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GIS Applications in Disaster Risk Management

Dr. Geeta Rawat
Department of Social Sciences
Shri Guru Ram Rai University, Dehradun, Uttarakhand
ORCID id - https://orcid.org/0009-0007-7163-9847

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Abstract— Geographic Information Systems have become one of the most important technological tools available to disaster managers, planners, and policymakers seeking to reduce the human and economic toll of natural and human induced hazards. This paper examines the role of GIS across the full disaster risk management cycle, encompassing hazard identification, vulnerability and risk assessment, early warning, emergency response, and post disaster recovery. Drawing on published research spanning flood, earthquake, landslide, and multi-hazard contexts, the paper synthesizes evidence on how spatial data integration, remote sensing, and geospatial modeling have improved the accuracy and timeliness of disaster related decision making. The paper also examines the growing role of volunteered geographic information and crowdsourced mapping in rapid post disaster response, most notably demonstrated during the 2010 Haiti earthquake. While GIS applications have substantially strengthened disaster risk management capacity worldwide, the paper identifies persistent challenges related to data availability, technical capacity, interoperability, and the institutional integration of geospatial tools into governmental disaster management structures. The paper concludes by outlining priorities for strengthening GIS based disaster risk management, particularly in resource constrained regions that remain disproportionately exposed to natural hazards.

Keywords— geographic information systems, disaster risk management, remote sensing, hazard mapping, vulnerability assessment, early warning systems

Introduction

Natural disasters, including floods, earthquakes, landslides, cyclones, and droughts, continue to impose severe human, economic, and environmental costs across the world, with the frequency and intensity of many hydrometeorological hazards increasing in association with climate change and expanding human settlement in hazard prone areas. Effective disaster risk management requires the ability to understand where hazards are likely to occur, who and what is exposed to them, how vulnerable different populations and assets are, and how resources can be most efficiently deployed before, during, and after a disaster event. Because nearly all of these questions have an inherently spatial dimension, Geographic Information Systems have emerged as a foundational technology for modern disaster risk management.

A Geographic Information System is a computer based tool that allows users to capture, store, manipulate, analyze, and visualize spatially referenced data. When combined with satellite and aerial remote sensing, digital elevation models, and increasingly with real time sensor networks and crowdsourced data, GIS enables disaster managers to move beyond static paper maps toward dynamic, continuously updated spatial decision support systems. As Goodchild (2006) observed in an early and influential discussion of the subject, GIS offers a unique capacity to integrate diverse datasets, from population distribution to infrastructure location to hazard exposure, into a single analytical framework that can inform planning for catastrophe before it occurs and support coordinated response once it does.

The application of GIS in disaster risk management spans the entire disaster management cycle. In the pre-disaster phase, GIS supports hazard mapping, vulnerability assessment, and the identification of high risk zones that should be prioritized for mitigation investment or land use restriction. During the response phase, GIS enables real time tracking of hazard progression, such as flood extent or wildfire spread, and supports the coordination of emergency resources, evacuation routing, and damage assessment. In the recovery phase, GIS supports the monitoring of reconstruction progress and the identification of communities that continue to require assistance long after a disaster has receded from public attention.

This paper reviews the existing literature on GIS applications in disaster risk management, with particular attention to empirical studies on flood, earthquake, and landslide hazards, as well as the emerging role of volunteered and crowdsourced geographic information in disaster response. It then discusses the objectives and methodology of the study, before examining the specific applications of GIS across different phases of the disaster management cycle. The paper subsequently considers the principal challenges limiting the effectiveness of GIS based disaster risk management, before concluding with recommendations for strengthening geospatial capacity within disaster management institutions.

Literature Review

The academic literature on GIS applications in disaster risk management is extensive and spans several decades of methodological development. Goodchild (2006) provided one of the foundational conceptual contributions to this field, arguing that GIS is uniquely suited to disaster planning because catastrophic events are fundamentally spatial phenomena whose impacts depend on the geographic distribution of hazard, exposure, and vulnerability. This early work helped establish the conceptual vocabulary, including the now widely used framework of hazard, exposure, and vulnerability, that continues to underpin much of the subsequent empirical literature on GIS and disaster risk.

Building on this conceptual foundation, Tralli, Blom, Zlotnicki, Donnellan, and Evans (2005) examined the specific contribution of satellite remote sensing to hazard monitoring across multiple disaster types, including earthquakes, volcanic eruptions, floods, landslides, and coastal inundation. Their review demonstrated that satellite based sensors, when integrated with GIS platforms, provide a synoptic and systematic framework for observing hazard processes over large areas and extended time periods, generating geospatial information products that increasingly inform the operational requirements of emergency managers and policymakers at multiple levels of government. This work remains an important reference point for understanding how remote sensing data streams are transformed into actionable disaster risk information within a GIS environment.

A comprehensive treatment of the role of GIS across the full disaster risk management cycle is offered by Van Westen (2013), who examined how geographers and geomorphologists contribute to hazard assessment, elements at risk mapping, and vulnerability and risk assessment. The study emphasizes that multi-hazard risk assessment is a complex, data intensive, and inherently multidisciplinary undertaking, and that GIS provides the essential spatial framework within which data from hydrology, geology, engineering, and social science can be integrated into a coherent risk assessment. Van Westen's work is particularly notable for highlighting the growing role of mobile GIS technologies in supporting field based data collection during both hazard assessment and post disaster damage assessment activities.

Complementing this conceptual and methodological literature, Joyce, Belliss, Samsonov, McNeill, and Glassey (2009) conducted a systematic review of satellite remote sensing and image processing techniques used for mapping natural hazards and disasters. Their review catalogued the strengths and limitations of different sensor types and processing techniques across a range of hazard categories, concluding that while remote sensing offers considerable value as a source of spatial information during disasters, the diversity of hazard types and data requirements means that no single sensor or processing technique is universally applicable, requiring disaster managers to select and combine data sources according to the specific hazard and operational context.

Within the specific domain of landslide hazard assessment, Pradhan and Lee (2010) demonstrated the application of GIS integrated machine learning techniques, using a back-propagation neural network model to generate regional landslide susceptibility maps for the Cameron Highlands in Malaysia. Their study illustrated how GIS can serve as a platform not only for data visualization but also for sophisticated predictive modeling, combining terrain, geological, and land cover variables to identify areas at elevated risk of future landslide occurrence. This line of research has since been extended and replicated across numerous other landslide prone regions, establishing GIS integrated statistical and machine learning approaches as a standard methodology in landslide susceptibility mapping.

More recent scholarship has continued to expand the scope of GIS and remote sensing applications across additional hazard types. Kumari, Agarwal, Agrawal, Agarwal, and Garg (2025) provided a comprehensive review of remote sensing technologies applied to geological disaster management, covering droughts, earthquakes, tsunamis, landslides, and cyclones. Their review highlighted both the substantial progress made in sensor and satellite technology and the persistent challenges associated with disaster monitoring during the acute emergency phase, particularly when communication networks are disrupted, underscoring the continued importance of alternative and resilient data transmission networks for maintaining situational awareness during active disaster events.

Focusing specifically on flooding, one of the most frequently studied hazard types in the GIS and remote sensing literature, Amatebelle, Owolabi, Ogundeji, and Okolie (2025) conducted a systematic review of 274 peer-reviewed articles examining remote sensing and GIS applications in flood disaster risk management over the preceding two decades. Their analysis found substantial growth in research output in this area, driven by the capacity of remote sensing and GIS to monitor flood prone areas and to support flood hazard prediction, hazard mapping, and impact assessment. The review also identified regional disparities in research output, noting comparatively limited representation of certain regions, including parts of Africa, despite their significant exposure to flood risk, a finding with direct implications for how research investment and capacity building efforts might be more equitably targeted in the future.

Beyond hazard assessment and monitoring, the literature has also examined the role of GIS in supporting emergency response and community engagement following a disaster event. Zook, Graham, Shelton, and Gorman (2010) documented the extensive use of volunteered geographic information and crowdsourced mapping platforms, including OpenStreetMap and Ushahidi, in the aftermath of the 2010 Haiti earthquake. Their case study demonstrated that geographically dispersed volunteers were able to rapidly generate detailed spatial datasets covering roads, medical facilities, and other critical infrastructure in a context where authoritative geographic data had previously been sparse, providing humanitarian responders with usable maps within days of the disaster. This study is widely regarded as a landmark demonstration of how participatory and crowdsourced approaches to geographic data collection can complement traditional institutional GIS capacity, particularly in data poor environments.

Taken together, the literature reviewed here demonstrates a clear trajectory in the field, moving from early conceptual arguments for the relevance of GIS to disaster planning, through the development of increasingly sophisticated remote sensing and predictive modeling techniques for specific hazard types, toward more recent recognition of the value of participatory and crowdsourced geographic information in supporting rapid response. Across this body of work, a consistent theme emerges: GIS functions most effectively as an integrating platform that brings together diverse data sources, analytical techniques, and stakeholder contributions into a coherent spatial framework for understanding and managing disaster risk.

Objectives of the Study

This study pursues three central objectives. First, it aims to synthesize existing research on the application of GIS across the different phases of the disaster risk management cycle, including hazard assessment, vulnerability and risk analysis, emergency response, and post disaster recovery. Second, it seeks to examine how remote sensing, predictive modeling, and volunteered geographic information have each contributed distinct capabilities to disaster risk management practice. Third, it aims to identify the principal challenges that continue to limit the effective institutional adoption of GIS in disaster risk management, particularly in resource constrained settings, and to propose directions for strengthening geospatial capacity in this field.

Research Methodology

This study employs a descriptive and analytical research design based on secondary sources. Evidence was drawn from peer reviewed journal articles, systematic reviews, and edited academic volumes addressing the application of GIS and remote sensing technologies to disaster risk management across multiple hazard types, including floods, earthquakes, landslides, and geological hazards more broadly. The literature was selected to represent both foundational conceptual contributions to the field and more recent empirical and systematic review studies, allowing the analysis to capture both the historical development of GIS based disaster risk management and its current state of practice. The analytical approach is qualitative and interpretive, synthesizing findings across studies to identify recurring themes, methodological approaches, and unresolved challenges, rather than testing a specific quantitative hypothesis. This method is well suited to the objective of the paper, which is to provide an integrative

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overview of a technologically and methodologically diverse field rather than to generate new primary empirical findings.

GIS Applications Across the Disaster Risk Management Cycle

The application of GIS in disaster risk management can be organized around the conventional disaster management cycle, comprising mitigation and preparedness, response, and recovery, each of which draws on distinct but interconnected geospatial capabilities.

In the mitigation and preparedness phase, GIS is used extensively for hazard mapping and vulnerability assessment. Hazard maps, which delineate areas exposed to specific risks such as flooding, landslides, or seismic activity, are typically constructed by combining historical hazard occurrence data with physical variables such as elevation, slope, soil type, land cover, and proximity to hazard sources. As demonstrated by Pradhan and Lee (2010) in the context of landslide susceptibility mapping, GIS platforms increasingly incorporate statistical and machine learning models that improve the predictive accuracy of these hazard maps beyond what purely qualitative or expert judgment based approaches can achieve. Vulnerability mapping complements hazard mapping by identifying the population groups, infrastructure, and economic assets most likely to be adversely affected should a hazard event occur, often incorporating socioeconomic indicators such as poverty, housing quality, and access to health services alongside physical exposure data.

In the early warning and monitoring domain, GIS is integrated with real time and near real time remote sensing data to track the development and progression of hazard events. Radar and optical satellite sensors are used to monitor rainfall, river discharge, and soil saturation in flood prone areas, while seismic networks and interferometric radar techniques support the monitoring of ground deformation associated with earthquake and volcanic activity. Tralli et al. (2005) emphasized that the integration of these diverse remote sensing data streams within a common GIS framework allows for the generation of consolidated hazard status products that can directly inform the decisions of emergency managers regarding evacuation and resource pre-positioning.

During the emergency response phase, GIS supports real time situational awareness, resource coordination, and damage assessment. Pre- and post-event satellite imagery can be compared within a GIS environment to rapidly identify damaged infrastructure and affected populations, informing the prioritization of search and rescue and relief efforts. The Haiti earthquake response documented by Zook et al. (2010) illustrates how, in addition to institutional remote sensing and GIS capacity, crowdsourced and volunteered geographic information can substantially augment official response efforts, particularly in contexts where pre-existing authoritative spatial data is limited. Mobile GIS applications further allow field teams to collect georeferenced data on damage and needs in real time, feeding directly into centralized coordination platforms used by government agencies and humanitarian organizations.

In the recovery phase, GIS supports the monitoring of reconstruction progress, the tracking of population displacement and return, and the identification of communities that continue to require assistance after the acute emergency phase has ended. Longitudinal comparison of satellite imagery over months or years following a disaster allows researchers and agencies to assess the pace and equity of recovery across different geographic areas, informing the allocation of continued recovery resources toward communities that are lagging behind in rebuilding efforts.

Challenges and Barriers

Despite the substantial contributions of GIS to disaster risk management, several challenges continue to limit its full effectiveness. The first challenge concerns data availability and quality. Accurate hazard and vulnerability mapping depends on the availability of high resolution elevation data, historical hazard records, and up to date land use and infrastructure information, all of which remain incomplete or outdated in many low and middle income countries. As Amatebelle et al. (2025) note in the context of flood risk research, significant regional disparities in research output and data availability persist, with certain highly exposed regions remaining comparatively understudied and underserved by comprehensive geospatial datasets.

A second challenge relates to technical capacity and institutional integration. Effective use of GIS in disaster risk management requires trained personnel capable of managing spatial databases, applying appropriate analytical models, and interpreting results in ways that are useful for non-technical decision makers. Many disaster management agencies, particularly at the subnational level in developing countries, lack the technical staff, software licenses, and hardware infrastructure necessary to build and maintain robust GIS capacity, resulting in a persistent gap between the sophistication of academic GIS research and the operational reality of many disaster management institutions.

A third challenge concerns interoperability and data sharing across agencies and organizations. Disaster risk management typically involves multiple government departments, humanitarian organizations, and research institutions, each of which may use different data formats, coordinate systems, and software platforms. Without agreed standards and institutional arrangements for data sharing, valuable geospatial information generated by one agency or organization may remain inaccessible to others, reducing the overall effectiveness of the collective disaster response effort.

A fourth challenge relates to the timeliness and reliability of real time data during active disaster events. As Kumari et al. (2025) observe, communication networks are often partially or fully disrupted during major disasters, complicating the transmission of both remote sensing data and field collected information to central coordination platforms. This underscores the importance of resilient and redundant communication infrastructure, as well as offline capable mobile GIS tools that can continue to function and later synchronize data once connectivity is restored.

A fifth challenge concerns the integration of crowdsourced and volunteered geographic information with authoritative institutional data. While Zook et al. (2010) demonstrated the considerable value of crowdsourced mapping during the Haiti earthquake response, questions of data quality, verification, and long term sustainability continue to complicate the routine institutional adoption of volunteered geographic information within formal disaster management structures.

Policy Implications and the Way Forward

Addressing these challenges requires sustained investment and coordinated action across several dimensions. Governments and international development partners should prioritize investment in the collection and regular updating of foundational geospatial datasets, including high resolution elevation models, land use maps, and infrastructure inventories, particularly in regions that remain underserved relative to their level of hazard exposure. Freely available satellite data platforms and open geospatial data initiatives can play an important role in narrowing this data gap for resource constrained agencies.

Capacity building programs should be designed to build sustained technical expertise within disaster management agencies rather than relying solely on external consultants or short term project based support. Training programs that combine GIS and remote sensing skills with an understanding of local hazard contexts and institutional decision making processes are likely to yield more durable improvements in disaster risk management capacity than technology transfer efforts focused narrowly on software provision.

Interoperability should be strengthened through the adoption of common data standards and the establishment of formal data sharing agreements among government agencies, research institutions, and humanitarian organizations involved in disaster risk management. National spatial data infrastructure initiatives can provide an institutional framework for coordinating these efforts and ensuring that geospatial data generated for one purpose can be readily reused for disaster risk management applications.

Finally, disaster management institutions should develop clear protocols for integrating volunteered and crowdsourced geographic information into official response workflows, including mechanisms for data verification and quality control, so that the demonstrated value of participatory mapping efforts such as those documented following the Haiti earthquake can be more systematically and reliably harnessed in future disaster events.

Conclusion

Geographic Information Systems have become an indispensable component of modern disaster risk management, providing the spatial analytical framework needed to integrate hazard, exposure, and vulnerability information across the full disaster management cycle. The literature reviewed in this paper demonstrates that GIS applications, ranging from satellite based hazard monitoring and machine learning enhanced susceptibility mapping to crowdsourced disaster response mapping, have made substantial contributions to reducing disaster risk and improving the effectiveness of emergency response and recovery efforts. At the same time, this paper has shown that the full potential of GIS in disaster risk management remains constrained by persistent gaps in data availability, technical capacity, interoperability, and the institutional integration of geospatial tools, particularly in the resource constrained and disaster prone regions that stand to benefit most from these technologies. Closing these gaps will require sustained investment in geospatial data infrastructure, technical capacity building, and institutional coordination mechanisms that allow the full range of GIS based tools, from institutional remote sensing to volunteered geographic information, to be brought to bear more systematically and equitably in the ongoing effort to reduce disaster risk worldwide.

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