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The Role of GIS in Disaster Response: Improving Efficiency and Overcoming Challenges

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Abstract: Geographic Information Systems (GIS) have become an essential tool in modern disaster response, offering capabilities that enhance the efficiency and effectiveness of disaster management strategies. This paper explores the role of GIS in disaster response, emphasizing its applications in risk assessment, real-time monitoring, evacuation planning, and post-disaster recovery. The integration of GIS with advanced technologies such as Building Information Modeling (BIM), remote sensing, artificial intelligence (AI), and machine learning has expanded its potential, enabling more accurate predictions, faster decision-making, and optimized resource allocation. Despite its significant contributions, the use of GIS in disaster management faces challenges, including issues related to data quality, system interoperability, and user capabilities. This paper also highlights the importance of integrating GIS with other disaster management systems and the need for more inclusive disaster management solutions that consider vulnerable populations. Future developments, particularly in predictive modeling, real-time data processing, and AI-driven decision support, are poised to further strengthen disaster response efforts. By tackling existing limitations and embracing emerging technologies, GIS will play an increasingly critical role in enhancing disaster resilience and management.

Keywords: Geographic Information Systems (GIS), Disaster Response, Risk Assessment, Real-Time Monitoring, Resource Allocation, Remote Sensing

1. Introduction

Nowadays, technological innovations have played a pivotal role in advancing natural disaster management practices[1,2]. Technologies such as remote sensing and Geographic Information Systems (GIS) have proven invaluable in revealing key information derived from spatial data[3,4,5]. These technologies provide a deep understanding of catastrophic movements, environmental changes[6], urban planning[7], land use[8], socio-economic factors, and emergency relief resources[9]. Effective disaster management strategies are crucial for mitigating loss of life and property[10]. By developing and implementing innovative techniques for damage control, it is possible to reduce casualties, limit economic losses, and enhance disaster preparedness. These techniques include early warning systems[10], efficient evacuation strategies, and resilient infrastructure capable of withstanding the impacts of disasters.

GIS is a powerful technological tool that supports the collection, storage, analysis, and visualization of geospatial data[11,12]. In disaster management, GIS facilitates risk assessment, aids in formulating emergency plans, and informs post-disaster reconstruction[13]. In the domain of disaster prevention and control, remote sensing has become increasingly significant for studying geological disasters[14]. Recent advances in remote sensing sensors have enhanced the collection of high-resolution spatial data, advanced our understanding of Earth's surface and aiding the monitoring and analysis of natural hazards[15,16]. Technologies such as optical and microwave remote sensing are now integral to contemporary geological disaster research[15]. Optical remote sensing provides high spectral and spatial resolution, offering detailed insights into land-use changes[17]. In tandem with microwave sensing, these technologies supply comprehensive datasets that strengthen the monitoring of disasters. Continued advances in remote sensing will be essential for future developments in disaster management research.

Within urban disaster management, the integration of Building Information Modeling (BIM) and GIS has proven to be a particularly effective means of enhancing disaster response and resilience[18]. Despite its potential, adoption has remained limited, largely due to challenges in system interoperability and data integration. By merging BIM and GIS, authorities can access real-time geospatial data that improves decision-making during emergencies[19]. This synergy streamlines data collection, enhances situational awareness, and ultimately supports more efficient disaster response. In global health emergencies like the COVID-19 pandemic, GIS has similarly demonstrated its capacity to bolster disaster preparedness and response[20,21]. By integrating predictive analysis and AI with GIS, public health authorities can improve decision-making, optimize resource distribution, and refine emergency response strategies[22]. GIS-based systems can track disease spread, optimize evacuation routes, and reinforce emergency medical services, thereby strengthening overall disaster response frameworks. Similarly, effective Evacuation Management Systems (EMS) play an essential role in large-scale emergencies such as wildfires[23]. A GIS-based real-time EMS can improve evacuation routes, identify assembly points, and monitor route status in real time. By integrating stochastic models and GIS tools, such systems can streamline decision-making and ensure swift evacuations. This method has been applied in real-world scenarios, including the Gran Canaria wildfire, where it showed measurable improvements in response times and overall disaster management[23].

While the integration of advanced technologies like GIS, remote sensing, and AI has significantly improved disaster response capabilities, there remain several challenges and opportunities that must be explored. The increasing application of GIS in disaster management has not only highlighted its practical benefits but also underscored the importance of continuous advancements in both technology and methodology. As GIS continues to evolve, a deeper understanding of its applications, strengths, and limitations is necessary to guide future research and development. This review seeks to address these aspects by systematically analyzing recent studies on GIS in disaster response. The following sections detail the methodology used to select, evaluate, and synthesize the literature, providing an in-depth look at the current landscape of GIS applications in disaster management.

2. Material and methods

2.1. Literature Search Strategy

The literature search was conducted using the Web of Science Core Collection. The search strategy focused on two primary topics: GIS and disaster response. To ensure a comprehensive search, the Boolean operator AND was used to combine these topics, allowing for the retrieval of articles that were relevant to both GIS and disaster management. The search was restricted to articles published from 2021 onwards (inclusive), ensuring that only the most recent studies were included in the review.

This time frame was selected to capture the latest advancements and trends in the integration of GIS within disaster response, particularly in light of the evolving challenges and technologies post-2020.

2.2. Inclusion and Exclusion Criteria

The initial search yielded 220 articles from the Web of Science Core Collection. After screening for relevance and removing duplicates, 218 articles were retained. Inclusion criteria focused on peer-reviewed journal articles, conference papers, and systematic reviews exploring the application of GIS in disaster response. Only articles published from 2021 onward were considered, ensuring the incorporation of the latest advancements in GIS technology for disaster management. Studies were required to present empirical data, clear methodologies, and practical case studies on the use of GIS in disaster management—covering damage assessment, evacuation planning, and post-disaster recovery. Articles that lacked a clear focus on GIS or disaster response were excluded, as were those that did not undergo peer review. Reviews and meta-analyses without original data, research unrelated to disaster management (e.g., GIS in purely urban planning or environmental studies), and articles in languages other than English were similarly removed. Studies hidden behind paywalls or otherwise inaccessible, such as theses and proprietary reports, were not considered. Following these inclusion and exclusion criteria, the remaining articles were used for data extraction and analysis, forming a comprehensive review of current GIS applications in disaster response.

2.3. Data Extraction and Analysis

For each included study, key information was extracted to form a robust overview of the research landscape. This process began with recording general details—title, authors, publication year, and the journal or conference outlet—and identifying the study's specific focus on GIS-based interventions in disaster management, such as evacuation planning, damage assessment, or risk management. The methodologies of these studies—ranging from case studies and experimental designs to model simulations and system evaluations—were then summarized. The review also examined the integration of GIS with emerging technologies like BIM, remote sensing, machine learning, and AI to understand how these technologies collectively enhance disaster management processes. Key findings were distilled to underscore GIS's role in improving disaster preparedness, response, and recovery. Studies were grouped by methodological similarities, highlighting recurrent themes, challenges, and opportunities. This thematic approach revealed both evolving research trends and new technologies in disaster management. The review also critiqued limitations in various GIS applications, such as data quality, software constraints, and integration hurdles. Lastly, the studies' contributions to future research agendas and technological advances were assessed, providing a roadmap for continued innovation in GIS-based disaster response.

3. Results and Discussion

3.1. Increasing Publications on "GIS in disaster response" and Research Focus

Publications on GIS in disaster response have risen steadily in recent years, underscoring the growing recognition of GIS as an indispensable tool for disaster management. Specifically, the literature expanded from 47 articles in 2021 to 52 in 2022, then to 55 in 2023, and 64 by 2024. This uptick highlights the pivotal role of GIS in improving disaster response capabilities worldwide.

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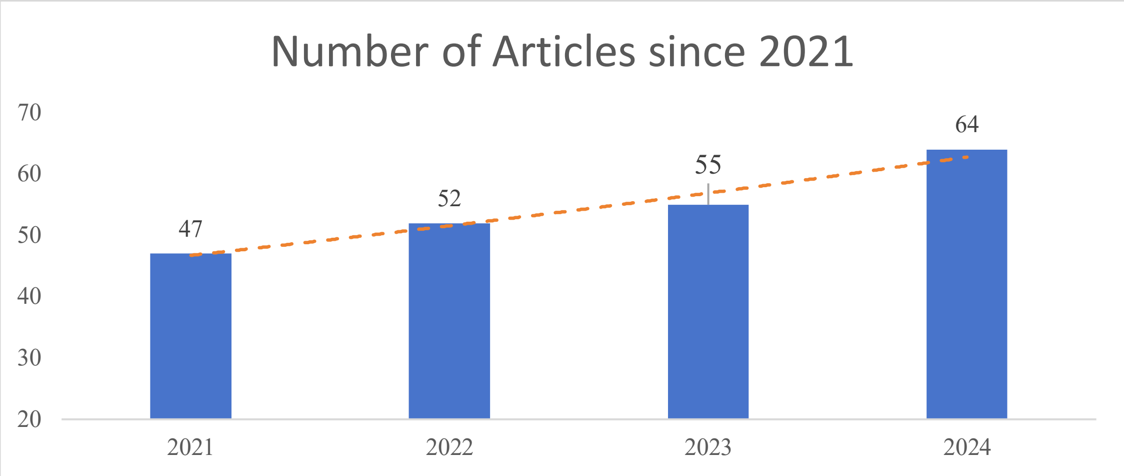

Figure 1: The number of articles on the topic of "GIS in disaster response" published since 2021

Several factors explain the heightened research interest. The frequency and intensity of natural disasters—earthquakes, floods, wildfires, hurricanes—have intensified globally, prompting a pressing need for more efficient, data-driven disaster response frameworks. GIS enables real-time data collection, analysis, and visualization, all of which enhance operational efficiency and decision-making in crisis scenarios. While earlier studies primarily focused on mapping and damage assessment, more recent work has extended into advanced applications, including real-time disaster response, evacuation planning, and post-disaster recovery. A notable trend involves integrating GIS with BIM, remote sensing, and AI to enhance predictive accuracy, optimize evacuation routes, and manage resources effectively. Researchers increasingly recognize GIS not just as a reactive tool for disaster response but also as a core component of proactive risk management strategies—such as modeling hypothetical disaster scenarios, forecasting vulnerability, and shaping early warning systems. Overall, the evolving research indicates a shift toward sophisticated, integrated GIS frameworks that adapt to the growing complexity of modern disaster events.

3.2. Rescue resource allocation and path planning

In disaster response, GIS is indispensable for optimizing resource allocation and path planning through its capabilities in data management, spatial analysis, and decision support[24]. By integrating data on infrastructure, vulnerability, and hazard exposure, GIS identifies areas needing immediate attention, such as hazardous materials storage or fault lines, facilitating effective risk assessments and prioritization of resources[25]. For rescue resource allocation, GIS optimizes the placement of urban emergency shelters by evaluating factors like construction costs, capacity, and accessibility via road networks[26]. This strategic placement ensures that shelters are effectively positioned to serve communities during emergencies. Moreover, GIS models' disaster scenarios to simulate evacuation routes and determine optimal locations for staging rescue teams, enhancing preparedness and response efficiency[27,28]. Path planning is another critical application where GIS maps damaged roads and infrastructure post-disaster, analyzes traffic flow, and identifies alternative routes for rescue operations. Real-time GIS-based traffic simulations enable dynamic path optimization, allowing rescue efforts to adapt as the situation evolves[29]. Integrating GIS with Building Information Modeling (BIM) and remote sensing further improves response efficiency by providing a precise understanding of damage impacts[30]. Advanced integrations, such as GIS with artificial intelligence (AI), drone-based data collection, and machine learning, continue to enhance rescue efforts' precision

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and speed[31]. These technologies facilitate more informed decision-making and better coordination among stakeholders, ultimately saving lives and reducing disaster impacts.

3.3. Location of shelters and emergency services

Determining optimal locations for shelters and emergency services is critical for efficient disaster response, and GIS provides essential support in this area. By merging spatial data with demographic, infrastructural, and environmental information, GIS enables planners to minimize disaster impacts and enhance community resilience[32,33]. GIS-based road network accessibility analysis ensures that shelters and emergency facilities are situated in easily reachable areas, facilitating rapid evacuations. For instance, during the Gran Canaria wildfire, dynamic optimization of shelter locations was achieved by integrating traffic flow data, pedestrian routes, and road condition assessments[23]. Additionally, GIS analyzes population density and distribution to ensure equitable access to shelters[34]. The response to Turkey's 2023 earthquake exemplifies how integrating centralized and decentralized GIS approaches can identify underserved areas and proactively address gaps in emergency coverage[35]. Furthermore, GIS evaluates existing shelters' capacities against projected demands by combining shelter data with real-time population movement and demographic information[36]. Advanced GIS models, such as the minimal facility point model, facilitate the determination of cost-effective shelter network layouts while meeting refuge requirements[37]. Multi-criteria decision-making models within GIS optimize site selection by balancing safety, accessibility, and cost-effectiveness, as demonstrated in urban flood and tsunami evacuation planning[38]. Additionally, GIS enhances network analysis and buffer zone methods to assess the maximum service area of emergency shelters within specific time frames, ensuring that shelters are both accessible and capable of providing timely refuge[39]. In tsunami-prone regions, buffer analysis effectively maps safe zones and evacuation routes, thereby minimizing casualties[40]. By leveraging these GIS applications, emergency planners can design shelter systems that ensure equitable access, maximize resource efficiency, and minimize disaster impacts. The integration of advanced technologies such as remote sensing, machine learning, and real-time monitoring further augments GIS's effectiveness in shelter and emergency service planning, thereby strengthening community resilience against future disasters[41].

3.4. Advanced Technological Integration for Enhanced Decision Support

By combining GIS with artificial intelligence (AI), machine learning, cloud computing, and the Internet of Things (IoT), disaster response systems have become more robust and efficient[42,43]. AI and machine learning algorithms within GIS platforms enable the analysis of large datasets to identify patterns and predict disaster events with greater accuracy[44]. For example, these technologies can forecast the likelihood and impact of earthquakes, floods, and wildfires, facilitating proactive measures such as optimizing evacuation routes and protecting critical infrastructure[45,46]. Cloud computing provides scalable storage and processing power, allowing GIS to handle vast amounts of data generated during disasters[24]. Cloud-based GIS solutions support seamless collaboration among emergency responders, government agencies, and humanitarian organizations by enabling real-time data sharing and updates. This enhances coordination and improves the efficiency of disaster response efforts, especially during large-scale events. These tools create interactive maps that display real-time data overlays, predictive models, and simulation results, aiding in understanding disaster progression and planning effective response strategies. In summary, the integration of GIS with AI, machine learning, cloud computing, and IoT technologies significantly enhances real-time decision support in disaster management. These advanced technological integrations empower GIS to provide comprehensive predictive analytics, facilitate seamless collaboration, and deliver real-time insights, thereby improving preparedness, response, and recovery efforts[47]. As these technologies continue to evolve, their synergistic application with GIS is expected to play an increasingly critical role in building resilient and adaptive communities capable of effectively mitigating the impacts of future disasters.

3.5. Challenges of GIS

Despite these innovations, GIS-based disaster management encounters notable hurdles. Data quality, system interoperability, and limited user training persist as key roadblocks. For example, inconsistent data formats and the lack of standardization across regions complicate the merging of GIS with other disaster-management platforms[48]. Addressing these issues will require internationally recognized data standards and stronger collaborative efforts among stakeholders. Data security and privacy also pose concerns, especially in cross-border disaster responses[44]. Blockchain technology offers a promising avenue for secure, transparent data sharing. By creating an immutable record of data transactions, blockchain could bolster GIS's reliability in scenarios demanding rapid, large-scale coordination.

4. Conclusion

Geographic Information Systems (GIS) play a vital role in disaster response, contributing significantly to risk assessment, real-time monitoring, resource management, and post-disaster recovery. Recent research affirms GIS's expanding influence, particularly when integrated with BIM, remote sensing, AI, and machine learning—combinations that substantially enhance both accuracy and speed in disaster response. Despite these gains, challenges related to data quality, interoperability, and user capabilities persist. Greater standardization and improved data-sharing protocols are needed to ensure a seamless integration of GIS with other disaster management platforms. Additionally, more work is required to make GIS-based solutions inclusive for vulnerable populations, especially in developing regions. Looking ahead, GIS is poised to evolve further through improved predictive modeling and proactive disaster mitigation. The real-time integration of cloud-based systems and AI-enhanced decision support holds great promise for refining both short-term and long-term disaster management strategies. As climate change and urbanization intensify global disaster risks, GIS will become increasingly central to building resilience and saving lives. By confronting current limitations and leveraging emerging technologies, GIS will remain at the forefront of a more effective, equitable, and timely global disaster management framework.

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