, predictive modelling, rapid information dissemination, improved situational awareness, evidence-based decision-making, and more efficient emergency coordination. Nevertheless, implementation is hindered by inadequate digital infrastructure, fragmented institutional arrangements, cybersecurity risks, data governance and privacy concerns, algorithmic bias, digital inequality, and limited technical capacity. The review therefore identifies human-centred AI, explainable decision-support systems, ethical data governance, inclusive digital access, community participation, interdisciplinary collaboration, and integration of indigenous knowledge as critical requirements for effective digital resilience. The proposed IDDRF provides an integrated pathway for policymakers, disaster management agencies, researchers, and technology developers to align digital innovation with governance, social inclusion, sustainable development, and long-term climate resilience.

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INTRODUCTION

The disaster phenomenon is increasingly complex because of the interplay between climate variability, rapid urbanization, technological disruptions, population growth, and interconnected socioeconomic systems. Contemporary disasters are characterized by uncertainty, cascading effects, compound hazards, and rapidly changing patterns of vulnerability, thereby exposing the limitations of conventional disaster management approaches that focus predominantly on response and recovery. Such reactive approaches often provide limited capacity for anticipating emerging hazards, understanding interconnected risks, coordinating real-time interventions, and building long-term adaptive capacity. Consequently, disaster management is increasingly shifting towards proactive, predictive, adaptive, and resilience-oriented approaches supported by digital transformation (DT). Digital technologies are changing how disasters are predicted, monitored, and managed through the integration of big data analytics, artificial intelligence (AI), Internet of Things (IoT)-based sensor networks, cloud computing, remote sensing, and real-time communication platforms (Abid et al., 2021; Khan et al., 2023).

Digital disaster management represents a broader transformation in which data-informed decision-making has become increasingly important to public safety, risk reduction, and resilience planning. Advanced information infrastructures enable the continuous collection, processing, integration, and interpretation of large volumes of heterogeneous data generated from environmental sensors, satellite systems, mobile devices, social media platforms, and other digital sources. These capabilities enhance situational awareness by providing emergency agencies with timely information about hazard evolution, affected populations, infrastructure conditions, and resource requirements. Consequently, digital systems can improve coordination among government agencies, humanitarian organizations, emergency responders, and local communities, thereby strengthening the efficiency and responsiveness of disaster management operations (Damaševičius et al., 2023).

Previous research has demonstrated the growing importance of connected digital ecosystems in emergency management. One notable development is the emergence of the "Internet of Emergency Services," which refers to interconnected digital devices, information systems, and communication networks that facilitate rapid information exchange, automated monitoring, and coordination of institutional responses. The integration of AI algorithms with sensor-based infrastructures can support early warning systems by identifying emerging threats, processing large volumes of information, and providing decision-makers with evidence for timely intervention. These capabilities represent a shift from conventional emergency response towards approaches that emphasize anticipation, prevention, preparedness, and continuous adaptation (Damaševičius et al., 2023; Krichen et al., 2023).

Remote sensing, satellite imagery, and social media analytics have further expanded the technological capabilities available for disaster risk management. Satellite-based observations provide extensive spatial information for monitoring floods, wildfires, earthquakes, and climate-related hazards, while social media platforms can generate near-real-time, user-generated information about localized impacts, community needs, and emerging situations. Such technologies can support damage assessment, emergency planning, resource allocation, and situational awareness, particularly when conventional information channels are disrupted during disasters (Krichen et al., 2023). However, the effectiveness of these technologies depends on the quality, availability, interoperability, and security of the data on which digital decision-making relies. Concerns relating to data quality, cybersecurity, privacy, interoperability, infrastructure availability, and unequal access therefore remain important challenges to the effective implementation of digital disaster management.

Importantly, the concept of disaster resilience has increasingly moved beyond a purely technological perspective towards a socio-technical understanding that recognizes the interaction between digital infrastructure, institutional governance, and community capacity. Traditional resilience assessments based on relatively fixed indicators may inadequately capture the complex interdependencies, dynamic vulnerabilities, and cascading consequences associated with contemporary disasters. Dynamic modelling approaches that incorporate social, environmental, institutional, and technological factors are therefore increasingly important for understanding and strengthening the adaptive capacity of vulnerable communities (Yabe et al., 2022). This perspective establishes resilience not simply as a function of technological capability but as a process through which societies, institutions, and communities effectively access, interpret, govern, and apply technological resources within specific local contexts.

Community participation has consequently become an important consideration in the digital transformation of disaster management. Although advanced technologies can strengthen prediction, monitoring, and response, their effectiveness may be constrained when decision-making remains excessively centralized and disconnected from local realities. Local actors require access to relevant information, digital competencies, and meaningful opportunities to participate in risk assessment and disaster risk reduction. Community engagement can also facilitate the incorporation of local experiences, context-specific vulnerabilities, and indigenous knowledge into technology-enabled disaster planning and decision-making (Ma et al., 2023; Imperiale & Vanclay, 2021). A people-centred approach is therefore essential if digital transformation is to produce resilience outcomes that are inclusive, locally relevant, and sustainable.

Alongside technological and social considerations, previous research has identified governance as a critical determinant of successful digital transformation in disaster management. Digital inequality, algorithmic bias, data ownership, privacy, ethical concerns, institutional capacity limitations, and inadequate regulatory frameworks can undermine the equitable deployment and use of digital technologies. Effective disaster governance must therefore develop alongside technological innovation by establishing appropriate mechanisms for transparency, accountability, data protection, institutional coordination, and responsible technology use (Velev & Златева, 2023; Saja et al., 2021; Argyroudis et al., 2021; Aboualola et al., 2023). Without such governance arrangements, technological advancement may reproduce existing inequalities or create new forms of vulnerability, particularly among communities with limited digital infrastructure and technical capacity.

Despite the growing body of research on digital technologies and disaster management, important gaps remain in the existing literature. Much of the available research focuses on individual technologies or specific stages of the disaster management cycle, such as AI-based prediction, IoT-enabled monitoring, GIS-based risk assessment, remote sensing, or digital communication. Although these studies demonstrate the potential of individual technologies, they often examine technological capabilities separately from the governance, social, ethical, and institutional conditions required for their effective application. Consequently, there remains limited synthesis of how technological innovation, governance arrangements, community participation, digital inclusion, and disaster-management outcomes can be systematically integrated within a single resilience-oriented framework. This fragmentation limits the development of a holistic understanding of digital disaster resilience and creates a need for an integrated conceptual approach.

Furthermore, limited attention has been given to the interaction between emerging technologies and community-level resilience, particularly concerning the integration of indigenous knowledge, digital inclusion, ethical governance, and human-centred decision-making. The mere availability of sophisticated digital tools does not necessarily guarantee improved disaster resilience. Their effectiveness depends on whether institutions possess the capacity to deploy them responsibly, whether communities can access and understand the information generated, and whether decision-support systems remain transparent, explainable, and responsive to local needs. Addressing these interconnected dimensions is therefore necessary for moving from technology-centred disaster management towards genuinely resilient and inclusive digital disaster governance.

Against this background, this review examines the development and application of digital transformation in disaster management, with particular attention to its contribution to disaster prediction, early warning, risk assessment, emergency response, recovery, and climate adaptation. It further examines the governance, ethical, institutional, and social challenges associated with digital transformation and synthesizes the evidence into an Integrated Digital Disaster Resilience Framework (IDDRF). The review specifically seeks to establish how technological, governance, social, and outcome dimensions can be connected to support more effective and sustainable disaster resilience.

The findings of the review demonstrate that digital transformation can substantially strengthen disaster resilience through real-time monitoring, predictive analytics, improved early warning, enhanced situational awareness, rapid information dissemination, evidence-based decision-making, and more efficient coordination of emergency resources. However, the review also finds that technological capabilities alone are insufficient. Institutional capacity, ethical data governance, cybersecurity, digital inclusion, community participation, digital literacy, interdisciplinary collaboration, and equitable access to technology are critical conditions for achieving sustainable outcomes. Based on this synthesis, the IDDRF integrates technological innovation with governance and social dimensions to provide a more comprehensive approach to digital disaster resilience. The framework has implications for policymakers, disaster management agencies, researchers, technology developers, and communities seeking to design human-centred, inclusive, ethical, and adaptive disaster management systems. It also highlights the importance of explainable AI, responsible data governance, and the integration of indigenous knowledge with emerging digital technologies in strengthening climate adaptation and long-term disaster resilience.

METHOD

The method of this study was a narrative literature review, which was selected to synthesize the current knowledge on digital transformation in disaster management and the implication for disaster resilience and sustainable development. To identify relevant peer-reviewed journal articles, conference proceedings, book chapters, and international reports, the major scientific databases, such as Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, Taylor & Francis Online, Wiley Online Library, and Google Scholar, were used. To conduct the literature search, combinations of the keywords were used, including digital transformation, disaster management, artificial intelligence, the Internet of Things, big data analytics, remote sensing, blockchain, community resilience, climate adaptation, and digital governance.

Research papers were selected if they focused on the use of new and emerging digital technologies for disaster risk reduction, emergency management, governance, community resilience, and/or sustainable development. Publications that were not directly related to digital disaster management, duplicate publications, opinion articles without empirical or conceptual contributions, and non-English publications were excluded. Selected literature has been critically examined and grouped thematically: digital transformation evolution, emerging technologies, governance issues, socio-economic issues, community resilience, and future research directions. The literature search results were compiled to summarize existing knowledge, research needs, and emerging trends, leading to the conclusion of an Integrated Digital Disaster Resilience Framework that shows how technological innovation and governance mechanisms, social inclusion, and disaster resilience outcomes interact.

RESULTS AND DISCUSSION

Traditional Disaster Management Approaches

Traditional disaster management was developed mainly with the objective of emergency response systems, which were oriented in action to react to disasters once they had happened, instead of preventing or anticipating them. These approaches were heavily dependent on institutional procedures, manual collection of information, physical communication, and hierarchical command chains in coordinating emergency operations. Traditional disaster management systems relied on the judgment of disaster management staff in the field, paper documents, radio communications, local perceptions of the impact of disasters, and the allocation of resources. These systems laid the groundwork for the structured approach to disaster response, but sometimes they were hampered by the lack of timely information, poor situational awareness, and disorganized communication between various agencies.

In the case of traditional disaster management, the emphasis was placed on the prompt dispatch of disaster relief personnel, evacuation planning, short-term accommodation arrangements, and disaster relief operations after the disaster. Decision-making was based on experience and on the judgment of the decision-makers rather than continuous monitoring of the environment or predictive intelligence based on disaster history. As a result, there was much reactive responding with interventions after a lot of damage had been done. This operational mindset narrows the possibilities of proactive risk reduction and early intervention, especially in disasters with high dynamics like floods, wildfires, pandemics and severe weather events (Rad et al., 2021; Fischer-Preßler et al., 2024).

With the increasing frequency, complexity, and socioeconomic impacts of disasters globally, the shortcomings of traditional disaster management became more apparent.

One of the most important shortcomings was reliance on the information systems, which were not comprehensive enough to enable sharing of critical data between the emergency agencies. Lots of information was often confined within different organizations, causing duplicate efforts, delayed decision-making, and suboptimal use of emergency resources. Moreover, conventional systems weren't able to merge various data sources at once, and during complicated emergencies, it was extremely difficult to create a comprehensive situational assessment (Abid et al., 2021; Ghadge, 2023).

One more constraint was the manual monitoring and interpretation that slowed and limited the speed and precision of disaster assessment. Emergency managers often made decisions without having access to complete and up-to-date information without continuous surveillance technologies, adding to the uncertainty in their decision-making. Lack of predictive ability also pushed the focus of disaster preparedness planning towards the past, not the future, in terms of dynamic risk forecasting. This meant that vulnerable communities were often notified too late to take effective action to protect themselves, therefore lowering the overall resiliency of disaster management systems (Yan et al., 2024; Majemite et al., 2024).

Transition Toward Technology-Driven Disaster Management

As traditional emergency management has gradually become constrained, the shift to technologically based disaster management systems that focus on prevention, preparedness, prediction, and resilience has been further enhanced. Digital disaster management relies on cutting-edge computational technologies to convert vast amounts of disparate information into usable intelligence as opposed to traditional disaster management approaches. This paradigm shift has completely transformed the concept of disaster governance by bringing in every aspect of the disaster management cycle (Krichen et al., 2023; Vermiglio et al., 2021), including AI, ICT, cloud computing, remote sensing, Internet of Things (IoT) devices, and geospatial analytics.

One of the key features of this change is the shift towards data-driven decision-making, with the constant collection and analysis of real-time data from satellites, weather stations, drones, IoT sensors, mobile devices, and social media. Integrated digital platforms allow emergency managers to monitor evolving hazards, assess exposure, estimate resources needed, and coordinate emergency operations, not just based on human observations. Such technologies can greatly enhance situational awareness and minimize uncertainty in high-speed disaster scenarios (Abbasi et al., 2024; Eren & Duman, 2025).

One of the latest advancements in digital transformation is the development of predictive disaster systems. Predictive analytics and machine learning algorithms allow disaster managers to detect patterns and predict the occurrence of hazards and their likely consequences and to provide early warnings before the disaster occurs. Predictive systems are used by analyzing historic data and real-time environmental observations to enable proactive mitigation measures that minimize casualties, infrastructure damage, and economic losses. From reactive response to anticipatory action, this change significantly enhances disaster preparedness and long-term resilience (Jain, 2024; Khan et al., 2023).

The shift has also fostered the emergence of smart disaster management frameworks, where digital technologies are interconnected and are brought together in a single decision-making environment. They are being developed to integrate AI-driven analytics, geospatial information systems, IoT (Internet of Things)-based monitoring networks, cloud-based communication capabilities, and crowdsourced information to enable coordinated responses from governments, humanitarian actors, the private sector, and affected communities. These comprehensive designs foster interoperability, streamline risk evaluation processes, manage resources efficiently, facilitate data-driven policymaking, and foster greater collaboration among stakeholders and citizens (Abdul et al., 2024; Fischer-Preßler et al., 2024).

Moreover, there is growing use of high-resolution geospatial information and machine learning modelling applications in smart disaster management to develop a dynamic monitoring environment to continually update the risk profile as new information is received. The use of remote sensing technologies, satellite images, and IoT sensors offers a complete picture of the environment, which helps to better detect hazard precursors and enhance emergency planning. Such innovations have fundamentally changed the way disasters are managed from a singular institutional effort to a collaborative, scalable, and adaptive approach, better able to respond to increasingly complex, interconnected disaster risks (Eminoğlu & Tarhan, 2025; Abbass et al., 2025; Chavula et al., 2025; Kangana et al., 2024; Saputra et al., 2025).

Emerging Technologies Transforming Disaster Management

The growing scale, magnitude, and sophistication of natural and man-made disasters has spurred the application of new digital technologies to disaster management systems. In contrast to traditional coordination and intervention methods, modern disaster management increasingly involves the use of integrated technological ecosystems in order to enhance preparedness, response, recovery, and resilience. Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, Geographic Information Systems (GIS), big data analytics, blockchain and digital communication platforms have revolutionized disaster governance, making it a data-driven, proactive and evidence-based discipline that can predict disasters and inform decision-making. The combination of these technologies enhances situational awareness, optimizes humanitarian logistics, bolsters inter-agency coordination, and allows for real-time monitoring of disaster risks at various spatial and temporal levels (Ghaffarian et al., 2023; Krichen et al., 2023). Moreover, the use of Industry 4.0 technologies makes it easier to manage infrastructure in a resilient way, improves the visibility of supply chains, and promotes adaptive disaster governance that is able to react effectively to the growing uncertainty of the environmental and geopolitical context (Rad et al., 2021; Abid et al., 2021).

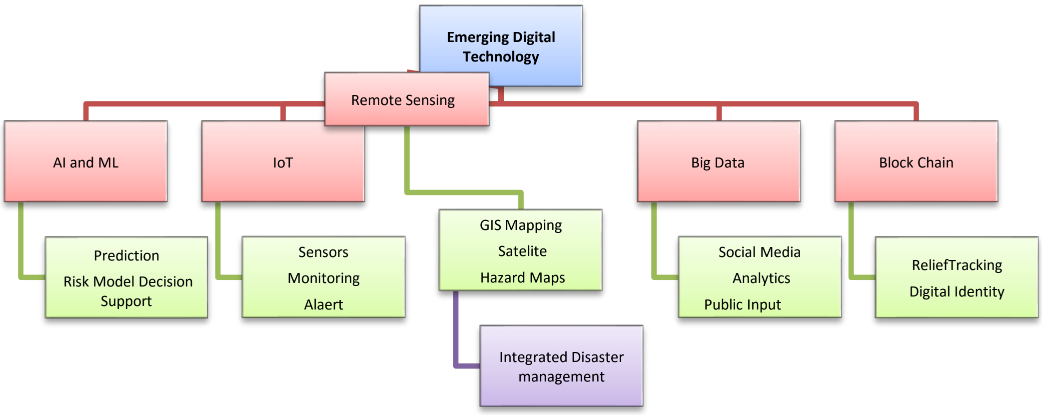

Fig 1. Integrated technological ecosystem supporting digital transformation in disaster management

1. Artificial Intelligence and Machine Learning Applications

The use of artificial intelligence (AI) and machine learning (ML) in digital disaster management has emerged as a pivotal technology that allows computers to process vast amounts of information, uncover patterns and trends, and produce predictions with minimal human input. AI algorithms can learn from new data, continuously enhancing the accuracy of disaster predictions and improving the efficiency of disaster management over time, as opposed to the traditional statistical methods.

Disaster prediction is one of the most important use cases of AI. Machine learning models combine meteorological data, hydrological data, satellite data, and seismic data with climate data to provide early warnings of floods, hurricanes, droughts, earthquakes, landslides, and wildfires. Early prediction helps emergency responders to provide early warnings, organize efforts, and minimize loss of life and property due to disaster. (Krichen et al., 2023; Khan et al., 2023).

AI also plays a role in risk modeling by integrating demographic data, environmental factors, infrastructure features, and socioeconomic data to assess vulnerability and exposure. They can support governments in recognizing high-risk communities, prioritizing investments to mitigate risks, and creating evidence-based disaster preparedness strategies.

A second major use case is automated decision support, where AI-powered systems use real-time data from multiple sources to recommend operational actions like evacuation routes, resource deployment, shelter allocation, and emergency logistics, etc. These systems are able to greatly shorten the decision-making process and increase the coordination among emergency personnel.

In post-disaster scenarios, AI can be used to analyze satellite imagery, drone photos, and aerial surveys to assess damage automatically. Humainitarian groups can use deep learning algorithms to quickly detect infrastructure damage, such as buildings, roads, bridges, and other structures, enabling them to allocate resources for rescue and recovery more effectively (Jain, 2024).

However, there are some problems yet to be overcome. Algorithms are less effective when data is not of high quality or missing or not reported consistently. If training data are not representative, then algorithm bias can result in unequal risk predictions for vulnerable populations. In addition, the opacity of complex AI models poses questions about accountability and trust among the public, especially when AI-driven decisions impact emergency resource allocation (Ghaffarian et al., 2023).

2. Internet of Things (IoT) and Smart Disaster Monitoring

The adoption of the Internet of Things (IoT) has radically transformed the way disasters are monitored by linking together a proliferation of sensors that monitor and communicate with environmental information on a continuous basis. Such smart monitoring networks provide real-time observations and greatly enhance detection of hazards and emergency responses.

The Internet of Things (IoT)-based environmental sensors capture rainfall, river level, soil moisture, air quality, temperature, seismic activity, wind speed, and structural conditions of critical infrastructure. These sensors constantly send data to central monitoring systems, which have the ability to automatically identify abnormalities.

The ability to monitor conditions in real time provides emergency managers with current data on the evolving disaster conditions, rather than just periodic field reports. The real-time situational awareness enables authorities to track the movement of hazards, detect new threats, and better manage emergency operations (Atadoga et al., 2024; Odimarha et al., 2024).

Another use of IoT networks is automatic warning systems, where when the sensors observe some condition that exceeds a certain threshold, alerts are immediately sent. Communities are warned via mobile apps, SMS, emergency sirens, and digital platforms, enabling preemptive evacuation and risk mitigation.

Successful implementation of IoT, however, relies on considerable infrastructure needs, such as sufficient electricity, internet connection, cloud computing resources, and communication networks. Furthermore, the maintenance expenses are high, especially in developing nations, due to the constant need for sensor calibration, sensor replacement, cyber security protection, and software updates.

Remote Sensing, GIS, and Satellite-Based Technologies

Spatial disaster analysis and emergency planning have been made essential with the help of remote sensing, Geographic Information Systems (GIS), and satellite technologies. The high-resolution satellite imagery is able to give continuous observations over large geographical areas, which are often not accessible during disastrous situations.

These technologies are useful for hazard mapping, such as mapping flood-prone areas, landslide susceptibility areas, wildfire risk areas, coastal erosion, and earthquake fault lines. GIS combines all the information from the environment, demographics, and infrastructure to create a comprehensive disaster risk map to direct the land use planning and disaster mitigation measures.

Satellites continuously monitor rainfall intensity, river discharge, reservoir levels, and inundation extent for flood monitoring. Together with the hydrological models, these observations enhance the accuracy of flood forecasting and preparedness for emergencies.

Remote sensing also plays a role in land-use assessment, providing planners with resources to assess urban sprawl, deforestation, wetland loss, ecosystem change, and other factors that affect disaster vulnerability. This information helps in the development of policies for sustainable development that will lower the risk of future disasters.

Satellite imagery can be used post-disaster for damage assessment, thereby rapidly estimating the damage to infrastructure, displacement of population, agricultural losses, and environmental impacts after disasters. These evaluations enable rapid recovery planning and humanitarian response, as well as helping to minimize reliance on time-intensive ground assessments (Dacre et al., 2024; Khan et al., 2023).

1. Big Data Analytics and Social Media Intelligence

With the widespread adoption of digital communication systems, unprecedented opportunities have emerged for disaster-related information to be collected and analyzed. Big data analytics pulls together the structured and unstructured data from satellites, IoT sensors, mobile devices, weather stations, government databases and social media platforms which provide the intelligence needed to inform emergency management decisions.

One of the larger applications is in real-time information gathering, where millions of digital observations are analyzed to detect newly found hazards, impacted populations, infrastructure and resource needs, etc. Advanced analytics allows disaster management officials to track disasters during actual events, not just after.

One of the most important aspects of crisis communication is the ability to reach people quickly with warnings and instructions in order to ensure their safety. Social media platforms play a critical role in delivering emergency warnings, evacuation instructions, and other public safety messages in a timely manner. Social media is also being used for disinformation and to coordinate emergency-related responses by both governments and humanitarian organizations.

In addition, digital platforms facilitate citizen involvement, enabling citizens to report an incident, upload photos, share locations of hazards, and provide crowdsourced information that supplements official disaster data. The information collected by the community helps increase awareness and facilitates more responsive disaster management.

However, there are still a number of problems to overcome. Fast dissemination of misinformation can cause confusion and lead to a loss of emergency readiness. Besides, the personal data collection on a large scale also brings up a lot of questions concerning data privacy, user consent, ethical data management, surveillance, and sensitive information (Dennehy et al., 2021; Alvarenga et al., 2023).

2. Blockchain and Digital Platforms for Disaster Response

Blockchain technology introduces a new layer of transparency, accountability, and security to digital records, enhancing accountability in humanitarian operations. Blockchain provides governments, humanitarian organizations, donors, and affected communities with greater trust and lower risk of fraud in transactions.

A significant use case is transparent relief distribution, where all financial transactions and the distribution of aid are recorded on the blockchain, allowing for a more efficient allocation of resources for those originally intended and reducing corruption and duplication.

Digital identity management is another use case where blockchain can assist by offering secure digital identity to IDPs who have misplaced their official documents in disaster situations. Digital identities ensure people have access to health, financial, insurance, and humanitarian services without needing to carry physical proof.

One of the other notable uses is humanitarian logistics, as blockchain can enhance transparency in the relief supply chain, from procurement to distribution. Blockchain can be used in combination with IoT devices to monitor inventory, transportation paths, storage conditions, and delivery status in real time, which boosts operational efficiency and accountability (Dubey et al., 2022; Iftikhar et al., 2022).

As blockchain technologies evolve, AI capabilities and their connection to the Internet of Things (IoT), cloud, and digital platforms hold the promise to build highly resilient disaster management ecosystems that enable the secure sharing of information, automated resource coordination, and adaptive humanitarian response in complex emergency contexts.

Table 1. *Emerging Digital Technologies and Their Applications in Disaster Management*

Technology	Major Applications	Key Benefits	Major Challenges
Artificial Intelligence & Machine Learning	Disaster prediction, risk modelling, automated decision support, damage assessment	Early warning, predictive analytics, rapid decision-making	Data quality, algorithm bias, lack of transparency
Internet of Things (IoT)	Environmental sensing, real-time monitoring, automated alerts	Continuous monitoring, rapid detection, improved situational awareness	Infrastructure dependency, maintenance costs, cybersecurity
Remote Sensing & GIS	Hazard mapping, flood monitoring, land-use analysis, post-disaster assessment	Accurate spatial analysis, rapid damage estimation	High implementation cost, technical expertise
Big Data & Social Media	Real-time information collection, crisis communication, public participation	Faster information sharing, improved coordination, crowdsourced intelligence	Misinformation, data privacy, information overload
Blockchain & Digital Platforms	Relief distribution, digital identity, humanitarian logistics	Transparency, accountability, secure transactions	Scalability, interoperability, regulatory challenges

Digital Disaster Management: Governance Challenges

Digitalization of disaster management has given a huge boost to the preparedness, response, recovery and resilience through the use of Artificial Intelligence (AI), Big Data Analytics, Internet of Things (IoT), Blockchain, Remote Sensing and Cloud Computing. The adoption of these technologies is not just about technological innovation, though, and effective governance structures are crucial for ensuring accountability, interoperability, ethical implementation, and public trust. The complete implementation of a digital disaster management system is still limited by weak institutional capacity, divided policies, insufficient legal systems, and ethical issues. For this reason, the need to set up comprehensive governance mechanisms has become a necessity to make sure that digital technologies are deployed in a responsible, transparent, and equitable manner in disaster risk reduction programs (Fischer-Preßler et al., 2024; Vermiglio et al., 2021).

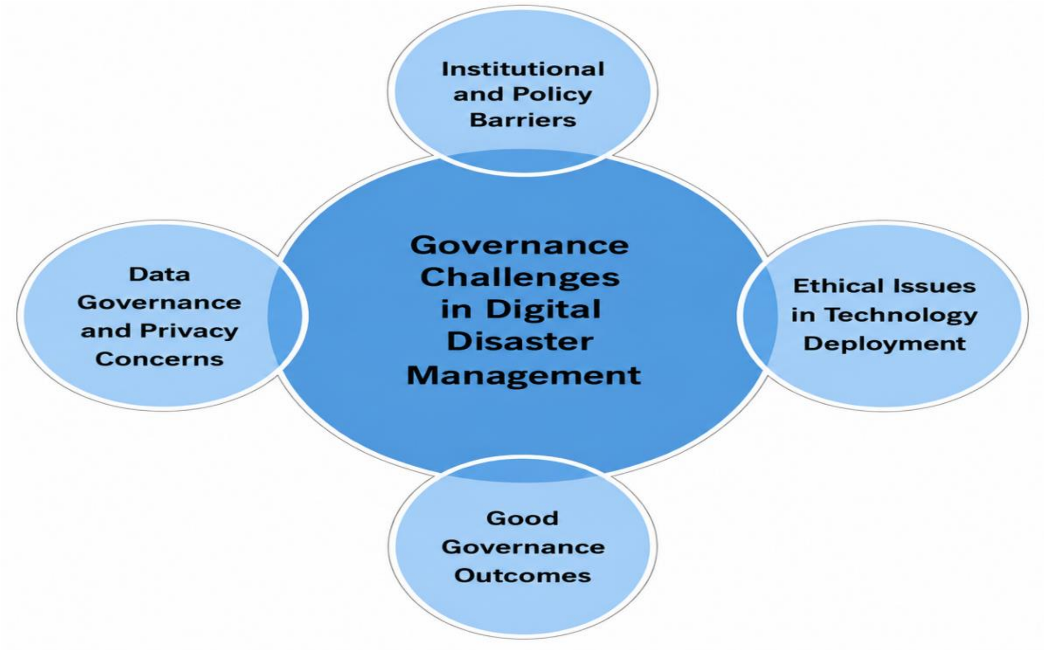

Fig 2; Governance Challenges in Digital Disaster Management

1. Institutional and Policy Barriers

Institutional and policy barriers continue to be one of the major hindrances to digital transformation of disaster management. Many governments acknowledge the role of digital technologies in DRR, but the ability to implement them is hindered by a lack of institutional capacity, by a lack of coordination and by a lack of regulation.

Limited government capacity is one of the challenges. Most disaster management organisations, especially in developing nations, are under-resourced in terms of funds, human resources, digital infrastructure and technical expertise to be able to implement new and advanced technologies like AI, IoT and cloud-based disaster management systems. Poor investment in digital infrastructures hinders the collection, processing and utilisation of timely disaster information.

Lack of coordination between government ministries, emergency management bodies, humanitarian actors, research institutions and private sector actors is another important challenge. Disasters are often dealt with by using a variety of separate databases, which are not interlinked, leading to disjointed information sharing, duplicated efforts and slow response. There is a lack of coordination mechanisms in operation, which means that during complex emergencies that require rapid information sharing, the efficiency of operations is lowered. (Abdul et al., 2024)

In addition, numerous countries are still lacking in comprehensive technology policies for the use and control of new digital technologies in disaster management. There is generally limited legislation concerning artificial intelligence, digital communication platforms, cybersecurity or cross-border data sharing, and existing disaster management legislation is more concerned with disaster response. Lack of standardisation also makes cooperation in disaster response more challenging as interoperability between digital systems is limited (Mani et al., 2023).

Institutional challenges can be addressed by implementing national digital disaster management strategies that include common technical standards, enhanced institutional coordination, interagency collaboration, and investments in the development of a digital infrastructure and a digital disaster management workforce (Abualenain, 2024).

2. Data Governance and Privacy Concerns

In the era of digitalisation, there has been a growing reliance on digital technologies, and a lot of information on disaster events has been produced, which has created a need for effective data governance in disaster management. The benefit of real-time information is to provide situational awareness and better decision-making, but it also raises many legal, ethical, and security issues.

Ownership of data is one of the significant issues. The production of disaster information involves various actors such as governments, satellites, telecom, humanitarian organisations, private technology companies and citizens themselves. Lack of clear ownership structures can lead to uncertainty and confusion about access to the data, rights of sharing, ownership of the data, and who is responsible for long-term storage. In an emergency situation, when speedy decision-making is crucial, these uncertainties can result in the delay of information exchange.

Another key challenge is cybersecurity. Cloud computing, interconnection communication networks, IoT devices and online databases have become a vital part of digital disaster management systems, and these are becoming potential targets of cyberattacks. Emergency operations may be undermined by unauthorised access, ransomware, data manipulation and service disruptions, which can impact public confidence and delay humanitarian response. As a result, disaster management organisations need to have effective cybersecurity measures in place, such as using encryption, secure authentication processes, regular system monitoring, and vulnerability evaluations.

But also critical is the advocacy of responsible data use. The gathering of geospatial data at scale, social media data, mobile phone records and personal information is of concern to privacy, informed consent and ethical data handling. Organisations have to make sure that disaster information is collected only when it is needed; stored securely; used transparently; and protected against misuse and in compliance with national and international data protection regulations (Fischer-Preßler et al., 2024).

3. Ethical Issues in Technology-Based Disaster Management

With the use of increasingly widespread AI and automated decision-support systems comes complex ethical issues that need to be managed properly and monitored on a regular basis.

An often talked about problem is algorithmic bias. Predictive models are trained on historical data, which can include inaccuracies, omissions, and demographic imbalances, potentially leading to skewed recommendations. AI systems are trained on historical data, and if that data is flawed, inaccurate, or imbalanced with respect to demographics, the predictive models can produce biased recommendations. These biases can affect evacuation priorities, resource distribution, vulnerability analysis, and emergency responses, which can impact marginalised or at-risk groups. This means ongoing validation, multiple data sets and independent auditing are vital to reduce discriminatory outcomes (Visave, 2024).

One of the other major issues is digital exclusion. While digital technologies enhance the efficiency of disaster management operations, many vulnerable communities may not be equally accessing digital services due to digital illiteracy, a lack of communication infrastructure, and access to the internet as well as smartphone devices. Early warning systems and digital emergency services are difficult to access for the rural population, older people, people with disabilities and low-income groups. Equality in the digital world needs to be addressed by policy to ensure inclusiveness, investment in communication facilities in rural areas, and the creation of accessible multilingual platforms.

Responsible governance calls for the responsible use of AI. Many AI systems operate as "black boxes" that are hard for emergency managers and the public to comprehend, as automated decisions are generated. The lack of transparency will decrease accountability and can raise doubts about the trustworthiness of digital disaster management systems. To deploy AI responsibly, it is essential to have explainable algorithms, human oversight, transparent decision-making processes, and accountability mechanisms that allow for expert review before the recommendations are put into practice (Visave, 2025).

The efforts of strengthening data governance, fixing the weaknesses of institutions and embedding ethical principles within technology deployment represent essential preconditions to build resilient, trustworthy and inclusive disaster management systems that are able to effectively meet future disaster challenges.

Table 2. *Governance Challenges and Recommended Solutions in Digital Disaster Management*

Governance Challenge	Major Issues	Potential Solutions
Institutional Capacity	Limited funding, inadequate technical expertise	Capacity building, workforce training, infrastructure investment
Policy and Coordination	Fragmented agencies, weak interoperability	National digital disaster policies, interagency coordination frameworks
Data Governance	Data ownership, privacy, cybersecurity	Data-sharing agreements, cybersecurity standards, privacy regulations
Ethical AI	Algorithmic bias, lack of transparency	Explainable AI, independent auditing, human oversight
Digital Inclusion	Unequal technology access, digital literacy gaps	Inclusive digital policies, rural connectivity, accessible technologies

Socioeconomic dimensions and community resilience

Digital transformation has already been used to enhance the preparedness and response to disasters using state-of-the-art technologies; however, it requires equitable access to digital resources and community engagement to be effective. Socio-economic differences, poor infrastructure, and lack of digital skills remain a barrier to the benefits of technology-driven disaster management, especially in vulnerable communities. So, digital resilience must go hand-in-hand with technology innovation and social inclusion, community engagement, and sustainable development principles so that no population is left behind in disaster preparedness, response, and recovery (Argyroudis et al., 2021; Çetindamar et al., 2025).

1. Digital Inequality and Vulnerable Communities

Insufficiently addressing digital inequality is one of the largest challenges to effective disaster risk reduction. Many vulnerable groups lack reliable Internet access, have weak information and communication technology facilities, and cannot access digital communication platforms, which affects their capacity to receive early warnings and emergency information.

Access barriers are one of the most significant barriers, where poverty, digital literacy, and affordability are the common issues that affect the ability of a person to access a digital disaster service. These disparities hinder preparedness for and response to emergency situations.

The rural–urban technology gap is also a significant issue. Typically, urban areas have a stronger communication network, high-speed Internet, and digital services, while rural areas have lower levels of network coverage and technological resources. This leads to increased vulnerability of the rural population during disasters because there is a lag in dissemination of information during disaster. This explains that the dissemination of information in disasters takes a longer time in rural areas, which results in increased vulnerability of the rural population during disasters (Gupta et al., 2024).

Moreover, challenges in the infrastructure, such as precarious power supplies, communication infrastructure, and lack of digital infrastructure, affect the effectiveness and efficiency of technology-based disaster management, especially in extreme weather events. To tackle these disparities, investments should go into resilient communication systems, affordable internet access, and digital capacity building (Onoja & Ajala, 2022).

2. Community participation in technology-based disaster management

By leveraging local experience and knowledge with technological innovations, community participation plays a key role in making digital disaster management effective and sustainable.

Local knowledge is another crucial approach, in which indigenous practices, historical experiences, and community observations enhance hazard identification and preparedness planning, alongside scientific data. Local and scientific knowledge is an effective mix that can result in more locally specific and culturally appropriate disaster management strategies (Hageer, 2025).

Citizen science, in which community members provide disaster-related data by using mobile apps, social media, drones, and crowdsourcing sites, is another promising strategy. Enhanced real-time situational awareness and better emergency response through public participation.

Communities also have a crucial role to play in community-based warning systems, where early warnings and evacuation coordination are carried out by a network of community volunteers, community leaders, and community-based digital communication systems. These participatory systems reinforce public trust and disaster resilience by bringing people together.

3. Digital Transformation and Sustainable Development

Digital disaster management directly contributes to sustainable development through enhancing resilience, minimizing the losses of disasters, and inclusive economic growth.

Digital technologies can contribute to the achievement of several Sustainable Development Goals (SDGs), including SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Digital risk assessment, real-time monitoring, and early warning systems increase disaster preparedness while safeguarding lives, infrastructure, and livelihoods (O'Sullivan et al., 2021).

Furthermore, the digital transformation process contributes to climate adaptation by providing tools for monitoring climate risks, forecasting the climate, and adapting based on evidence. The use of AI, remote sensing, and IoT can help governments predict climate-related threats and take proactive measures to mitigate them.

In addition, inclusive innovation guarantees that technology solutions are available to any community, whatever their income or location, gender or disability. Inclusive digital policies contribute to social equity and boost the resilience of communities and sustainable development (Rydzewski, 2025).

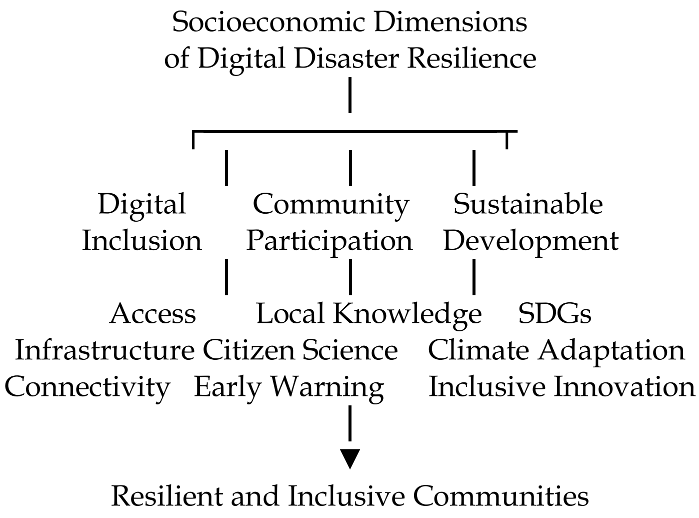

Fig 3. Socioeconomic Dimensions of Digital Disaster Resilience

Future Perspectives and Research Directions

The future of digital disaster management lies in developing intelligent, inclusive, and ethically governed systems that combine advanced technologies with human expertise. Emerging innovations should focus not only on improving technological capabilities but also on ensuring accessibility, transparency, and sustainability across diverse communities.

One promising direction is AI–human collaborative disaster management**,** where artificial intelligence supports emergency managers by providing predictive analytics and decision support while human experts retain responsibility for critical decisions. Such collaboration enhances efficiency without replacing human judgment.

Another important research area is the development of **smart cities and disaster resilience**. Smart cities integrate IoT sensors, AI, cloud computing, and digital communication systems to monitor infrastructure, detect hazards, and coordinate emergency response in real time, thereby improving urban resilience.

Future studies should also prioritize **inclusive digital technologies** that address digital inequality by developing affordable, accessible, and user-friendly disaster management solutions for vulnerable populations.

Strengthening **ethical technology governance** remains equally important. Future governance frameworks should promote transparency, accountability, privacy protection, explainable AI, and responsible data management to increase public confidence in digital disaster systems.

Finally, greater emphasis should be placed on the **integration of indigenous knowledge with digital systems**. Combining traditional environmental knowledge with satellite observations, AI models, and GIS technologies can improve hazard prediction, community acceptance, and locally appropriate disaster management strategies. Such interdisciplinary approaches will contribute to more resilient, equitable, and sustainable disaster risk reduction systems while supporting long-term climate adaptation and community resilience (Jiang et al., 2025).

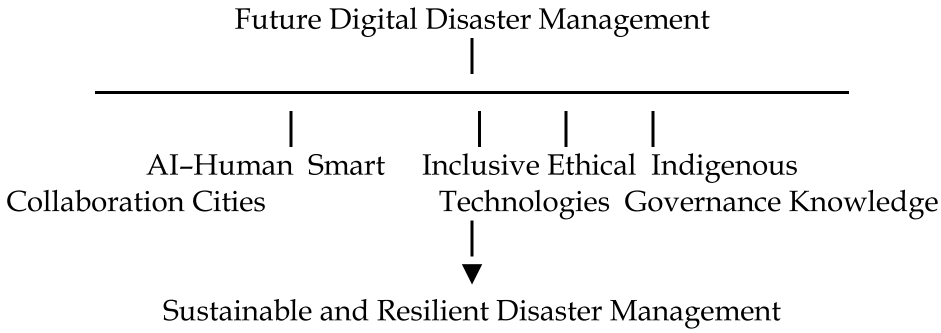

Figure 4. Future Directions in Digital Disaster Management

CONCLUSION

Digital transformation has become a fundamental paradigm shift for disaster management, moving from emergency response to proactive, predictive, and resilience-oriented risk management. The development and integration of AI, IoT, GIS, remote sensing, big data, blockchain, and digital communication technologies have enabled enhanced hazard prediction, monitoring, decision-making, humanitarian coordination, and post-disaster recovery. However, the implementation of these technologies is still hindered by institutional challenges, disjointed governance, cyber security, ethical issues, poor digital infrastructure, and socioeconomic inequalities.

Technological innovation will not ensure disaster resilience, as the review illustrates. Governance frameworks, policies, data governance, community engagement, digital literacy, and a level playing field for technology access all play a role in sustainable digital disaster management. Moreover, the incorporation of indigenous knowledge with the digital systems can ensure the relevance, acceptance, and effectiveness of the DRR strategies, especially in the vulnerable and resource-poor communities.

The Integrated Digital Disaster Resilience Framework, proposed, brings together the roles and functions of technology, governance, and social inclusion to reach the goal of improved disaster prediction, effective emergency response, and sustainable disaster resilience. Interdisciplinary collaboration, ethical AI, inclusive digital innovation, and evidence-based policymaking should thus be key areas of focus for future work to ensure digital transformation positively supports resilient communities and sustainable development in the face of increasingly frequent disasters.

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AUTHOR CONTRIBUTIONS STATEMENT

The author solely conceived, designed, conducted, analysed, interpreted, and wrote the study and approved the final manuscript.

AI USAGE STATEMENT

AI tools were used only for language refinement, while the author verified all content and remains fully responsible for the manuscript.

CONFLICT OF INTEREST

The author declares no financial, professional, or personal conflict of interest related to this study.

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