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Review Article

The role of artificial intelligence in enhancing disaster management: implications for medical and public health preparedness

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ABSTRACT

Natural disasters, including earthquakes, wildfires, floods, and disease outbreaks, have catastrophic consequences for human lives, infrastructure, and economies worldwide. Their increasing frequency and intensity, exacerbated by climate change and urbanization, present significant challenges to disaster management. Traditional approaches often struggle to cope with the scale and complexity of modern disasters. This narrative review examines the potential of artificial intelligence (AI) to transform disaster management, exploring its applications across the disaster cycle. By assessing AI's role in damage assessment, early warning systems, resource allocation, and post-disaster rehabilitation, the review identifies opportunities to enhance disaster response and recovery efforts. Additionally, it addresses challenges related to AI implementation, such as algorithmic bias, data quality, and ethical considerations, to develop equitable and robust AI-driven disaster management strategies. A comprehensive literature review was conducted to identify key research on AI's role in early warning systems, disaster management, damage control, resource allocation, and post-disaster recovery. AI holds significant potential to improve disaster response and recovery. It can enhance early warning systems, optimize resource allocation, and improve damage assessment. Furthermore, AI can support post-disaster repair and rehabilitation efforts. However, challenges such as data quality, ethical concerns, and algorithmic bias must be addressed to ensure the responsible and effective application of AI in disaster management. By harnessing the power of AI, we can build more resilient societies and reduce the impact of future disasters. To fully realize AI's potential, it is essential to integrate it into research, development, and ethical frameworks, ensuring its responsible and efficient implementation.

Keywords: AI, Disaster, Public health, Management

INTRODUCTION

Natural disasters are extreme events typically triggered by sudden climate changes or various environmental conditions.[1] These events, caused by the Earth's natural processes, are large- scale, adverse occurrences that often lead to fatalities, trauma, and widespread destruction of property. They pose significant threats to human life, disrupt social networks and services, cause communal resource losses, and result in identifiable mental and physical health effects among affected populations. Over recent years, the potential of artificial intelligence (AI) has been increasingly explored in managing various operational systems, such as infrastructure, cybersecurity, and manufacturing. AI has also been integrated into environmental health risk management (EHRM), a specialized discipline that focuses on disaster preparedness, response, recovery, and medical care for survivors during and after emergencies. As the field of EHRM evolves, it is incorporating new technologies, including AI, to improve disaster management practices.[2,3]

Advancements in remote disaster technologies have significantly improved in recent years, especially in response to global crises like the COVID-19 pandemic. AI, for example, can enhance flood prediction accuracy and provide early warnings for earthquakes when integrated with global networks. Similarly, AI and machine learning are being used to improve hurricane forecasting. The humanitarian and economic challenges posed by these crises underscore the potential of AI and machine learning to predict and mitigate future disasters. AI can be instrumental in four key areas of disaster management: mitigation, preparedness, response, and recovery.[4]

The frequency, intensity, and geographical scope of natural disasters have escalated, partly due to climate change, population growth, and urbanization, creating global concerns. In the past two decades, the frequency and magnitude of disasters, along with the economic losses they cause, have increased significantly. According to the 2022 Disasters Year in Review (Emergency Event Database, EM-DAT) published by the Center for Research on the Epidemiology of Disasters (CRED), natural hazards like floods, storms, and earthquakes were the major events of 2021. The number of such events in 2021 was 432, far exceeding the average of 357 catastrophic events annually from 2001 to 2020. The increase in catastrophic events in 2021 led to significant economic losses, causing 10,492 deaths, affecting 101.18 million people, and resulting in USD 252.1 billion in monetary losses. The COVID-19 pandemic, which first emerged in December 2019 in Wuhan, China, subsequently spread to over 200 countries and regions, resulting in more than 2 million cases and 120,000 deaths by April 2020. Although most disasters in 2021 were hydrological, geographical events like earthquakes claimed the most lives.[6]

Recent advancements in computational techniques, information and communication technologies (ICTs), AI, and big data hold significant potential for managing the vast amounts of data generated by public health surveillance and real-time epidemic monitoring systems. These technologies can also facilitate instant updates and situation briefings from government bodies, as well as more efficient utilization of human health resources. During the initial response to the COVID-19 outbreak, China employed AI technologies, such as facial recognition cameras to track the movement of infected individuals, robots to deliver food and medicine, and automated systems to disinfect public areas while broadcasting public health messages encouraging people to stay at home.[8]

However, despite significant advancements, a key limitation identified in disaster management is the lack of understanding regarding the convergence of social and behavioral factors. Addressing these gaps is critical to improving disaster management strategies. By integrating behavioral and social sciences with emerging technologies, it is possible to develop comprehensive, equitable, and bias-free disaster management strategies. While AI presents immense potential in this field, challenges such as privacy concerns, ethical dilemmas, and data integration issues hinder its full-scale implementation. Addressing these challenges and investing in infrastructure development, research, and innovation will be crucial in harnessing AI's potential for disaster management.[9]

Despite the considerable progress made in disaster management, the growing frequency and severity of natural disasters—fueled by climate change and rapid urbanization—continue to pose significant challenges to global safety and public health. Traditional disaster management approaches are increasingly overwhelmed by the scale and complexity of these events, highlighting the urgent need for innovative solutions. AI presents a promising avenue to improve disaster preparedness, response, recovery, and integration of medical and public health services. However, the full potential of AI in disaster management remains largely untapped due to challenges like ethical concerns, data limitations, and the need for interoperability with existing systems.

This narrative review seeks to bridge this knowledge gap by comprehensively exploring the opportunities and challenges associated with integrating AI into disaster management systems. By examining AI's role in the medical and public health domains, this review aims to contribute to the development of more effective, resilient, and human-centered disaster management strategies to fully realize AI’s potential in disaster management, collaboration among practitioners, researchers, and policymakers is essential. By investing in research, development, and ethical frameworks, we can build resilient societies and save lives.

AI IMPACT ON NATURAL DISASTER MANAGEMENT

Natural disasters can result in significant financial losses and catastrophic damage. Effective strategies and methods are essential in the critical field of disaster management to address the various challenges posed by such events. This section extensively discusses natural disaster management strategies, techniques, roadblocks, and potential future directions. AI applications, risk mapping, tracking, remote sensing, advances in drone and machine learning technologies, urban planning based on smart cities, hotspot analysis, and environmental impact assessments all play crucial roles in disaster management.[15]

AI breakthroughs have substantially improved our ability to predict and respond to disasters over the past decade. Developments in AI are evident across multiple disaster management phases, including preparedness, crowd-sourced information systems, rescue operations, and humanitarian relief. While robotics and automated systems have existed for some time, recent advancements in sensor technologies and computational capabilities have made them significantly more autonomous and intelligent.[13]

AI's primary goal is to enhance the efficiency of disaster management processes. AI systems, such as sensors and emergency aid platforms, improve data exchange through ontologies, supplying valuable insights for disaster response and supporting real-time decision-making.[13] AI is also adept at analyzing large volumes of social media data, particularly through machine learning (ML) techniques, transforming massive data streams during disasters into coherent and reliable information. Deep learning, one such approach, is renowned for predicting various systems' behaviors, which is critical in emergency management to mitigate disaster threats. Integrating hierarchical time-series models with deep learning algorithms has shown promise in handling forecasting challenges.[13]

The current AI applications in disaster management span the entire disaster cycle: mitigation, preparedness, response, and recovery. Several AI-based decision support tools have been demonstrated across different stages of disaster management.[11] Research typically begins by addressing a range of natural disasters, such as floods, earthquakes, wildfires, and infectious diseases. Model-driven engineering is evaluated for its utility in simulating flood scenarios, which aids in preparedness and response planning. This study specifically examines earlier Google Earth Engine (GEE)-related research and highlights other studies involving GEE.[12]

Remote sensing, an indispensable tool in disaster management, provides geographic data in diverse contexts. Neglecting its reuse can have disastrous consequences. Therefore, creating a flood and disaster support system based on a disaster management metamodel—incorporating various disaster management processes tailored to catastrophic events—is essential.[12]

The metamodel clarifies knowledge domains and supports the operationalization of various disaster management tasks such as risk assessment, preparedness, emergency responses, rescue operations, relief distribution, and reconstruction.[12]

Harnessing AI in flooding management

Flooding is one of the most frequent natural disasters, causing substantial harm to both lives and the environment. Modern flood management systems have leveraged AI to enhance forecasting, risk assessment, and response planning. By analyzing large volumes of historical and real-time data, ML algorithms can predict flood events with greater accuracy, allowing for proactive decision-making.[12]

Geographic information systems (GIS) play a crucial role in flood disaster management by integrating spatial data to create model-driven approaches that streamline decision-making and promote interoperability among stakeholders.[12] Sensor networks and the internet of things (IoT) are instrumental in collecting real-time data, such as rainfall levels, infrastructure status, and flood severity. This real-time monitoring helps predict flood events before they occur and supports decision-making during flood management.[12]

AI's role in flood management also extends to big data analysis and cloud computing, enabling more efficient processing and storage of data. Social media analysis, particularly through the aggregation of posts, images, and comments, has been used to improve flood modeling and risk assessment.

For instance, AI systems have been developed to process photographs shared on social platforms, extracting visual properties and metadata to enhance flood forecasts.[16]

Earthquake management using AI

AI is also revolutionizing earthquake management by providing rapid and precise alerts when an earthquake is imminent. These systems can notify individuals within seconds to minutes before strong tremors, allowing for preparation and reducing casualties.[12] Advances in seismic detectors that use S- and P-waves to detect earthquakes are being integrated with AI technologies to minimize the impact of aftershocks. AI algorithms analyze seismic data, assess risk, and identify vulnerable areas, contributing to more effective early warning systems.[12]

Remote sensing technologies, such as MODIS, ASTER, Landsat, and RADARSAT, provide valuable hazard maps that help in assessing disaster risk.[12] AI systems that utilize convolutional neural networks (CNNs) are proving

effective in detecting seismic activity by analyzing continuous seismic data.

These models use multiple layers of CNNs to extract various levels of abstraction, improving the accuracy of earthquake predictions.[17] Generalized phase detection (GPD) and CNN-based models have demonstrated effectiveness in identifying seismic phases and predicting earthquake magnitudes.[17]

AI-driven approaches in tackling wildfires

Wildfires, often caused by natural events like lightning strikes or human activities such as arson, present significant challenges to disaster management.[12,19] AI has gained popularity in leveraging cutting-edge technologies, including sensor networks and data analytics, to improve wildfire detection and management. These technologies collect high-resolution data that can be used to predict fire behavior and risk, enhancing disaster preparedness.

AI also aids in tsunami prediction by combining data from the Global Navigation Satellite System with AI algorithms. Regression analysis, deep learning, and convolutional neural networks are increasingly used for disaster mapping, damage assessment, and interagency collaboration during emergencies.[13]

AI platforms, such as MOBILIZE, provide real-time intelligence to assist disaster management agencies in assessing risks and exposures. This platform offers a user-friendly interface to upload and examine data on hazards, facilitating collaborative risk management.[13]

Leveraging AI for pandemic management

The COVID-19 pandemic highlighted AI's potential to manage public health crises. AI has been instrumental in diagnosing, tracking, and mitigating the spread of infectious diseases.[21] AI systems can address the complexities of pandemics by analyzing vast amounts of epidemiological data, tracking virus behaviors, and predicting future outbreaks.[22]

AI's role in pandemic management spans diagnosis, treatment, vaccine development, and healthcare optimization. AI-powered mobile apps, knowledge portals, online chatbots, and community query platforms have been developed to facilitate information dissemination and healthcare coordination during the pandemic.[22] The integration of AI with traditional healthcare systems enables faster responses, better resource allocation, and more targeted interventions.

ADVANTAGES

AI plays a crucial role in enhancing disaster management and medical preparedness. Its ability to process vast amounts of data in real-time allows for early detection and prediction of health crises, such as disease outbreaks or environmental hazards.[23,26] This predictive capability helps healthcare providers implement preemptive measures, saving lives and minimizing disaster impact. Furthermore, AI enhances resource allocation by ensuring that medical supplies and resources are directed to areas most in need, based on real-time data analysis. Automated systems, such as chatbots, facilitate the dissemination of timely and accurate information, reducing misinformation during crises.

While AI improves decision-making during disasters by providing valuable insights, it is crucial to maintain human oversight. A balanced approach, where AI complements human expertise, is necessary to mitigate the risks of over-reliance on technology.[30,31]

AI's limitations in understanding complex human behavior during disasters should also be acknowledged, and ethical oversight is essential to ensure responsible deployment. By analyzing population health, resource availability, and disaster impacts, AI can optimize the distribution of critical supplies, such as vaccines and medical equipment, and forecast the spread of infectious diseases.[32,33]

CHALLENGES

Despite its potential, AI in disaster management faces several challenges. The availability of high-quality, real-time data is essential for AI systems, but acquiring such data during disasters can be difficult. Additionally, AI systems rely on robust infrastructure, which may be compromised during emergencies. Privacy and security concerns regarding health data must also be addressed. Another challenge is algorithmic bias, where AI systems may perpetuate existing inequalities. Ensuring that AI systems are developed with fairness, accountability, and transparency is crucial to overcome these challenges.[27,29]

While AI offers significant benefits, it is important to balance AI capabilities with human expertise. Addressing these challenges responsibly will allow AI to enhance disaster management efforts, improving community resilience and reducing disaster impacts.[28,34,35]

LIMITATIONS

This paper highlights the role of AI in disaster management but also acknowledges several limitations. Reliable, real-time data is crucial for AI to function effectively, yet data availability may be limited during disasters. Additionally, AI technologies may not be generalizable to all contexts, particularly those with limited resources or compromised infrastructure.

Ethical issues related to privacy, rights, and algorithmic bias are significant concerns that need further investigation. The over-reliance on AI could undermine critical human decision-making, and the digital divide may hinder the equitable distribution of AI solutions. Finally,

AI's inability to fully understand complex human behavior in disaster scenarios may lead to poor decision-making.[35,36]

IMPLICATIONS FOR MEDICAL AND PUBLIC HEALTH PREPAREDNESS

The integration of AI into medical and public health preparedness promises significant improvements in disaster response. To fully realize these benefits, addressing the challenges of data quality, infrastructure, and ethical concerns is essential. Ensuring a balance between AI and human expertise will be key to maximizing the positive impact of AI in public health and disaster management.[35,37]

AI IN THE FUTURE FOR ENHANCING DISASTER MANAGEMENT

AI's role in disaster management will continue to grow, particularly with the increasing frequency and severity of natural disasters. By analyzing diverse data sources, AI can predict disasters with greater precision and enable early warning systems. AI platforms, such as IBM's Watson and Google's initiatives, are already proving their worth in forecasting floods and earthquakes.[39,40]

Machine learning algorithms, combined with AI and IoT, can improve resource distribution, optimize evacuation routes, and enhance preparedness. The use of AI in conjunction with drones for aerial surveillance and data collection further enhances situational awareness during disasters.[42]

CONCLUSION

The integration of AI into disaster management offers a promising solution in the face of escalating natural disasters. AI enhances disaster response, recovery, and preparedness by improving early warning systems, enabling timely evacuations, and minimizing casualties. With advanced data analytics, AI can predict high-risk areas, optimize resource allocation, and support critical decision-making processes. Furthermore, AI-driven technologies contribute to infrastructure repairs, debris removal, and damage assessment, streamlining the recovery process. However, the successful implementation of AI in disaster management must address ethical concerns, data privacy issues, and potential biases in AI models. Ensuring the responsible design and use of AI is essential to avoid unintended consequences. By combining technological advancements with human creativity, we can develop more resilient societies, mitigate the impact of natural.

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