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The Role of Geographic Information Systems (GIS) in Disaster Management in India

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Abstract

Geographic Information Systems (GIS) have an important role in upgrading disaster management strategies, especially in disaster prone countries such as India. This research discusses the applications of GIS in disaster management in India concentrating on contributions that GIS can provide at the disaster preparedness, response, recovery and mitigation level. GIS takes advantage of spatial data to reflect the dynamic and uncertain characteristics of the hazard so as to make accurate hazard mapping, real time monitoring and reasonable resource allocation possible, and efficiently reducing the impacts of disasters. Although, a potential, its adoption faces several problems in India, including poor infrastructure, shortage of trained personnel, lack of sharing of data on uniform patterns, and low public awareness. These challenges are discussed in this study and recommendations formulated to promote efficient integration of GIS in disaster management in India. Strengthening our infrastructure; improving capacity building, agency collaboration; leveraging technology such as artificial intelligence (AI) and drones. This research highlights the necessity of policy reforms and institutional support, necessary to achieve maximum effectiveness of GIS in disaster management, and in turn may help in building a more resilient and disaster prepared India.

Keywords

GIS, disaster management, India, disaster preparedness, hazard mapping

Introduction

As India is rich in geographical diversity, population density and socio economic vulnerability, it is one of most disaster prone countries in the world, with large number of natural and man made disasters. The country is prone to recurring threats to human lives, livelihoods and infrastructure ranging, as it does, from the devastating floods of the northern plains to the cyclones of the eastern and western coasts, earthquakes of the Himalayan belt to droughts of central and southern regions. As a consequence of climate change, urbanisation, and environmental degradation, the frequency, and in particular, the intensity of disasters, have been ever on the rise, necessitating efficient Disaster Management Systems. Disaster management in India is a multi layered process starting from risk assessment, preparedness, response and recovery which takes place through a landscape of technology with the notion of minimising the impact of disaster. In view of this, Geographic Information Systems (GIS), a transformative tool, has come up and is giving spatial insights as well as actionable intelligence which facilitates effective decisions during different phases of disaster management.

Systems used to capture, store, analyse and then visualise spatial and geographic data are known as Geographic Information Systems or GIS. While GIS fuses satellite imagery,

geospatial data sets and real time data streams; it equips disaster management authorities with the capability to pinpoint danger zones, chart areas at risk and construct early warning systems. GIS has potential in disaster management not only in the collection of data, but also in coordination among stakeholders, effective allocation of resource and real time monitoring of disaster event. The integration of GIS elements in disaster management frameworks has been a slow process in India, having been pioneered by organisations including the Indian Space Research Organisation (ISRO) and the National Disaster Management Authority (NDMA). GIS has huge promise but its uptake has been disparate around regions owing to various challenges such as poor infrastructure, shortage of trained personnel and insufficient public consciousness to its potential.

The purpose of this research paper is to analyse the role of GIS in disaster management in India to identify these applications in disaster preparedness, response, and post-disaster recovery. The study further aims to find out the challenges and opportunities for GIS implementation, in the Indian context. The paper reviews best practises and lessons learned by analysing case studies of recent disasters where GIS was used effectively as part of the recovery management plan for recent disasters, such as the Kerala floods of 2018 and Cyclone Fani of 2019. Additionally, this research aims at proposing actionable recommendations for strengthening GIS integration in India's disaster management policies and practises. It is our hope within this study to better understand how technology, as exemplified by GIS, can further strengthen disaster resilience and reduce the effects of disasters on vulnerable communities.

Literature Review

Geographic Information Systems (GIS) integration in dispensing management has received a lot of interest globally with many studies articulating the likelihood to aid in dispensing preparedness, response and recovery. In this section, we review existing literature on GIS technology and its global applications as well as Indian context. It also reviews the GIS framework of disaster management in India as it relates to the intersection of GIS with disaster mitigation.

Geographic Information Systems (GIS) have come to be recognised as a key tool in disaster management, providing spatial data analysis to tackle the complex issues occurring during disasters. Goodchild (2006) argued that GIS can map and visualise hazard prone areas, which allows decision makers to develop targeted DRR strategies specific to areas at risk. In disaster scenario, GIS has been extensively used in worldwide including use in 2004 Indian Ocean tsunami, Hurricane Katrina in the US and Fukushima nuclear disaster in Japan cases. According to Cutter et al. (2003), not only do GIS offer the tools for risk assessment; they also provide the means for damage assessment and reconstruction planning in post-disaster recovery. A further utility of GIS as applied to disaster management is illustrated by the integration of novel techniques such as remote sensing and artificial intelligence example by Matsuoka and Yamazaki (2004) currently used in post earthquake damage assessment using satellite imagery.

National initiatives and increasing frequency of disaster have driven the adoption of GIS in India. Geospatial technology has advanced significantly thanks to the work of Indian Space Research Organisation (ISRO) through National Remote Sensing Centre (NRSC). Chennai

(IANS): Initiatives of the Indian Space Research Organisation (ISRO) like Bhuvan (the geospatial data service platform) are providing vital geographical data to help manage the disaster. Flood risk mapping using GIS has been applied by Srivastava et al. (2014) with the Brahmaputra basin as a case study identifying high risk areas through geospatial analysis. Likewise, the Ministry of Earth Sciences and IMD used GIS for cyclone tracking and early warning mechanism, getting rid of many casualties in recent years. Jha et al. (2020) conducted research on use of GIS in urban flood management and focuses on how cities such as Mumbai and Chennai (where unplanned urbanisation has increased the risk of flooding).

The Disaster Management Act of 2005 frames India's disaster management framework, which includes setting up of National Disaster Management Authority (NDMA) and State Disaster Management Authorities (SDMAs). The Act also emphasises the technology use, including GIS, during disaster preparedness and mitigation. The guidelines on disaster risk reduction produced by NDMA recommend the use of geospatial data for hazard zonation, vulnerability assessment and resource planning. Sharma and Gupta (2017) studies underlines the use of GIS to this end, especially in the disaster prone states, including Uttarakhand, Odisha and Assam. This is highlighted in the Sendai Framework for Disaster Risk Reduction (2015 2030) which underscores the contribution of geospatial technology to global disaster risk reduction goals to which India is fully committed.

There is no dearth of academic and policy literature on the intersection of GIS and disaster management. Kumar et al. (2019) examines how GIS has been applied to real time disaster monitoring and decision making in India. For example, GIS based models were used by the authors to predict landfall locations and coordinate evacuation efforts in the event of Cyclone Fani (2019). Spatial analysis through the use of GIS in drought management, for example, is demonstrated by Roy and Saha (2020) by identifying Maharashtra's water-scarce areas. Although these models have been developed, implementation of GIS in disaster management continue to face challenges. Often cited as limiting factors to effective GIS utilisation are lack of trained personnel, inadequate funding, and data sharing problems between agencies (Bhatia et al., 2018).

Gaps in Existing Research

The role of GIS in disaster management is well covered in the literature, however, some gaps nonetheless remain. For example, natural disasters receive most of the attention in GIS, with very little research on the use of GIS for human made disasters such as urban fires and industrial accidents. In addition, further localised studies are needed to address the region specific challenges and opportunities towards GIS implementation. Furthermore, existing research also revealed that GIS can only be significant if it is to be integrated with other technologies like Internet of Things (IoT) and machine learning which would help improve disaster management outcomes. Socioeconomic impact of GISbased disaster management solutions, especially in rural and marginalised communities, needs further study.

GIS Application in Disaster Management.

In the field of disaster management, Geographic Information Systems (GIS) have revolutionised the practise by providing powerful tools for mapping, analysing and visualisation of spatial data. It can be applied to every phase of disaster management cycle,

starting with preparedness, through to response, recovery and mitigation. However, decision makers can use GIS technology to predict risks, manage resources, and develop strategies to save lives and minimise damage. Based on the flood devastation and the cyclone fury in Indian region, GIS has become a necessary tool for risk assessment and mitigation of socio economic impact of these disaster events.

GIS is important in disaster preparedness, for hazard mapping and risk assessment. Utilising spatial data, authorities are able to determine areas around which particular hazards are vulnerable, including flood plains, seismically active regions, or coastal regions prone to cyclones, among others. For instance ASSAM and Bihar are the areas where recurring floods are the menace and GIS has been very helpful here in making flood risk maps. GIS tools help to build detailed maps that show flood prone areas by using geographical data concerning topography, pattern of rainfall and river basins. These maps can help authorities create early warning systems and disaster preparedness plans: preemptive evacuation plans and infrastructure reinforcements. GIS based modelling aids in the anticipation of cyclone path and intensity in cyclone prone states like Odisha and Andhra Pradesh thereby making high time evacuation and utilisation of resources possible. In addition, GIS serves as a tool for land use planning and zoning in identifying high risk area and directing the development of infrastructure that is resilient and minimises exposure to hazards.

In disaster response GIS becomes essential for real time monitoring, coordination and resource distribution. Accurate and up to date spatial data in the immediate aftermath of a disaster can play a very important role in effective decision making. The ability to visualise affected areas is one of GIS's special abilities, giving authorities an idea of the extent of the damages and which areas have to be prioritised for rescue operations. For instance, during the 2018 Kerala floods, GIS was employed to chart rising water levels and places that flooded while guiding rescue agencies where they needed to go to rescue trapped populations. Further augmenting situational awareness, GIS is integrated with the satellite imagery and drone technology giving situational awareness in high resolutions of disaster affected areas through visuals. In addition, use of GIS simplifies coordination in relief efforts, for instance, in mapping the location of emergency shelters, medical facilities and supply chains. For instance, GIS was utilised to monitor evacuation routes and to reallocate resources in order to minimise casualties during Cyclone Fani in 2019, as compared to previous cyclones.

In the recovery phase, GIS assists in after disaster damage assessment and postdisaster reconstruction and rehabilitation planning. Restoring infrastructure, fixing homes, and safeguarding affected communities all need much data after a disaster, and that information is often inaccurate or missing. The use of GIS tools allows to analyse the impact of disasters on various sectors (transportation, utilities, agriculture), by means of its overlaying pre and post disaster data. For example, GIS was widely used to estimate the extent of structural damage and plan reconstruction of urban areas following the 2001 Gujarat earthquake in India. In flood prone area GIS helps to determine areas with immediate drain and sanitation operations to prevent second disasters like disease outbreaks. In addition, GIS can help authorities monitor the progress of recovery efforts and guarantee that the recourses are assigned equally amongst affected populations.

However, GIS has a significant transformational role for long term disaster risk reduction and mitigation beyond disaster specific applications. Historical data and patterns are analysed with GIS to thus identify trends and shape policies that will lessen or reduce vulnerability. For example, GIS based studies of drought patterns in Maharashtra served as input to the development of water management strategies to buffer the effect of future droughts. In areas prone to landslides such as Himachal Pradesh and Uttarakhand, GIS is also used to create susceptibility maps, to plan the construction of protection barriers as well as safe paths of evacuation. For instance, the integration of GIS with newer technology like machine learning and Internet of Things (IoT) thus makes GIS all the more robust for disaster mitigation. For example, GIS enabled IoT devices can detect in real time environmental parameters (e.g. rain intensity and soil moisture), thus triggering early warnings for disasters such as flooding or landslides.

However, despite the multiple applications of GIS, its application in disaster management in India is beset with problems such as poor infrastructure; insufficient knowhow on GIS; and limited means of exchanging data. These challenges can only be addressed with investments in geospatial infrastructure, training programmes for disaster management personnel and interagency collaborative frameworks for data sharing between the government and private organisations. But wherever communities rush to implement GIS in disaster management like the Kerala floods and Cyclone Fani, proves that GIS can redefine the face of disaster management in India. Using GIS with the other technologies and adopting proactive approach to manage the disasters, India can increase its resilience for disasters to come, protecting lives and livelihoods of its people.

Challenges in Implementing GIS in Disaster Management

Although GIS has great potential in the simulation of disaster scenarios and their subsequent management, the implementation of Geographic Information Systems (GIS) in disaster management in India is fraught with setbacks, most of which are due to infrastructural, technical and institutional barriers. A major challenge is inadequate leveraging of GIS technology infrastructure for use across all regions, especially in rural and disaster prone areas. Metropolitan cities and urban centres have access to GIS tools and geospatial databases whereas remote regions do not enjoy a sufficient technological infrastructure to be able to utilise these tools. The lack of GIS adoption has become a digital divide, hampering the wider development of GIS and thus preventing vulnerable populations of rural areas from greater protection during emergencies.

But what seems to be another critical challenge is the shortage of qualified personnel in terms of using GIS tools (hardware and software) for disaster management. GIS implementation demands credibility in spatial data analysis as well as software operation and geospatial technology integration with other disaster management systems. But there are many disaster management authorities, particularly at State and District levels who lack appropriately skilled staff to be able to handle such jobs. This skills gap doesn't only restrict the use of GIS, it also reduces the productivity of disaster response and recovery work.

Furthermore, sharing and accessibility of data in GIS also present a considerable challenge in making use of GIS for disaster management. However, spatial data that are essential to GIS are

very large, and must often be distributed among a potentially large number of agencies, or be suppressed for policy and legal reasons. The Indian Space Research Organisation (ISRO), the National Disaster Management Authority (NDMA) and the like, produce useful geospatial data without any centralised framework for data sharing, which results in delays and inefficiency. Furthermore, data from various agencies are not standardised and thus, the integration of these data for a comprehensive GIS analysis is made difficult.

In addition, funding constraints have made it even more difficult to adopt GIS in disaster management. Establishment and maintenance of the GIS infrastructure requires considerable financial outlays such as buying advanced software, hardware and satellite imagery. Unfortunately, in many cases the allocation of resources to support GIS technology competes with other state governments and disaster management agencies' significant priorities and thus the underinvestment in geospatial systems. In addition, public awareness of GIS capabilities is narrow, limiting the demand for inclusion in disaster management architecture, and restricting its widespread use.

Opportunities for Enhancing GIS Applications in Disaster Management

The challenges in this regard are high but the potential for expanding and enhancing GIS applications for disaster management in India is also high. The existing barriers can be overcome by increased availability of advanced technologies alongside government initiatives. One of the biggest opportunities is the integration of GIS with the upcoming technologies including, artificial intelligence (AI), machine learning (ML) and internet of things (IoT). Disaster management agencies can combine use of GIS with AI and ML algorithms to create predictive models that are more accurate in prediction of disaster event occurrences. For instance, AI driven GIS systems can anticipate floods or landslides by analyses of historical weather patterns, terrain data, and real time natural indicators such as those related to air pressure, temperature and cloud volume.

It is also evident that fortification of GIS applications in disaster management is justified by the current growing importance of open data initiatives. Bhuvan by ISRO, and the Geographical Data Portal by National Informatics Centre (NIC) present many such sources that can be used for assessing disaster risk and planning. By encouraging more open data sharing between government agencies, private organisations and research institutions we can construct a robust ecosystem for GIS based disaster management. The collaboration of this kind would allow a smooth integration of different datasets into applications of GIS, enhancing the accuracy and the effectiveness of using GIS.

Another key opportunity to deal with the GIS utilisation skills gap is the capacity building and training programmes. Disaster management authorities can strengthen the capacity of personnel at all levels through investments on education and professional development initiatives, thereby equipping personnel to operate GIS tools utilising the technical self knowledge they will gain. Academic Institutes like Indian Institutes of Technology (IITs) and National Institutes of Technology (NITs) can partner with our office to create specialised training programmes and workshops on Geospatial technologies. Moreover, support to public private partnership with GIS software providers for disaster management agencies who will receive access to cutting edge tools and resources.

Also, Policy reforms and government initiatives can interlink GIS integration with disaster management. India's commitment towards the global frameworks of the Sendai Framework for Disaster Risk Reduction (2015–2030) and the Sustainable Development Goals (SDGs) highlight the need for adopting innovative technologies to contribute towards disaster resilience. The use of GIS applications can be institutionalised by the government across all phases of disaster management by embedding GIS applications in national disaster management policies and guidelines. In addition, the adoption of GIS can be expedited by dedicating funds specifically for geospatial infrastructure and research, meaning that it is available, even in developing regions.

Recommendations

To enhance the role of Geographic Information Systems (GIS) in disaster management in India, a multi-faceted approach is necessary. This includes addressing existing challenges, leveraging emerging technologies, and fostering collaborations among stakeholders. Below are detailed recommendations:

1. Strengthening Infrastructure and Accessibility

- **Invest in Geospatial Infrastructure:** Allocate dedicated funding for the development and maintenance of GIS infrastructure, especially in disaster-prone and underdeveloped regions. This includes advanced GIS software, high-resolution satellite imagery, and real-time data acquisition tools.
- **Expand Internet Connectivity:** Ensure robust internet access in rural and remote areas to facilitate the real-time use of GIS tools during disasters.
- **Develop Centralized Data Portals:** Establish a centralized geospatial data repository under the National Disaster Management Authority (NDMA) to ensure uniform data access across states and agencies. This portal should include hazard maps, historical disaster data, and live updates during emergencies.

2. Capacity Building and Skill Development

- **Train Disaster Management Personnel:** Conduct regular training programs and workshops to equip disaster management officials with the technical skills required for GIS operation and analysis.
- **Incorporate GIS in Academic Curricula:** Introduce GIS as a core subject in engineering, geography, and disaster management programs at universities to create a pool of skilled professionals.
- **Promote Public Awareness:** Increase public awareness about the benefits of GIS in disaster management through community engagement programs and outreach campaigns.

3. Policy Reforms and Integration

- **Institutionalize GIS in Policies:** Embed GIS applications into the Disaster Management Act, 2005, and other national policies to ensure its consistent use across all phases of disaster management.
- **Encourage Open Data Sharing:** Develop a clear policy framework that promotes open data sharing among government agencies, research institutions, and private organizations while ensuring data security.
- **Allocate Dedicated Budgets:** Mandate state and district disaster management authorities to allocate a portion of their budgets for GIS adoption and utilization.

4. Leveraging Emerging Technologies

- **Integrate GIS with AI and IoT:** Combine GIS with Artificial Intelligence (AI) and Internet of Things (IoT) technologies to develop predictive models and real-time monitoring systems. For instance, IoT sensors can monitor environmental parameters and feed data into GIS systems for better disaster prediction.
- **Adopt Drone and Satellite Technology:** Utilize drones and high-resolution satellites for rapid mapping and damage assessment during disasters. GIS platforms can integrate these data sources for more accurate and timely decision-making.
- **Explore Mobile-Based GIS Solutions:** Develop mobile applications that provide GIS-based disaster information to the public, enabling better preparedness and response at the community level.

5. Fostering Collaborations and Partnerships

- **Encourage Public-Private Partnerships:** Partner with private companies specializing in geospatial technologies, such as ESRI, Hexagon, and Indian startups, to develop customized GIS solutions for disaster management.
- **Collaborate with International Organizations:** Leverage expertise and resources from global organizations like the United Nations Office for Disaster Risk Reduction (UNDRR), World Bank, and Asian Development Bank for capacity building and knowledge exchange.
- **Facilitate Inter-Agency Coordination:** Strengthen coordination between national, state, and local agencies to ensure seamless integration and utilization of GIS during disaster scenarios.

6. Focus on Research and Development

- **Promote GIS Research:** Encourage research on innovative GIS applications for disaster management, such as real-time hazard monitoring, vulnerability mapping, and post-disaster recovery planning.
- **Develop Region-Specific Solutions:** Support studies that focus on region-specific disaster risks, such as landslides in the Himalayan states, droughts in Maharashtra, or cyclones in Odisha.

- **Integrate Indigenous Knowledge:** Combine GIS technology with local knowledge and practices to develop culturally and contextually appropriate disaster management strategies.

7. Enhancing Real-Time Applications

- **Develop Early Warning Systems:** Use GIS to integrate data from meteorological departments and disaster monitoring systems for effective early warning systems that can provide timely alerts to vulnerable populations.
- **Improve Resource Allocation:** Use GIS to map and optimize the allocation of emergency resources, such as shelters, medical supplies, and rescue personnel, during disasters.
- **Monitor Recovery Efforts:** Utilize GIS to track post-disaster recovery and reconstruction efforts, ensuring transparency and equitable resource distribution.

8. Promoting Sustainable Practices

- **Support Resilient Infrastructure:** Use GIS for land-use planning and identifying safe zones for infrastructure development to reduce vulnerabilities to disasters.
- **Incorporate Climate Data:** Integrate climate change projections into GIS models to develop long-term disaster mitigation strategies.
- **Encourage Community Participation:** Empower local communities to use GIS tools for disaster preparedness and planning, ensuring inclusivity in disaster management efforts.

By implementing these recommendations, India can strengthen its disaster management framework and maximize the potential of GIS to save lives, protect livelihoods, and build resilience against future disasters. A collaborative and forward-thinking approach will ensure that GIS becomes a cornerstone of disaster risk reduction and management in the country.

Conclusion

Use of Geographic Information Systems (GIS) for disaster management is an innovative solution to the escalating incidence and intensity of disasters in India. GIS technology facilitates the mapping, analysing and visualising of spatial data that bring about much needed insights for disaster preparedness, response, recovery, and mitigation. In a country with such a wide diversity and vulnerability to disasters, GIS (evidence based decision making making based on available resources) can bring down loss of lives and livelihoods, and minimise economic losses. Real world disaster cases in Assam and Bihar involve flood risk mapping and in Odisha and Andhra Pradesh, cyclone management, where GIS already proved its usage.

Nevertheless, GIS has not yet been fully utilised because of problems like poor infrastructure, lack of skilled manpower, poor data sharing mechanism and low public awareness. The presence of such barriers necessitates a targeted effort in augmenting GIS integration into India's disaster management framework. These challenges are only solved through investments in infrastructure, capacity building and policy reforms, and the fostering of collaborations between government agencies, private organisations and academic institutions.

The potential for GIS in disaster management is huge. Technologies such as artificial intelligence (AI), the Internet of Things (IoT), and drones have the potential to enhance GIS applications to support real–time monitoring and predictive modelling and even more precise response strategies. India will further enhance its resilience to disaster by establishing high quality open data initiatives and strengths its partnerships with global organisations. In addition, through public awareness and community participation, it is possible to make sure that those in the most vulnerable populations can also benefit from GIS based disaster management.

Thus, GIS is no more a tool; rather it is a key enabler of sustainable disaster management in India. With a proactive and collaborative approach, India can utilise GIS and make a safer and more resilient nation that can handle future disasters, provide protection to its people and development. The more the technology will grow, the more important the role of GIS into disaster management frameworks will be, making it the basis for the more safe and sustainable future.

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