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Research article

Role of Emerging Technology in Disaster Management in India: An Overview

Manindra Singh Hanspal[1*], Bijayananda Behera[2]

[1] Post Graduate Department of Law, Sambalpur University, Jyoti Vihar, Burla, Sambalpur, Odisha, India, mhanspal21@gmail.com

[2] Lajpat Rai Law College, Constituent College of Sambalpur University, Sambalpur, Odisha, India.

* *Corresponding: mhanspal21@gmail.com*

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Abstract

India's diversified topography and dense population present unique challenges for disaster management. Developing technologies for disaster management plans has the potential to improve reaction times and lessen the adverse effects of natural catastrophes. This paper meticulously examines the role of various technologies, including Artificial Intelligence (AI), Geographic Information Systems (GIS), mobile communication systems and drones, in fortifying disaster management efforts across India. Through a literature review and multiple case studies, including the 2018 Kerala floods, Cyclone Fani in 2019, and the COVID-19 pandemic response, this research demonstrates how AI-driven predictive models enabled early warning and resource optimization, GIS facilities precise hazard mapping and rapid damage assessment, and drones provided critical aerial data in inaccessible areas for relief efforts and rescue operations. This research underscores the potential of technology to enhance recovery operations management, accelerate disaster prediction, and enhance response times. However, we must acknowledge technical constraints, infrastructure shortcomings, and legislative barriers to achieve full-scale application. This article argues that regulatory changes, improved training initiatives, and expanded public-private partnerships are necessary to create more resilient disaster management systems. Subsequent investigations should concentrate on creating flexible and durable technology to tolerate the intricate disaster situations encountered in India. The present study highlights the pivotal function of technology in revolutionizing disaster management methodologies in India, promoting a proactive strategy for incorporating cutting-edge technological solutions.

Keywords

Disaster Management, Geographic Information Systems (GIS), Artificial Intelligence (AI), Technologies, India.

1. Introduction

India's unique geographic and climatic features make it particularly vulnerable to various natural calamities, such as cyclones, floods, earthquakes, and droughts. Recurring natural disasters are a widespread phenomenon in India. The nation's vast coastline, the Himalayan region, and the extensive plains are prone to hydro-meteorological and geological hazards. According to the National Disaster Management Authority (NDMA), almost 40 million hectares are at risk of flooding, and around 59% of India's landmass is susceptible to earthquakes. An essential requirement for efficient disaster management is that 68% of the cultivated land is vulnerable to droughts (Shakeri, 2022). Droughts cause significant loss of life and property and impede socio-economic growth. Over the years, India's approach to disaster management has evolved significantly, transitioning from a reactive to a proactive and policy-driven framework.

India's disaster management paradigm changed due to the 2001 Gujarat Bhuj earthquake and the 2004 Indian Ocean tsunami. Implementation of the Disaster Management Act in 2005 represented a key achievement, creating a legislative structure for a holistic, prevention-mitigation-oriented strategy for disaster management. The Disaster Management Act 2005 establishes a three-tier framework, i.e., the National Disaster Management Authority (NDMA), State Disaster Management Authority (SDMA), and District Disaster Management Authority (DDMA), to coordinate and implement disaster management efforts at various levels. Under this Act, the **National Disaster Management Authority (NDMA)** was instituted as the central agency responsible for overseeing and coordinating disaster management initiatives, ensuring a consistent and cohesive approach across the country. India implemented the National Cyclone Risk Mitigation Project (NCRMP) to strengthen resilience further, targeting cyclone-prone coastal regions. This project, executed in partnership with state governments, aims to reduce the vulnerability of communities through improved early warning systems, disaster response infrastructure, and risk mitigation measures. The **Digital India initiative** has advanced the incorporation of digital and geospatial technologies in disaster management, facilitating real-time data analysis, rapid information dissemination, and improved coordination among agencies. Through Digital India, satellite-based insights from the **Indian Space Research Organisation (ISRO)** enhance disaster predictions and response strategies, further illustrating the government's commitment to a technologically informed disaster management framework. These developments underscore India's dedication to leveraging policy frameworks and technological advancements, laying the groundwork for integrating emerging technologies like Artificial Intelligence, Geographic Information Systems (GIS), and drones into the disaster management ecosystem. Despite these institutional advancements, the scale and frequency of disasters have necessitated incorporating innovative solutions to enhance preparedness, response, and recovery mechanisms. The following schematic representation best illustrates the structure of the Legal-Institutional Framework of the Disaster Management Act (2005) in India.

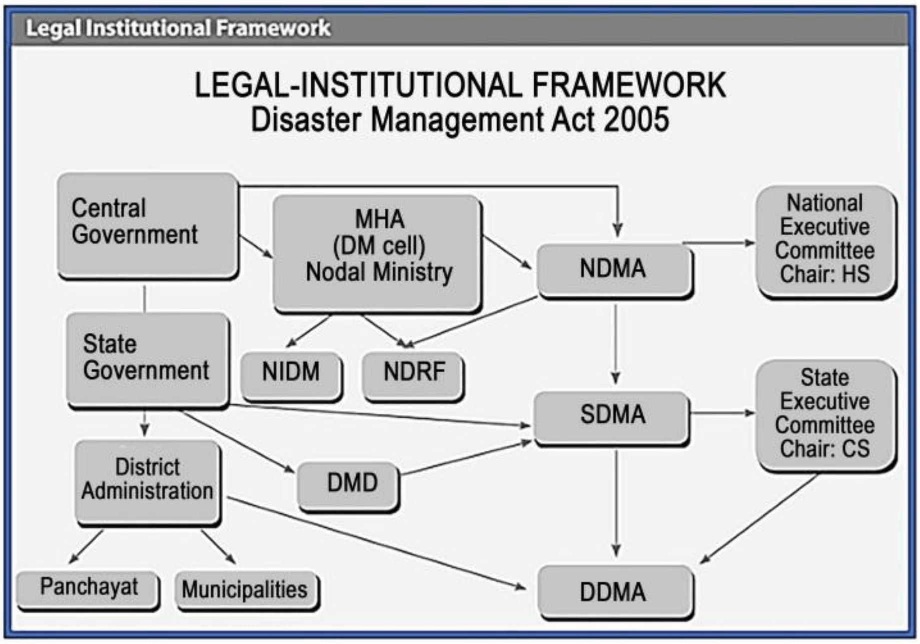

Figure 1. Legal-Institutional Framework of the Disaster Management Act (2005) in India
(Image source: https://compass.rauias.com/disaster-management/act-2005-2nd-arc-recommendations/)

In recent years, the role of emerging technology in disaster management has gained prominence, offering new avenues to tackle the challenges posed by natural and artificial disasters. Technological innovations such as Geographic Information Systems (GIS), Artificial Intelligence (AI), drones and remote sensing are transforming the landscape of disaster management by providing real-time data, enhancing predictive capabilities, and improving coordination among stakeholders. For instance, GIS and remote sensing technologies are instrumental in mapping hazard-prone areas, monitoring environmental changes, and assessing damage post-disaster. These tools enable authorities to prepare more accurate risk assessments and disaster preparedness plans (Tomaszewski, 2020). UAVs (Unmanned aerial vehicles) have emerged as a vital technology for disaster response, capable of conducting aerial surveys in inaccessible areas, delivering essential supplies, and assisting in search and rescue operations. During the 2018 Kerala floods, drones were crucial in locating stranded individuals and assessing the damage (Munawar, 2021). Artificial Intelligence (AI) and machine learning algorithms analyze vast amounts of data to predict disaster events and optimize response strategies. AI-driven models can predict the likelihood of disasters such as floods or cyclones with greater accuracy, thus providing timely warnings and enabling better preparedness (SP, 2024). Moreover, mobile technology and social media platforms have revolutionized communication during disasters, facilitating rapid dissemination of information, crowdsourced data collection, and real-time updates on the evolving situation.

India has been leveraging these emerging technologies to improve its disaster management framework. For example, the Indian Space Research Organisation (ISRO) has been at the forefront of using space-based technology for disaster management. ISRO's satellites provide critical data for early warning systems, disaster impact assessments, and recovery efforts. Integrating satellite data with GIS has enhanced the country's ability to manage disasters more effectively (Stout, 2024). Additionally, the government has initiated various programs to incorporate technology in disaster management. The National Cyclone Risk Mitigation Project (NCRMP) aims to reduce the vulnerability of coastal communities through improved early warning systems and strengthened disaster response infrastructure.

Further, the Digital India initiative seeks to harness digital technologies to enhance disaster resilience by improving information dissemination and coordination among agencies. The increasing adoption of these technologies underscores their potential to mitigate the impacts of disasters and improve resilience. However, to fully realize the benefits of technological interventions in disaster management, we must address challenges like the digital divide, lack of technical expertise, and robust policy frameworks.

2. Literature review

Research conducted worldwide has actively examined emerging technologies in disaster management, demonstrating their potential to boost disaster resilience. Studies have explored various technological interventions, such as Geographic Information Systems (GIS), remote sensing, drones, Artificial Intelligence (AI), and mobile technologies, which have proven effective in different phases of disaster management: preparedness, response, recovery, and mitigation. (Nouali-Taboudjemat, 2009), (Kaur, 2019) emphasizes the potential of information and communication technology (ICT) in enhancing crisis response and decision-making. The integration of Information and Communication Technologies (ICT) is pivotal, enabling a holistic Disaster Risk Management (DRM) framework that supports decision-making during crises (Bania, 2023). Blockchain technology is emerging as a robust solution for secure data transactions, ensuring the protection and anonymity of personal information during disaster scenarios (Hassan, 2019). Artificial Intelligence (AI) and Machine Learning (ML) are extensively applied to manage large datasets, identify critical features, and classify disaster-related data, significantly improving disaster management processes (Linardos, 2022). Geographic Information Systems (GIS) and remote sensing are pivotal in disaster management because they can map hazard-prone areas, monitor environmental changes, and assess damages post-disaster. GIS technology facilitates the visualization and analysis of spatial data, which is crucial for risk assessment and decision-making processes (Goodchild & Glennon, 2010). The utilization of geospatial technologies, including Remote Sensing (RS) and Spatial Data Infrastructure (SDI), has enhanced data acquisition, analysis, and dissemination, facilitating effective disaster management across all phases (Ghosh, 2023). Similarly, remote sensing provides real-time data that enhances situational awareness during disasters, as evidenced by its use in monitoring wildfires, floods, and hurricanes (Joyce et al., 2009). Pre-disaster management leverages IoT, Big Data, and Machine Learning to enhance early warning systems and predictive analytics, helping to mitigate potential damages (Bouzeraa, 2022). Technologies such as robotics, drones, and mobile devices are crucial in all disaster management phases, aiding in prediction, real-time response, and post-disaster analysis (Bhandari, 2022). Mobile crowdsensing (MCS) through smart devices enables the collection of vast amounts of data, crucial for informed decision-making and efficient disaster management (Cicek, 2023). Drones have emerged as valuable tools in disaster response. They can reach inaccessible areas, conduct aerial surveys, and deliver essential supplies. A study highlighted the efficacy of drones in search and rescue operations, particularly in urban environments affected by earthquakes (Adams & Friedland, 2011). Drones equipped with thermal imaging cameras can locate survivors trapped under debris, expediting rescue efforts.

The concept of smart cities incorporates edge computing, IoT, and social media analytics to create emergency-aware systems, enhancing the ability to predict, detect, and manage disasters effectively (Aboualola, 2023). Lastly, aerial and networked technologies, such as drones and satellites, have reoriented disaster management towards a volumetric and planetary approach, impacting power dynamics between authorities and affected populations (Enns, 2022). This comprehensive integration of diverse technologies underscores the global effort to improve disaster management and mitigate the adverse effects of natural and human-induced disasters. Artificial Intelligence (AI) and machine learning have revolutionized predictive analytics in disaster management. AI models can more accurately predict the likelihood and impact of disasters, enabling better preparedness and early warning systems (Varsha, 2024). For instance, AI algorithms analyze vast datasets to forecast floods, cyclones, and landslides, allowing authorities to take pre-emptive measures (Wang & Srinivasan, 2017). Mobile technologies and social media platforms have also transformed disaster communication and information dissemination. Social media platforms like Twitter and Facebook provide real-time updates, crowdsourced information, and coordination among responders and affected communities (Houston et al., 2015). Mobile applications developed for disaster management offer features such as early warning alerts, emergency contact information, and resources for disaster preparedness (Tan, 2017).

The use of technology in disaster management in India has significantly evolved, leveraging advancements in Information and Communication Technologies (ICTs) to enhance the efficiency and effectiveness of disaster response and mitigation efforts. ICTs, including the Internet, Geographical Information Systems (GIS), Remote Sensing, and Satellite-based communication systems, play a crucial role in all stages of disaster management, from pre-disaster prevention and preparedness to post-disaster recovery and reconstruction (Mohan, 2020). Mishra et al. (2024) utilized geospatial tools to assess Cyclone Michaung's impact on Andhra and Tamil Nadu coastal zones, revealing substantial infrastructure, agricultural, and ecological damage. The study underscores the importance of vulnerability mapping for targeted disaster preparedness, though it recommends broader, long-term analyses to capture ongoing effects and socio-economic factors. Early warning systems have proven effective in large-scale evacuations, as evidenced by the successful evacuation of 1.2 million people during Cyclone FANI in Odisha in 2019 (Mohanty, 2022). Remote sensing and geospatial techniques are valuable for tracking and monitoring natural disasters like tropical cyclones, providing essential data for timely evacuations and risk assessments (Sharma, 2021). Social media platforms have emerged as vital tools for real-time information dissemination and public engagement, allowing the general public to report incidents and contribute to disaster monitoring, thereby enhancing the overall disaster management process (Ojha, 2022). Integrating robotics, drone technology, mobile phones, and artificial intelligence plays a crucial role in predicting upcoming disasters, facilitating rapid response efforts, and assessing damage in the aftermath of disasters (Abid, 2021). The Kerala floods of 2018 highlighted the importance of innovative rescue and rehabilitation models, showcasing the critical role of technology in managing large-scale disasters (Linardos, 2022). Despite these advancements, challenges remain, such as the need for more comprehensive and coordinated efforts at the national and state levels to fully harness the potential of these technologies. While India faces significant disaster risks due to its geo-climatic conditions and socio-economic vulnerabilities, the strategic use of technology offers promising solutions to mitigate these risks and enhance disaster resilience.

The Indian Space Research Organisation (ISRO) has leveraged remote sensing for disaster management, providing critical data for early warning systems and damage assessments. Drones have also played a significant role in disaster response in India. In various disasters, drones were deployed for aerial surveys, helping to locate stranded individuals and assess the extent of the damage (Goyal, 2022). The operational efficiency of drones in disaster-hit areas emphasizes their ability to access remote and flooded regions that were otherwise inaccessible (Garg, 2022). Artificial intelligence (AI) is increasingly using in India for predictive disaster analytics. The AI models analyzed historical data, weather patterns, and topographical information to forecast flood-prone zones, thus aiding in disaster preparedness and resource allocation (Abid, 2021). Mobile technology and social media have revolutionized disaster communication in India as well. The Digital India initiative has seen the development of mobile applications that provide early warning alerts and resources for disaster preparedness (Ministry of Electronics and Information Technology, 2021). Social media platforms have been instrumental during disasters, enabling real-time information sharing and coordination among responders and the public. For instance, during the 2015 Chennai floods, social media was extensively used for rescue operations and relief coordination (Joseph, 2018). The existing body of research underscores the significant role of emerging technologies in disaster management globally and highlights their practical application in the Indian context. Integrating GIS, remote sensing, drones, AI, and mobile technologies has enhanced India's disaster preparedness, response, and recovery capabilities. However, challenges such as the digital divide, lack of technical expertise, and the need for robust policy frameworks remain, and stakeholders must address these to realize the full potential of these technologies.

3. Emerging technologies in disaster management

Integrating emerging technologies into disaster management practices offers substantial benefits regarding response time, risk assessment accuracy, and effective resource allocation.

3.1. The Role of Big Data in Disaster Management:

Big data plays an essential role in disaster management by allowing the collection, processing, and analysis of vast and diverse datasets, helping authorities make informed decisions during emergencies. By aggregating data from weather sensors, social media feeds, satellite images, and on-ground reports, big data analytics enables real-time monitoring of evolving disaster conditions, which is crucial for early warnings and rapid response efforts (Yin et al., 2012). For instance, predictive analytics can analyze weather patterns and historical data to forecast potential disasters, allowing communities to prepare in advance and authorities to allocate resources efficiently. A prominent example is the 2015 Chennai floods, where big data was instrumental in timely information dissemination and rescue coordination. Analysis of social media activity, combined with meteorological and geographic data, helped identify severely impacted areas, direct resources effectively, and communicate critical updates to the public (Dharmapuri, 2017). As big data technology advances, it promises to enhance disaster preparedness, response, and resilience by providing actionable insights that reduce risks and save lives.

3.2. Blockchain Technology in Disaster Management:

Blockchain technology is a secure, decentralized platform that enhances transparency and accountability in disaster management. It creates a tamper-proof ledger that records transactions, ensuring all aid distribution activities are traceable and verifiable. It is crucial in disaster scenarios where efficient and fair allocation of resources can save lives (Kshetri, 2017). By preventing tampering, blockchain minimizes fraud, unauthorized fund diversion, and resource misallocation—challenges that often complicate relief efforts. A significant example of blockchain's impact on disaster management is the United Nations World Food Programme's (WFP) use of blockchain to improve food distribution in crisis zones. This initiative streamlined distribution, reducing the risk of fraud and enhancing operational efficiency while ensuring that aid reaches those in need accurately and transparently (Mattila, 2016). As blockchain technology evolves, it promises to further transform disaster relief by instilling trust and efficiency in aid operations, benefiting humanitarian agencies and disaster-prone communities.

3.3. GIS and Remote Sensing in Disaster Management:

Geographic Information Systems (GIS) and remote sensing are fundamental technologies in disaster management, providing detailed spatial and temporal data that aid in every disaster response phase. GIS facilitates the mapping and analysis of high-risk areas, allowing authorities to identify vulnerable zones, plan evacuation routes, and allocate resources efficiently. By overlaying data on topography, population density, and infrastructure, GIS enhances preparedness and risk assessment, making predicting potential disaster impacts easier and optimizing response strategies (Goodchild & Glennon, 2010). On the other hand, remote sensing uses satellite and aerial imagery to monitor disaster events, such as floods, cyclones, and wildfires. This technology captures critical information on environmental changes, the extent of damage, and areas requiring immediate attention. In India, GIS and remote sensing have been crucial in managing major disasters; for instance, they were instrumental in monitoring the impact and planning response efforts during the Kerala floods and Cyclone Fani (Goyal, 2024). Together, these tools allow for a faster, data-driven response, supporting recovery operations by assessing infrastructure damage and prioritizing reconstruction needs, ultimately enhancing resilience in disaster-prone regions.

3.4. The Role of Mobile Technology and Communication in Disaster Management:

Mobile technology is pivotal in disaster management by enabling quick and reliable communication between authorities, responders, and the public. During disasters, mobile networks and applications are instrumental in disseminating critical information, such as early warnings, evacuation instructions, and real-time updates, allowing people to make timely, life-saving decisions (Wang et al., 2020). Mobile devices with location-based services provide emergency managers valuable data on affected populations' whereabouts, helping effectively prioritize and target relief efforts. In India, mobile applications like the 'SACHET App' are designed to enhance disaster preparedness and response. The SACHET App, launched by the National Disaster Management Authority, delivers real-time alerts, safety guidelines, and emergency contact information to users, improving public awareness and readiness during emergencies (SACHET, 2021). Additionally, mobile platforms facilitate two-way communication, enabling affected individuals to report their status or seek assistance, enhancing response teams' situational awareness. These advancements underscore mobile technology's importance in making disaster response more efficient, coordinated, and responsive to the community's needs.

3.5. The Use of Drones and Robotics in Disaster Management:

Drones and robotics play a growing role in disaster management, helping teams conduct search and rescue operations, evaluate damage, and supply remote areas. Drones offer quick surveys of disaster-stricken areas and provide high-resolution images for assessing situations and planning relief efforts (Erdelj et al., 2017). Robotics can assist in hazardous environments, making search and rescue missions safer and more efficient (Murphy, 2014). Drones, or Unmanned Aerial Vehicles (UAVs), operate without an onboard human pilot, typically controlled remotely or autonomously via pre-programmed routes. Equipped with cameras, sensors, and GPS technology, drones can capture high-resolution aerial images, relay real-time data, and access areas that may be dangerous or difficult for human responders. In disaster management, drones play a crucial role by providing rapid aerial assessments of disaster-stricken areas, which is invaluable for identifying damage, locating stranded individuals, and coordinating relief efforts (Papyan et al., 2024). Their ability to reach isolated regions quickly allows authorities to assess the scale of a disaster within hours, enabling faster decision-making and resource allocation. Additionally, robotics—including ground-based robots—are used in search and rescue missions to access hazardous environments, such as collapsed buildings or flooded areas, where human entry may be too risky. These robots can perform tasks like locating survivors and delivering essential supplies, enhancing the safety and efficiency of rescue operations.

3.6. The Role of Artificial Intelligence and Machine Learning in Disaster Management:

Artificial Intelligence (AI) and Machine Learning (ML) enable computers to process large amounts of data, recognize patterns, and autonomously make predictions or informed decisions. In disaster management, AI and ML are essential tools that enhance preparedness, response, and recovery. By analyzing historical and real-time data—such as weather patterns, satellite imagery, and seismic records—AI and ML algorithms can predict disasters like floods, earthquakes, and hurricanes with greater accuracy, allowing authorities to issue timely warnings and organize pre-emptive evacuations (Sun et al., 2022). During a disaster, AI can optimize response efforts by quickly assessing areas in need, prioritizing rescue missions, and managing resources effectively. Additionally, AI-powered chatbots provide real-time information and assistance to affected individuals, reducing pressure on emergency services (Wang et al., 2018). In recovery phases, AI and ML help assess damage, streamline rebuilding, and allocate resources where needed most, ultimately making disaster management more proactive, efficient, and resilient.

3.7. Internet and Social Media in Disaster Management:

The Internet and social media have become essential tools in disaster management, facilitating rapid communication, coordination, and resource mobilization. Platforms like Twitter, Facebook, and Instagram enable authorities and organizations to broadcast emergency alerts instantly, reaching large audiences with critical information on evacuation routes, shelter locations, and safety protocols (Alexander, 2014). Social media also serves as a valuable resource for situational awareness, with affected individuals sharing real-time updates, photos, and videos that help responders assess on-the-ground conditions more accurately (Houston et al., 2015). Additionally, crowdsourcing platforms allow people in disaster zones to report their status, submit damage assessments, and request assistance, enabling emergency management teams to map needs and allocate resources effectively (Gao et al., 2011). This collective information sharing accelerates response times and informs data-driven decisions. Beyond immediate response, social media supports post-disaster recovery by connecting survivors with aid organizations and volunteers, strengthening community resilience and fostering cross-sector collaboration.

Emerging technologies have significantly enhanced disaster management capabilities in India. Big data analytics, blockchain, GIS, mobile technology, drones, AI, and social media provide innovative solutions that improve the effectiveness and efficiency of disaster response. These technologies facilitate rapid decision-making and resource optimization, ultimately saving lives and mitigating the impacts of disasters.

4. Methodology: Criteria for Case Study Selection

This study selected the Kerala floods (2018) and Cyclone Fani (2019) as case studies to represent diverse disaster types and illustrate technology's role in disaster management. Selection criteria included (1) Disaster Type: varied events like floods and cyclones; (2) Severity and Impact: high-impact disasters with significant social, economic, and environmental consequences; and (3) Technology Application: cases where emerging technologies (e.g., GIS, drones, early warning systems) extensively used, highlighting modern trends in disaster response.

5. Case studies

Case Studies in Disaster Management

This section presents a series of case studies showcasing the practical application of emerging technologies in disaster management across India. These cases illustrate how GIS, drones, and mobile applications strengthen response capabilities, enable timely interventions, and significantly reduce the adverse impacts of disasters on affected communities.

5.1. Case Study 1: Kerala Floods (2018)

In 2018, Kerala experienced one of the most devastating floods in its history, affecting millions and causing significant economic losses. Technology was pivotal in managing this disaster. The state government utilized satellite imagery and Geographic Information Systems (GIS) to predict the flood's impact and coordinate rescue operations. Social media platforms served as a vital communication channel, enabling real-time information sharing among authorities and the public. Crowdsourced data from platforms like Twitter and Facebook were analyzed to effectively identify the most affected areas and direct relief efforts (Walia, 2022).

5.2. Case Study 2: Cyclone Fani (2019)

Cyclone Fani, which struck Odisha in May 2019, was a severe tropical cyclone that required extensive disaster management efforts. Early warning systems, powered by satellite technology and meteorological data, allowed for timely evacuations, significantly reducing casualties. The Indian government deployed drones to assess damage and restore connectivity by inspecting damaged infrastructure. Moreover, social media and mobile applications enabled effective communication between authorities and the public, ensuring information about shelters, relief distribution, and safety measures reached the affected populations (Jena, 2021).

5.3. Case Study 3: COVID-19 Pandemic

While not a natural disaster in the traditional sense, the COVID-19 pandemic presented unique challenges, prompting the adoption of emerging technologies in disaster management. India leveraged digital tools and technologies to manage the crisis effectively. The Indian Government created the Aarogya Setu mobile application to track the spread of the virus, provide real-time data on infection rates, and assist in contact tracing efforts (Aarogya Setu App). Telemedicine platforms facilitated remote consultations, reducing the burden on healthcare facilities and enabling continuous care for non-COVID patients (Narayane et al., 2020). Furthermore, drones were utilized for surveillance, disinfection of public areas, and delivery of medical supplies, ensuring minimal human contact. These technological interventions significantly improved the pandemic response, showcasing the critical role of technology in managing public health emergencies.

5.4. Case Study 4: Himachal Flood (2023)

In 2023, Himachal Pradesh faced severe floods, and emerging technologies, particularly drones, played a crucial role in the disaster response. Rescue teams used drones for aerial surveillance to assess the extent of the flood damage, locate stranded individuals, and deliver essential supplies to inaccessible areas. The real-time data collected by drones helped plan and execute rescue operations more effectively. Additionally, drones assisted in infrastructure inspections, ensuring that repair and restoration work could be prioritized and executed promptly (Sharma, 2024).

The case studies of the Kerala floods, Cyclone Fani, and the COVID-19 pandemic, Himachal Flood, 2023, highlight several vital improvements in disaster management due to the deployment of emerging technologies. The Kerala floods in 2018 and Cyclone Fani in 2019 highlight distinct applications of emerging technologies in disaster management across different types of natural disasters, demonstrating how tools like GIS, drones, and early warning systems enhance response capabilities, improve resource allocation, and mitigate disaster impacts effectively. Table 1 compares technology usage in flood and cyclone disaster management in India from a global perspective. It examines specific technologies deployed, their roles in response and recovery, challenges encountered, and lessons learned from each disaster.

Table 1. Comparative Analysis of Technology Usage in Flood and Cyclone Disaster Management in India with Global Perspectives.

Aspect	Kerala Floods	Cyclone Fani (2019)	Global Perspectives
Technology Used	- GIS for flood-prone mapping and real-time monitoring - Satellite imagery from ISRO - Drones for high-resolution images - Social media for crowd-sourced updates	- Early warning systems supported by IMD's satellite and meteorological data - Drones for post-cyclone damage assessment - Mobile applications for information dissemination	- In the US, the Hurricane Katrina response used GIS to map flood-affected areas and satellite imagery to monitor impact[1]. - Japan's Typhoon Hagibis response utilized drones and early warning alerts for assessment[2].
Role of Technology in Response and Recovery	- GIS and satellite imagery enabled real-time mapping, aiding in evacuation and resource allocation - Drones provided high-resolution imagery for identifying stranded individuals - Social media allowed real-time citizen reports to guide response efforts	- Early warning systems enabled timely evacuation of over a million people - Drones assessed infrastructure damage and inspected power lines post-cyclone - Mobile applications helped communicate shelter locations and safety measures	- Haiti Earthquake (2010) relief used drones for rapid assessment, though infrastructure limitations hindered data collection[3]. - Typhoon Hagibis in Japan saw coordinated efforts with drones for targeted post-disaster assessment.

Key Challenges	- Data overload and verification difficulties with unfiltered social media information. - Coordination challenges in filtering reliable data from crowdsourced updates.	- Regulatory restrictions on drone usage in populated areas. - Logistical challenges in managing mass evacuations and restoring communication infrastructure quickly.	- The US response to Hurricane Katrina faced delays due to restricted drone deployment and limited data verification. - Haiti struggled with infrastructure gaps affecting drone and satellite usage[3].
Lessons Learned	- Social media and GIS are valuable in floods for enhancing real-time responsiveness, but data verification is crucial to prevent misinformation. - Drones proved effective for surveying inaccessible flooded areas, suggesting a need for faster regulatory permissions.	- Early warning systems and pre-positioned resources are essential for cyclones, as timely evacuation can significantly reduce casualties. - Mobile applications streamline communication, improving public safety during evacuations.	- Coordinated international efforts and standardized protocols (e.g., Typhoon Haiyan and Typhoon Hagibis) demonstrate that consistent application of technology can enhance disaster response across countries.
Future Implications	- Develop frameworks for social media monitoring to ensure credible information in real time. - Policy reforms to expedite drone deployment in emergency response.	- Strengthen early warning systems and coastal evacuation plans. - Expand mobile technology infrastructure for coordinated disaster communication.	- Global disaster response systems could benefit from enhanced collaboration and standardized technology protocols, as seen in international responses to Typhoon Haiyan and Hurricane Katrina.

The table provides a comparative analysis of technology use in managing the Kerala floods and Cyclone Fani, with insights from global examples. In India, GIS, drones, and social media supported flood response, while early warning systems and mobile apps improved cyclone preparedness. Key challenges included data verification and regulatory restrictions. Lessons highlight the importance of timely evacuation, adaptable technologies, and standardized protocols, as seen in responses like Japan's Typhoon Hagibis with drones and early warnings (Kanbara et al., 2021), Hurricane Katrina's GIS usage (Garg et al., 2022), and Haiti's earthquake response, impacted by infrastructure gaps (Sheller et al., 2013).

6. Challenges and barriers

While emerging technologies offer significant advantages in disaster management, their implementation in India faces numerous challenges and barriers. This section explores these obstacles and suggests possible solutions.

6.1. Technical Challenges

- **Interoperability Challenges:** Integrating data from various platforms is difficult, complicating coordinated disaster response efforts.

- **Environmental Impact on Technology:** Rain, clouds, and strong winds can reduce the accuracy of satellite imagery and drone operations, affecting real-time assessments.
- **Data Quality for AI/ML:** AI models need large, high-quality datasets for accurate predictions, but disaster conditions often result in incomplete or inaccessible data, reducing the model.

6.2. Infrastructure and Training Requirements

- **Lack of Technological Infrastructure:** Many rural and remote areas lack reliable Internet and power supply.
- **Skill Gaps:** Disaster management personnel often lack the technical expertise to use advanced technologies. Continuous training is essential.

6.3. Policy and Regulatory Environment

- **Regulatory Barriers:** Strict regulations on drone usage and data privacy pose challenges in disaster management. India's Drone Rules 2021 limit drone operations, requiring permissions that can delay emergency response. Additionally, pending data protection laws aim to safeguard privacy, highlighting the need for policy updates to enable timely, compliant technology deployment in disaster scenarios.
- **Data Privacy Concerns:** There is a need for robust data governance to protect sensitive information while using AI/ML.
- **Insufficient Funding:** There is a lack of sustained financial support for technological infrastructure and research. Programs like Digital India are steps in the right direction but require more investment.

7. Future directions

Strategic advancements and policy reforms are necessary to further enhance disaster management in India through technology. This section outlines potential future directions that could help overcome existing barriers and leverage technology more effectively.

7.1. Technological Advancements

Continuous innovation will enable faster, more effective disaster response.

- **Enhanced AI Prediction:** Develop advanced AI algorithms with improved accuracy for disaster prediction, tailored explicitly to India's varied climate and geographic conditions. These algorithms can provide more reliable early warnings, optimize resource allocation, and reduce the impact of disasters on vulnerable populations, thereby strengthening India's resilience to natural hazards.
- **Resilient Drones:** Design drones capable of withstanding harsh weather, ensuring reliable data collection and rescue operations during extreme conditions.
- **IoT Integration:** Expand the use of IoT devices to improve real-time monitoring and early warning systems.
- **Mobile Connectivity:** Strengthen mobile network resilience to ensure uninterrupted communication in remote and disaster-prone areas.

7.2. Policy Reforms

Comprehensive policy reforms are crucial for integrating emerging technologies like AI and drones in disaster management. Key recommendations include:

- **Expedited Drone Approvals:** Implement a fast-track clearance process for deploying drones in emergencies.
- **Establishing Guidelines for AI in Emergencies:** Develop preliminary guidelines for AI's ethical and practical use in disaster response, anticipating future formal AI regulations.
- **Humanitarian Exemptions:** Allow specific exemptions for drones and AI systems to operate in restricted areas during disasters to facilitate timely response.
- **Enhanced Data Protection:** Enforce data privacy protocols in line with India's proposed Personal Data Protection Bill, ensuring secure use of sensitive data by AI and drones.
- **Cross-Agency Collaboration:** Strengthen collaboration among regulatory bodies like DGCA (Directorate General of Civil Aviation), NDMA (National Disaster Management Authority), and local authorities to streamline drone and AI technology usage.

These reforms will reduce delays, foster innovation, and uphold privacy standards, supporting effective disaster management.

7.3. Training and Capacity Building

Building human capacity is as crucial as technological innovation in disaster management. Comprehensive training programs and capacity-building initiatives empower disaster management personnel to utilize emerging technologies effectively. Establishing partnerships with academic institutions and international organizations can help develop standardized training modules, ensuring consistent knowledge transfer. These initiatives should focus on practical GIS, AI, drones, and data analytics skills, equipping responders to adapt quickly to dynamic disaster scenarios.

7.4. Public-Private Partnerships

Strengthening collaboration between government bodies, the private sector, and non-governmental organizations is essential for advancing technology integration in disaster management. Public-private partnerships bring diverse expertise, share financial burdens, and enhance resource availability, enabling faster and more cost-effective technology deployment. These partnerships can also facilitate knowledge exchange on best practices, improve data sharing, and drive innovative solutions tailored to local disaster response needs, ultimately building more resilient communities.

7.5. International Collaboration

Given the global nature of technology development, India could benefit from increased international collaboration. Engaging with global tech leaders and international disaster management agencies provides access to cutting-edge technologies and best practices the team can adopt for local needs. By addressing these future directions, India can enhance its disaster management capabilities, making them more efficient, timely, and effective. Integrating advanced technologies with well-designed policies and comprehensive training programs will pave the way for a safer and more resilient society.

8. Conclusion

This paper has examined the crucial impact of emerging technologies on improving disaster management capabilities in India, highlighting the transformative effect of satellite and remote sensing, Geographic Information Systems (GIS), drones, Artificial Intelligence (AI), Machine Learning (ML), and mobile technology. These advancements have improved the timeliness, accuracy, and coordination of disaster management efforts, reducing the impact of natural and artificial disasters. Key results include real-time data provision and imagery for monitoring and assessing disaster impacts, precise mapping and spatial analysis for risk assessment and resource allocation, enhanced accessibility and efficiency in response and recovery operations through drones and robotics, improved predictive analytics for better preparedness via AI and ML, and facilitated real-time information dissemination and community engagement through mobile technology. Despite these promising outcomes, several challenges remain, including technical issues with data interoperability and accuracy, infrastructure and training gaps, regulatory hurdles, and data privacy and security concerns. Addressing these challenges through enhanced data sharing standards, investment in infrastructure and capacity building, updated regulatory frameworks, and exploration of new technologies like blockchain and IoT is crucial. Continued collaboration between government, private sector, and academia will drive innovation and ensure effective implementation, positioning India as a global leader in leveraging technology for disaster management.

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