

Geo-Spatial Data Processing for Disaster Management

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Abstract

This paper x-rays geo-spatial data processing for disaster management, focusing on the development of a geospatial database of states, districts, and urban areas with spatial and non-spatial data at appropriate scales for emergency response in the event of natural disasters. To enhance mitigation and preparedness for both natural and man-made disasters, there's a concerted effort towards developing and organizing comprehensive geospatial databases. In the spatial realm, the vision includes multiple digitized layers on scales of 1:50000 for the entire country, 1:10000 for multi-hazard prone districts, and 1:2000 for mega-cities, covering hazard zonation, transportation networks, settlements, natural resources, hazardous industries, and resource inventories, among others. While a substantial amount of digital spatial data has already been developed by various government agencies, these data require collection and compilation. Integrating geospatial data from diverse sources with varying formats, semantics, precision, and coordinate systems is a critical challenge. Geospatial data processing for disaster management entails identifying datasets, assessing their availability and gaps, consolidating diverse datasets onto a common platform with standardized protocols, and establishing mechanisms for data access and dissemination during emergency situations; there is also a plan to integrate real-time data from various measurement stations such as Automatic Weather Stations, in-situ sensors, etc., in addition to remote-sensing, aerial, and lidar data. It is crucial to equip disaster management personnel with tools that facilitate decision-making based on scientific inputs. For this purpose several applications were selected, these include flood management information system, mobile-based applications, flood relief management application, and web application for identification of suitable locations for food shelters. These geospatial models play a crucial role in predicting the locations, impacts, timing, and durations of events, aiding jurisdictions in better preparation. Geospatial data and tools should be integral throughout every phase of disaster management, from planning and response to recovery and future event mitigation.

Keywords: emergency response, geospatial database, geospatial information technology (GIT), geospatial software/applications, natural disasters, non-spatial data, prediction, spatial data.

1. Introduction

Despite the United Nations declaring the 1990s as the International Decade for Natural Disaster Reduction (IDNDR), the global efforts to lessen the impacts of natural disasters during that period were unsuccessful [1]. Factors such as environmental degradation, rapid urbanization, and social marginalization, particularly in developing countries, contributed to this outcome [2]. The rising number of disasters indicates an increase in vulnerability to natural hazards, thus altering the geography of risk. Specifically, more people are now residing in low-lying coastal zones, seismically active areas, and densely populated urban regions [3][4][5][6]. As the geography and magnitude of hydrometeorological hazards, which have historically caused significant disasters [7], shift due to global climate change [8][9], vulnerable populations will face heightened risks. Defining this geography of risk is crucial, especially in developing countries, where disasters threaten vital social development goals such as poverty reduction, ensuring sufficient food, water, and sanitation, and environmental protection [10]. Given that natural disasters most heavily impact developing nations [11][12][1], geospatial data processing hold significant potential to mitigate casualties in these regions.

Natural disasters like earthquakes, floods, droughts, tornadoes, tropical cyclones, wildfires, tsunamis, volcanic eruptions, and landslides impact different regions worldwide with varying severity over time and space. According to the International Strategy on Disaster Reduction, disasters increased by 18 percent in 2021 compared to 2020 [80]. This rise is mainly attributed to the growing number of floods and droughts affecting large populations. In 2021, approximately 157 million people were impacted by disasters [80], causing damages estimated at 159 billion USD globally. USA ranks first among countries most affected by disasters in terms of population. Recently, USA has experienced widespread floods, droughts, landslides, and earthquakes. While natural disasters are unavoidable and fully recovering from the damage they cause is nearly impossible, potential risks can be minimized through early disaster warning strategies, and by preparing and implementing developmental plans that enhance resilience and aid in rehabilitation. Increased urbanization in developing countries and the encroachment of coastal and river plains by agricultural, residential, and industrial activities are major factors contributing to heightened vulnerability to natural hazards.

USA's territory is susceptible to natural disasters due to its unique geo-climatic conditions and topography. Recurrent events include floods, droughts, cyclones, earthquakes, epidemics, and landslides. Approximately 60% of the landmass is prone to earthquakes of varying intensities; over 40 million hectares are prone to floods; around 8% of the total area is prone to cyclones, and 68% of the area is susceptible to drought. Each year, disasters also result in significant losses of social and community assets. In addition to natural disasters, technological/man-made disasters such as industrial, chemical, biological, nuclear incidents, fires, transport accidents, power failures, and explosions pose serious threats to the nation's economic growth and cause loss of lives.

The Government of America has introduced a policy shift emphasizing mitigation, prevention, and preparedness in disaster management. This new approach is based on the belief that development cannot be sustainable unless disaster mitigation and preparedness are integrated into the development process. Another key aspect is that disaster management must be multi-disciplinary, spanning all sectors of development. The new policy also stems from the understanding that investments in mitigation, prevention, and preparedness are far more cost-effective than expenditures on relief and rehabilitation.

This policy has been translated into a National Disaster Framework, which includes institutional mechanisms, disaster prevention strategies, early warning systems, disaster mitigation, preparedness and response, and human resource development. The framework outlines the expected inputs, intervention areas, and the agencies involved at the National, State, and district levels. This roadmap has been shared with all State Governments and Union Territory Administrations. Ministries and Departments of the Government of America, as well as State Governments/UT Administrations, have been advised to develop their respective roadmaps using the national roadmap as a broad guideline. Now, a unified strategy supports the actions of all participating organizations and stakeholders. It is strongly recommended that GIS/digital databases of States, districts, and urban centers with spatial and non-spatial data at appropriate scales be developed along with spatial decision support tools for emergency response.

This paper aims to explore the application of Geo-Spatial Data Processing in disaster management, focusing on the development of a geospatial database of states, districts, and urban areas with spatial and non-spatial data at appropriate scales for emergency response in the event of natural disasters.

2. Literature Review

2.1 Natural Hazards and Disasters: An Overview

To provide context for the issues discussed, it's important to understand the relationship between natural hazards and natural disasters. Natural hazards vary widely in terms of frequency, duration, scale, and impact, influencing the spatial data and technology needed to effectively mitigate, prepare for, respond to, and recover from potential disasters.

In essence, natural hazards are unpredictable acts of nature, marked by extreme physical processes [13]. Examples include earthquakes, tsunamis, hurricanes, typhoons, droughts, wildfires, tropical storms, and floods. According to Alexander [11], "The fundamental determinants of natural hazards are location, timing, magnitude, and frequency." The spatial scale and duration of these hazards can differ significantly, which is crucial from a GIT perspective, especially regarding data requirements. For instance, landslides have a local impact, while major floods can affect large regions. Earthquakes strike with little warning and last only seconds to minutes, whereas droughts may develop over months and persist even longer. Therefore, hazards can be classified as 'rapid-onset' like floods and earthquakes or 'creeping crises' such as droughts and diseases [14]. Coppock [15] notes that slow-developing hazards are more akin to natural resource management from a mitigation standpoint.

McEntire [16] describes natural disasters as the disruptive, deadly, and destructive outcomes of triggering agents interacting with various forms of vulnerability. Simply put, a disaster risk exists when a hazard intersects with human habitation. The number of people affected by rapid-onset natural hazards is rising [17]. Particularly, hydrometeorological disasters (e.g., floods, landslides, wildfires, windstorms, and surges) have more than doubled since 1996 and accounted for over 90 percent of natural disaster deaths in the 1990s [1]. This discussion focuses on the role of GIT in mitigating rapid-onset natural hazards that pose a disaster risk.

Large-scale disasters present complex, multidisciplinary challenges for local disaster managers, related organizations, and international humanitarian/aid groups. Many natural disasters are characterized by brief reaction/response times, extensive property and infrastructure damage, and strained community resources. However, infrequent large-scale disasters are often far more deadly. The most deadly global natural disasters, involving 50,000 or more victims, include earthquakes, tropical cyclones (with coastal flooding), and river floods

[7]. These hazards have caused the worst disasters in both the 20th century and throughout human history, such as the 1970 Bangladesh flood and cyclone (300,000 victims), the 1976 China earthquake (242,000 victims), and the 1931 China flood (140,000 victims). The 2004 Sumatra earthquake and subsequent Indian Ocean tsunami also rank among the deadliest, with 283,000 reported fatalities [18].

2.2 Disaster Management Concept

Disasters can result from technological failures or natural processes and require swift decision-making. Modern disaster management and response strategies encompass multidimensional efforts to reduce vulnerability to hazards, mitigate the impact of disasters, and prepare for, respond to, and recover from such events. The primary aim of disaster management is to minimize the extent to which a community's condition worsens due to a disaster compared to its pre-disaster state. This goal is supported by various actions taken by disaster management participants both before a disaster (to prevent or lessen potential damage) and after (to recover from actual damage). Ideally, these activities would reduce the potential effects of a disaster.

Disasters are unpredictable in both occurrence and outcomes. Rapid-onset disasters like earthquakes cause significant damage to property or populations quickly, outpacing the ability to avert or avoid them. These disasters may also directly impact the resources and personnel needed for response, creating a profound sense of urgency and depleting human resources, equipment, supplies, and funds. All disasters have a temporal and geographic footprint, marking their duration and impact on the Earth's surface.

Geospatial data is critically important for disaster management. The required data for different emergencies ranges from spatial to attribute data. For technological disasters, spatial information requirements vary from 1:10,000 to 1:2,000, depending on the disaster type. An emergency database can be developed using an object-oriented design approach that involves data collection, processing, organization, and sharing through a centralized repository. There is a vast amount of geospatial data available, but it can be challenging for responders to find the right data at the right moment for rescue and recovery operations. Geospatial tools help responders identify areas of greatest impact, locate damaged buildings, or find injured residents, enabling quicker action, especially during the critical period immediately after the event when lives can be saved [19].

If pre-incident data is available, geospatial analysis can provide crucial insights into the changes caused by disasters. Geospatial models can predict the locations, footprints, times, and durations of events and their potential damage, aiding in better preparation. Recognizing the importance of emergency management, the Department of Space, Government of America, has proposed a program for developing a geospatial database at various scales with decision support tools and multi-institutional support. This database will leverage aerospace data and include core data, hazard-specific data, and dynamic data in both spatial and non-spatial forms. The proposed geospatial database aims to provide timely information to key players by utilizing the latest computer science and networking technologies.

The system configuration and network design, using state-of-the-art technology, consider functional requirements and incorporate features like multi-core/multi-processor systems, high-end storage, and network devices to ensure good system response despite additional security levels. A prototype decision support system was developed for natural disaster emergencies like floods.

2.3 Disaster Management and the Role of GIT

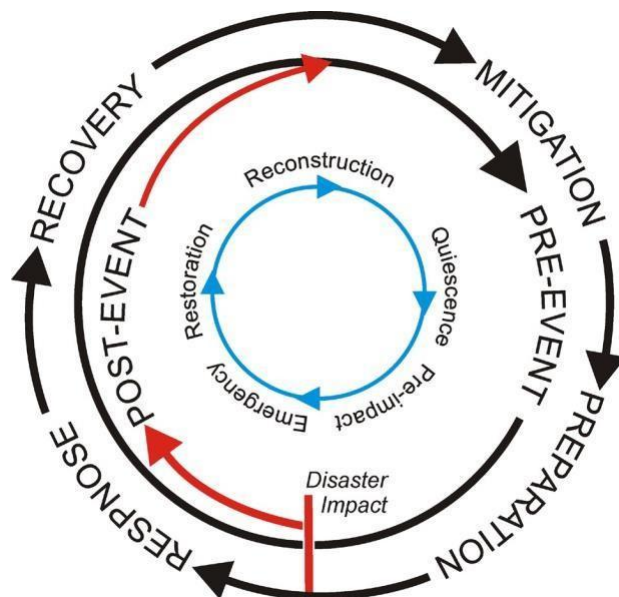


Fig 1: Disaster management cycle (Adapted from [11])

Disaster management is often conceptualized as a cycle (Figure 1) encompassing efforts to “mitigate against, prepare for, respond to, and recover from a disaster” [20]. These core components are widely discussed in emergency management literature [21] and frequently associated with natural disasters [22]. Thus, emergency and disaster management are interconnected; a disaster represents an emergency, but for the purposes of this paper, it will be referred to as the disaster management cycle.

Mitigation involves efforts to eliminate or reduce the risks to humans and property from natural or man-made hazards (e.g., risk assessment, insurance, engineering standards, land use management, public education). Preparedness includes activities necessary to the extent that mitigation measures have not, or cannot, prevent disasters [23]. This phase involves developing operational capabilities to respond to sudden disasters. During preparedness, “governments, organizations, and individuals develop plans to save lives and minimize potential disaster damage” [23]. This includes emergency planning, training exercises, implementing hazard warning systems, evacuation procedures, and stockpiling critical supplies. Additionally, “preparedness measures also seek to enhance disaster response operations” [23].

Response refers to actions taken immediately before, during, and after a disaster to save lives, reduce property damage, or improve recovery. The primary focus during this phase is providing emergency assistance to victims (e.g., search and rescue, emergency shelters, medical care, and food/water). Disaster responders “also seek to stabilize the situation and reduce the probability of secondary damage” [24].

Recovery, often termed ‘relief,’ involves activities that (1) restore vital life support systems and (2) return the area/population to its pre-disaster state. The first aspect is part of the short-term recovery plan, while the second is part of the long-term recovery, which may continue for years after a disaster. Reconstruction is closely linked with mitigation, aiming to reduce vulnerability and improve preparedness, making disaster management a cyclical process as shown in Figure 1.

Geospatial information technology (GIT) is crucial in all aspects of natural disaster management due to its capabilities in acquiring, interpreting, analyzing, mapping, and disseminating information. As a spatial decision support tool, GIS is invaluable for disaster management, which involves critical spatial decisions [22]. For example, GIT is fundamental in estimating and mapping risk, planning evacuation routes, identifying suitable shelter locations, locating disaster victims, and allocating resources during recovery efforts [25]. Therefore, GIT is an integral component of any comprehensive and effective disaster management strategy. Figure 2 illustrates the incorporation of GIT within the disaster management cycle, highlighting its central role in all phases.

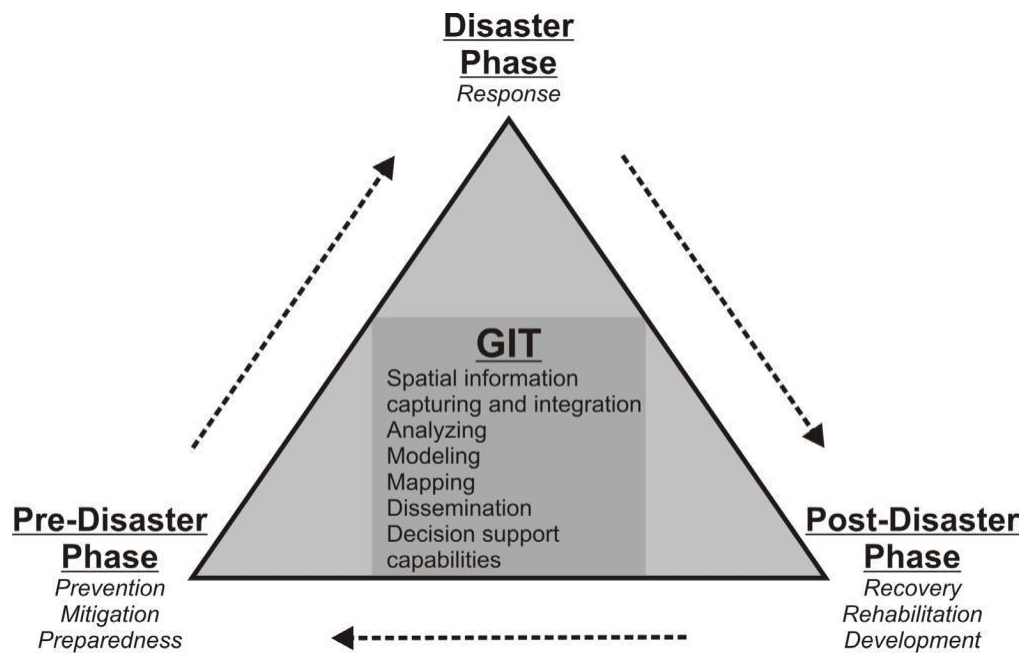


Fig. 2: A disaster management cycle incorporating GIT (adapted from [26])

Disaster management is inherently complex and requires the participation and collaboration of numerous institutions, organizations, and agencies operating at various levels—international, national, regional, and local. These entities use a variety of GIT tools based on their specific information needs, financial resources, and technical capabilities. While a robust national disaster management initiative is vital, Henderson[27] stresses the importance of decentralizing disaster management capabilities to regional or local levels due to the diverse demographic, socioeconomic, cultural, and infrastructural conditions within different areas of a nation. Ideally, regional and local authorities involved in disaster management should have the capacity to effectively use GIT. However, even in developed countries, limited financial resources can hinder the utilization of GIT at these administrative levels [28].

This decentralized approach is increasingly recognized as more effective than a centralized one, but as Montoya and Masser [29] point out, local authorities often lack the financial resources needed to develop and implement effective policies and plans that incorporate GIT. Laben [28] underscores the importance of having GIT alternatives available for all levels of the emergency and disaster management communities, ensuring that these technologies can be utilized regardless of financial constraints.

2.4 Geospatial Information Tools and Disaster Management

Geospatial Information Tools serve numerous disaster management functions, including hazard and risk assessment [30] [31], vulnerability assessment [32] [33] [34], vehicle dispatch and supply routing [35], damage assessment [36] [37] [38], and resource mobilization [25], among other critical tasks. This section explores the use of GIS, remote sensing, and Internet GIS in natural disaster management.

2.4.1 Geographic Information Systems (GIS)

A Geographic Information System (GIS) is an “organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information” [39]. GIS is an essential component of a comprehensive disaster management strategy, used to display, integrate, map, analyze, and model data and information derived from satellites and other spatial data sources [40]. GIS primarily function as support tools to answer critical questions and make informed, timely decisions that can save lives. One of the greatest strengths of GIS is their ability to integrate various data types, including geographic, social, economic, and political data, into a single system.

Utilizing GIS requires not only software but also hardware, data, and trained personnel. Thus, establishing a GIS capability involves acquiring the necessary spatial and descriptive (attribute) data, computer hardware, and skilled personnel [20]. Consequently, the use of GIS for disaster management varies widely among countries and within disaster-related organizations at different government levels [28]. These variations in GIS capabilities are evident in the extensive literature that examines GIS use in natural disaster management. This section reviews the GIS and disaster management literature to identify examples of GIS capabilities (software, data, hardware, and expertise) feasible for implementation in developing countries. These considerations are crucial and will be discussed further.

Given the distinct differences in using GIS for pre- and post-disaster management activities, this section is divided accordingly: one part addresses pre-disaster GIS use, and the other focuses on post-disaster use. However, before presenting these sections, it is necessary to discuss the importance of spatial data, the primary input for GIS and essential for their use.

2.4.1.1 The Importance of Spatial Data

The effective use of GIS largely hinges on the availability of spatially-referenced data, with its quality determined by locational accuracy, attribute data characteristics, and the adoption of standards facilitating data transfer [15]. The critical role of high-quality spatial data in aiding disaster management through GIS cannot be overstated. Various types of spatial information are instrumental for decision-making in disaster management, with the type, scale, and complexity of data varying based on the disaster's nature, scale, and phase [41], as well as the GIS capabilities of the implementing entity. Table 1 illustrates different types of spatial data applicable to disaster management within a GIS framework.

Table 1: Crucial spatial data for disaster management

Data/Information Type	Description
Disaster forecast	Information concerning the extent of a particular hazard or disaster
Vulnerability analysis	Information on critical facilities (hospitals, schools, shelters, police and fire facilities, dams, trauma centers, industrial facilities, etc.); Information regarding human vulnerability (age, gender, socioeconomic status, etc.)
Damage assessment	Data/imagery of the actual impact of a hazard
Resource inventory	Location information regarding supplies, equipment, vehicles, or other material resources
Infrastructure	Shows transportation networks (roads, railroads, bridges, traffic control points and evacuation routes) as well as complete utility grids (electric, gas, water, and sewer)
Mass care/shelter status	Monitors the movement of people to and from government or voluntary agency shelters by providing information on capacity, availability, supplies, and suitability to victims' needs

Source: Adapted from [42].

Over time, advancements in spatial data collection and utilization have introduced the concept of spatial data infrastructure (SDI). According to Musinguzi et al.[43], an ideal SDI encompasses “technologies, policies, standards, and human resources to acquire, process, store, distribute, and enhance the use of geo-spatial information”. The effectiveness of disaster management significantly relies on the availability, dissemination, and efficient use of information, much of which is spatial [44]. Thus, there is a crucial link between GIS, SDI, and the utilization of spatial information for disaster management purposes.

Most developed nations are in various stages of establishing national SDIs, with their success attributed to advanced technology, ample funding, trained personnel, and political support and stability [43]. Many factors contributing to successful national SDI development are often lacking in developing countries, resulting in significant disparities in spatial data quality and quantity between developed and developing nations. Without a national SDI, there is no effective mechanism for coordinating data collection or sharing spatial data among agencies, leading to data duplication and resource wastage. These limitations are especially problematic for disaster managers whose spatial data needs typically span across different departments or agencies [45]. Nonetheless, some developing countries are making strides, such as Sri Lanka, which recently initiated a national SDI in 2008 (<http://www.survey-dept.slt.lk/>). Their policy statement specifically addresses disaster management and the necessity of an SDI to mitigate inefficiencies.

While there are clear disparities between developed and developing countries regarding the quality and quantity of available spatial data, initiatives are underway to improve the current situation. Nebert [46] notes that “many national, regional, and international programs and projects are striving to enhance access to available spatial data, encourage its reuse, and ensure that further investment in spatial information collection and management results in an ever-expanding, readily available, and usable pool of spatial information”. Even though these initiatives may not be part of a formal SDI policy, they significantly benefit the global GIS community and other users of spatial data.

The Internet has significantly increased access to spatial data, with numerous websites now offering free access to various data types (e.g., political/administrative boundaries, roads, hydrology, digital elevation, land cover, etc.). However, despite the rapid growth in available spatial data, there has been insufficient focus on its quality, including “currentness, lineage, locational accuracy, completeness, and overall usefulness” [47]. This oversight is unfortunate, as the quality of spatial data is crucial when used for disaster management, where lives may be at stake. Although satellite imagery is a vital type of spatial data for disaster management and is widely available online, its discussion is reserved for subsequent sections. Here, spatial data refers only to vector data.

The scale of online spatial data can also limit its usefulness. Currently, data available for developing countries is often at the national scale and derived from small-scale map sources. Such data is inadequate for regional or local use due to reasons like locational inaccuracy and lack of attribute information. Even when the data scale is appropriate, additional time may be needed to clean, correct, or add relevant attribute data before it can be effectively used. Combining data from different sources can also pose challenges due to variations in coordinate systems and map projections. Engler and Hall [47] highlight that, in many cases, it may be more practical to create or purchase the required data elsewhere due to the work involved or the uncertainties associated with using freely available internet data.

Spatial data is crucial in all aspects of disaster management, but high-quality spatial data is often scarce, especially at the local level in developing countries. Enhancing the use of GIS for disaster management will require significant data collection efforts, which can be supported by an effective SDI policy. Rego [45] emphasizes that the development of spatial databases should follow a “bottom-up approach, starting from the lowest administrative unit in the country (e.g., the sub-district or district). The district databases would then feed into the state/provincial database and subsequently into the national database”. This bottom-up approach is particularly relevant for local-level GIT use in developing countries.

2.4.1.2 Pre-Disaster

In the phases of mitigation and preparedness before a disaster, GIS offers significant benefits. Effective disaster preparation and mitigation require comprehensive knowledge about the expected frequency, nature, and severity of hazardous events in an area, as well as the vulnerability of people, structures, infrastructure, and economic activities in at-risk areas [48]. This information is crucial for preparedness planning and for determining appropriate mitigation strategies. GIS facilitates the synthesis and analysis of such data to assess risk levels, evaluate vulnerability, simulate scenarios, plan evacuation routes, estimate resource needs, and produce various informative outputs to support decision-making. Several specific instances of GIS utilization in the pre-disaster phase are particularly pertinent for developing countries, and these are discussed as examples of effective GIT implementation in pre-disaster management.

Van Westen and Hofstee [48] present a case study demonstrating the use of GIS to establish a spatial database comprising buildings, land parcels, roads, and other infrastructure through the digitization of features from aerial photographs. Subsequently, field investigators collected specific attribute data for each digitized land parcel and building using a predefined checklist. Attribute data collected included land parcel usage (residential, industrial, commercial, etc.), building materials, building age, number of floors, and history of previous hazard damage. The resulting database, combined with historical data on past disasters such as flood depth, was utilized to generate various vulnerability and risk maps. These databases and maps serve as the foundation for future development and planning that considers both physical and human vulnerabilities. This study was conducted for Turrialba, Costa Rica, a city with a population slightly over 30,000. The data collection and analytical methods are relatively straightforward to replicate, making this an exemplary instance of GIS application practical for local-level disaster managers in developing nations.

Cutter et al. [32] introduce a county-level GIS methodology based on the concept of “hazards-of-place” for evaluating hazard vulnerability in spatial terms. Utilizing twelve environmental threats and eight social indicators (e.g., age, race/ethnicity, income levels, gender, building quality, etc.), their study illustrates how GIS can integrate both physical and social factors contributing to hazard vulnerability. Social demographics of the

population are typically available from national censuses and are frequently utilized in GIS to map human vulnerability to various natural hazards. The research approach and conceptualization of hazard vulnerability offer a blueprint for others to follow and address a gap in spatial analytical approaches to vulnerability assessment. Identifying vulnerability to natural hazards enables appropriate measures to reduce the social and economic impacts of potential disasters. However, the authors recognize that implementing this approach at the local level may face challenges concerning funding availability for training and data acquisition. Moreover, the results rely on a data-intensive methodology, which, while feasible in developed countries, may not be practical in most developing nations due to the lack of detailed spatial data, alongside other previously mentioned GIS implementation obstacles. Nonetheless, simplifying this methodology could still yield valuable hazard vulnerability insights.

Guinau et al. [49] utilized GIS to produce a susceptibility map for mitigating landslide risk. Their methodology focused exclusively on the biophysical factors contributing to landslides. By digitizing current and past landslide occurrences from aerial images, they developed a landslide inventory. This inventory was then overlaid onto terrain data, including lithology, slope, soil characteristics, and land use, enabling an analysis of terrain conditions in landslide-affected areas to identify zones with similar characteristics. Subsequent analysis led to the delineation of zones with low, medium, and high susceptibility to landslides. What stands out about this study is its illustration of a relatively straightforward GIS-based approach for assessing landslide vulnerability, which is viable for developing countries.

Dewan, Islam, et al. [30] merged GIS and remote sensing techniques to assess flood hazard and risk levels in Dhaka, Bangladesh. Limited digital geospatial data posed a significant challenge, necessitating the creation of several required data layers. Flood frequency and depth were estimated using multi-date Synthetic Aperture Radar (SAR) data from RADARSAT, based on past flood occurrences. Land cover was generated through a combination of methods and data sources, including digitization from high-resolution satellite imagery, newly produced topographic maps, field surveys, and handheld GPS units. Additionally, a geomorphic map was developed using a LANDSAT TM image from 1999, along with existing paper maps and field observations. Elevation data in the form of a Digital Elevation Model (DEM) was sourced from the Institute of Water Modeling (IWM), Bangladesh. All vector data layers were then converted to raster format at uniform resolutions. Through a relatively straightforward process involving assigning weighted scores to each data type to represent their varying importance and using GIS overlay functions, the authors created maps illustrating flood hazard potential and flood risk zones. The data collection methods, analytical techniques, and overall approach employed in this study showcase the innovative and adaptable use of GIT in conducting a hazard assessment at the city scale in developing nations.

Unregulated and informal urban housing development poses a recurring challenge in developing country cities [51], exacerbating vulnerability to natural hazards. To tackle this issue, Thomson and Hardin [51] employed GIS and satellite imagery (LANDSAT TM) to pinpoint potential sites for low-income housing in the eastern part of the Bangkok Metropolitan Area, where flood risk is a concern. They evaluated location, infrastructure, land cover, and environmental factors to determine suitable public housing sites. Due to limited spatial data availability, all GIS coverages were derived from satellite images or digitized from maps, including land use, land parcels, roads, and drainage networks. Land cover was determined using a mix of techniques, such as unsupervised classification for spectral clustering, supervised classification based on local knowledge, and aerial photographs for validation. Major roads were digitized from satellite imagery, and other data were generated using low-tech methods like visual interpretation and fieldwork. Utilizing basic GIS functions like overlay and buffering, they produced a map identifying sites meeting criteria for low-income housing: undeveloped, over 25 hectares, within 1 km of a road, and less susceptible to flooding. This map is applicable at medium to large scales (e.g., 1:20,000 – 1:50,000), and the analysis methods and techniques are deemed feasible for developing country cities considering available data and skill requirements. Enhanced knowledge of suitable housing site locations could guide development to mitigate natural hazard vulnerability.

Preemptive awareness of hazard spatial characteristics and vulnerability allows disaster management authorities and emergency responders to pinpoint areas most at risk, efficiently allocating resources. Such understanding is pivotal for devising effective mitigation and preparedness strategies, ultimately curbing the devastating consequences of natural disasters.

2.4.1.3 Post-Disaster

After a disaster strikes, responders, aid workers, and emergency personnel require timely and accurate information to facilitate relief efforts. This includes data on damage extent, potential victim locations, critical facility positions (like shelters, hospitals, and air strips), available resources (such as food, water, medical

supplies), infrastructure conditions (like damaged roads, bridges, and utility lines), and evacuation or supply drop-off points. Much of this information is spatial and can be effectively compiled and analyzed using GIS technology, then disseminated as maps. However, utilizing GIS post-disaster presents distinct challenges compared to pre-disaster use, primarily due to the urgency of time (Goodchild, 2006). Immediately following a disaster, information must be swiftly collected, analyzed, and transformed into useful products to aid response efforts. Hence, whenever feasible, GIS data should be gathered and analyzed beforehand, rather than assembled during the aftermath (ESRI, 2006). Delays in information flow can significantly impact outcomes, underscoring the importance of having a database of critical spatial data ready before disaster strikes. This enables rapid updates to reflect ground conditions and reduces the time required to produce vital information for disaster responders and emergency personnel.

Once the initial response phase concludes and the situation stabilizes, GIS becomes instrumental in analyzing disaster impacts and guiding the rehabilitation process to minimize vulnerabilities. This approach is termed 'invulnerable development' [16]. The following examples illustrate the indispensable role of GIS during the post-disaster management stages.

One fundamental use of GIS in the post-disaster phase is impact analysis. It aids response efforts by pinpointing areas most in need and informs reconstruction efforts to mitigate future disaster risks. For instance, De La Ville et al. (2002) utilized GIS along with IKONOS panchromatic images to assess the distribution of landslide erosion scars and their impact on urban areas across six mountain catchments in Venezuela. GIS was employed to analyze and map scar distribution and study contributing factors like slope, geology, and land cover affecting various mass movement types. Findings from this study served as the foundation for government agencies to prepare reconstruction plans for affected areas.

After the Indian Ocean tsunami in 2004, Magsud et al. [52] employed GIS following the activation of the International Charter on Space and Major Disasters to acquire both pre- and post-disaster high-resolution satellite images for rapid building damage assessment in Galle, Sri Lanka. The GIS facilitated the integration of various data types and aided visual analysis of building damage. They overlaid QuickBird multi-spectral imagery with a 1:5000 scale vector layer of buildings from the Survey Department in the GIS to identify pre-existing structures accurately. Furthermore, they conducted a ground survey of 81 buildings to assess post-disaster damage levels, categorized as "completely destroyed," "partially damaged mainly inside," "partially collapsed with roof intact," and "slightly damaged." GPS was utilized alongside ground photos to precisely record building locations and damage, respectively, enabling a comparison with satellite imagery. The study revealed that identifying heavily damaged buildings was feasible, but determining partial damage, especially if the roof remained intact, was challenging with satellite imagery alone. Mapped results indicated the locations of destroyed buildings, aiding in prioritizing response operations. The authors suggest that with sufficient trained personnel, near-real-time damage assessment could be achievable. Despite its simplicity, the study's analytical methods and data inputs are effective, making them suitable for disaster managers in developing nations, given adequate data availability and delivery methods.

In general, GIS is valuable for providing critical information to support disaster response operations. For instance, GIS has been utilized to assess disaster extent and damage, organize resource inventories and distribution, monitor shelter and transportation infrastructure statuses, and integrate diverse spatial data sources necessary for response guidance. Thus, GIS facilitates tasks like search and rescue, medical services provision, debris removal, sheltering, and infrastructure repairs. However, planning and coordinating such operations require numerous spatial data layers, and without them, the utility of GIS significantly diminishes. Therefore, the usefulness of GIS post-disaster largely depends on the availability of essential framework datasets like roads, critical facilities, and population density.

Lastly, Zerger and Smith [13] stress that GIS suitability differs between planning and real-time applications. They found that using GIS for real-time decision-making is challenging due to practical and implementation barriers, including insufficient training and the need for temporal resolution over spatial detail. Pre-disaster management functions, like vulnerability assessment or evacuation route planning, encounter fewer challenges compared to post-disaster GIS use, where time constraints and changing ground conditions prevail. Nevertheless, assuming adequate data and personnel, GIS's ability to support disaster response and recovery operations remains unquestionable.

2.4.2 Remote Sensing

Remote sensing (RS) has been repeatedly highlighted for its potential in providing crucial earth observation data for various aspects of disaster management, including hazard assessment, mitigation, preparedness, response, and recovery [53] [36] [54] [55] [37]. This is evident in the extensive scientific literature from 1972 to 1998,

comprising over 400 articles [56]. For instance, RS imagery can offer insights into the pre- and post-disaster conditions of an area, depicting land cover, topographic features, infrastructure, and population density [56]. Showalter's review [56] underscores RS's role in detecting, identifying, mapping, surveying, and monitoring hazards and their effects, while also contributing to damage assessment, improved planning, and data provision for disaster management functions. Simonovic [57] provides valuable insights into the suitability of specific satellites for different natural disasters based on repeat frequency, spatial resolution, and sensor types. Among the widely recognized RS capabilities for disaster management are multispectral scanners (optical sensors) and radar collection systems.

The utility of RS for disaster management is exemplified in flood-related scenarios, where it has been extensively explored. Satellite imagery assists in assessing past flood events [50] and developing flood hazard potential maps. RS technology, as highlighted by Zhang et al. [38] and Jayaraman et al. [54], significantly aids flood response and relief operations by offering inundation mapping and damage assessment capabilities. Flood disasters are particularly suitable for RS analysis due to their extensive spatial coverage and the unique spectral reflectance of water, making it distinguishable from other ground features [56]. In contrast, disasters like earthquakes, which may cause substantial damage, pose challenges for identification without high-resolution imagery or change detection capabilities.

Digital elevation data derived from remote sensing, often referred to as DEM or DTM, provide essential insights into surface topography and are frequently employed in natural hazard studies. DEMs serve as critical inputs for assessing landslide susceptibility [47], delineating flood risk potential [30], flood hazard mapping [50] [58], and various coastal hazard and disaster assessment purposes [36]. Moreover, DEMs are utilized to generate additional datasets required for specific disaster management analyses or visualizations, including slope, aspect, contour lines, flow direction, watersheds, solar insolation, and viewsheds, among others. Spatial resolution and vertical accuracy are pivotal factors determining the suitability of DEMs for disaster management applications.

The potential of remotely sensed data to aid disaster management is evident, yet several limitations and obstacles need consideration, including image resolution, repeat frequency, and sensor suitability. Particularly, low pixel resolution poses a significant challenge for using satellite imagery in disaster management, especially in remote areas and developing regions where only 15-30 meter Landsat or ASTER imagery is accessible. This limitation restricts the utility of RS data for creating essential digital datasets crucial for disaster management. For instance, Rüdener and Schmitz [59] found that Landsat 7 ETM+ data (30m resolution) could identify settlements but struggled with detecting linear features like roads and waterways.

Repeat frequency is another critical factor, as timely access to RS imagery is vital for post-disaster applications, yet some satellites may not be available within an appropriate timeframe [60]. Moreover, pre- and post-processing times, cloud cover, and time of day can impede image acquisition, affecting the suitability of optical sensors for disaster response [61]. Cloud cover and shadows, whether in optical or radar imagery, pose additional challenges, impacting the accuracy of damage assessment [52]. Therefore, cautious interpretation and ground truthing are necessary before making substantial decisions based on visual imagery analysis.

Acknowledging the significance of high-resolution satellite imagery in disaster management, numerous major space agencies and satellite operators ratified the International Charter on Space and Major Disasters by 2001. This collective agreement recognizes the inability of any single operator or satellite to meet the data-related demands of natural disaster management. The charter's objective is to establish a unified system for space data acquisition and delivery to those affected by disasters. It has been activated successfully on multiple occasions worldwide, from Ecuador to India to Russia, providing crucial high-resolution imagery at no cost. For instance, following the Indian Ocean tsunami, various agencies and private firms supplied remote sensing imagery for response and relief efforts. Despite developing countries lacking the capability to launch satellites, opportunities exist for acquiring high-resolution remotely sensed imagery for disaster management. However, challenges arise in effectively utilizing such data, particularly in developing countries where users may lack awareness of GIS and remote sensing capabilities and require additional assistance. Furthermore, the International Charter does not offer free imagery for pre-disaster geospatial information technology (GIT) operations.

The Haitian earthquake in January 2010 exemplified the invocation of the International Charter on Space and Major Disasters, with imagery acquired from various satellites including Japan's ALOS, CNES's Spot-5, the US WorldView and QuickBird platforms, Canada's RADARSAT-2, and the ESA's ERS-2 and Envisat sensors. The delivery of these datasets was facilitated by Google and GeoEye Inc. to provide high-resolution images. Additionally, platforms like the Google Earth Library offered critical infrastructure data for direct viewing in Google Earth formatted KML, allowing for rapid assessments by non-GIS experts and potentially enhancing relief efforts. The response to the Haitian disaster was notably swift compared to the 2004 Indian Ocean tsunami,

partly due to the imperative for rapid geospatial assessments during disasters. Initiatives like the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) and private organizations like ESRI Inc. played significant roles in providing mapping support and data for relief efforts in Haiti. The increased cooperation and knowledge gained about geospatial data needs in times of disaster have led to improved data availability, timeliness, and delivery methods for different practitioner communities.

In sum, remote sensing (RS) technology serves as a valuable tool for gathering spatial data that can facilitate various disaster management tasks, particularly when integrated with other spatial data (such as points, lines, and polygons) in a GIS. Satellite imagery plays a crucial role in responding to natural disasters in remote or inaccessible areas, or where primary geospatial data are absent or challenging to obtain. In such areas, satellite imagery often provides the most effective means of acquiring essential information. This is especially evident in numerous developing countries that often lack digital spatial data infrastructures.

2.4.3 Internet GIS

Internet GIS (IGIS), the fusion of GIS and the Internet, has rapidly evolved over the past decade and gained significant attention in the disaster and emergency management sector for two primary reasons. Firstly, GIS enables the centralization and visual representation of critical information pertinent to disasters, as most data requirements are spatial and mappable. Secondly, the Internet offers an ideal platform for diverse users with varying backgrounds and skills to access spatial information and mapping tools. Radke et al. [62] stress that data acquisition and integration are crucial aspects required for emergency and disaster response, both of which can be facilitated by IGIS. During the response phase, immediate access to relevant spatial data and information is paramount for disaster managers, local authorities, aid workers, and the public to make quick and effective decisions following a disaster. Organizations like the Global Disaster Information Network (GDIN) underscore the significance and value of disaster-related information and the necessity to acquire and share it efficiently.

The integration of GIS and the Internet commenced in the early 1990s and has since experienced rapid growth, propelled by advancements in computer and information technology as well as the establishment of spatial data infrastructure (SDI) worldwide. Therefore, it is essential to define and elucidate the capabilities of Internet GIS, explore its implications on disaster management, and assess its potential from the perspective of developing countries.

In this emerging realm of Internet GIS, there exists no consensus on the terminology used to describe GIS-based programs on the Internet. They are commonly known as Internet GIS, web-based GIS, distributed GIS, and On-line GIS, among other terms. Peng and Tsou [63] aid in clarifying these terms and categorizing different types of applications. Henceforth, the term 'Internet GIS' (IGIS) will be employed herein, defined as "network-based geographic information services that utilize wired or wireless Internet protocols to access geographic information, spatial analysis tools, and GIS Web services." It is important to note that although the term GIS is associated with "Internet," IGIS primarily focuses on displaying geographic information in map form and performing data dissemination tasks, often lacking the comprehensive GIS capabilities found in most desktop software. Kraak [64] observes that the majority of IGIS applications currently available are limited to interactive mapping, albeit some offer basic GIS functions such as address matching, proximity searches, and route planning similar to Google Maps. However, recent advancements are enabling the development of Internet distributed GIS services with capabilities to interact with multiple heterogeneous systems and servers supporting more advanced GIS functions, as reflected in the evolving standards for web-based GIS services.

The potential of IGIS in disaster management, particularly during the response phase, where access to spatial information is crucial, is significant [62]. Disasters can profoundly alter landscapes, spanning natural and built environments, often crossing organizational, sociological, political, and geographic boundaries, especially in the aftermath of large-scale disasters. Disseminating information about the disaster zone to stakeholders at local, regional, national, and international levels, both public and private, is essential. Much of this information, such as the locations of devastated towns, supply drop-off points, and intact transportation networks, is spatial in nature. IGIS is well-positioned to meet these information needs by facilitating the integration of diverse spatial datasets and offering accessibility from any location with an Internet connection.

During disaster response, which often operates in an ad-hoc manner involving various people and organizations from local to international levels, access to spatial information relevant to logistical operations is critical. Responding organizations and individual groups of people frequently engage in dynamic and spontaneous actions. While these efforts are encouraged, they could be more effective and better coordinated with enhanced spatial awareness of the disaster zone, facilitated by appropriate spatial information and maps accessed through IGIS-based platforms. Becking [53] emphasizes that developing geographic awareness is vital for understanding

disastrous situations effectively and making appropriate decisions. Traditionally, geographic information has been disseminated using paper maps, which are costly to produce, update, and distribute to all involved parties.

Experience has shown that a top-down approach to data sharing is not entirely effective, as disaster responders often need access to multiple department managers and organizations, each with their own unique maps and data [62] [23]. Identifying which data is available and how to access it efficiently can pose significant challenges. Moreover, this approach often leads to duplicated efforts. For instance, after the Indian Ocean tsunami, numerous agencies created damage maps almost simultaneously [39]. An alternative approach is to leverage existing IGIS architectures to establish a disaster information system with broad accessibility, enabling multiple users to access relevant spatial data and maps provided by various organizations through distributed servers/sources. An intuitive, user-friendly IGIS-based mapping system could enhance geographic awareness among disaster responders, many of whom have limited or no GIS experience but could benefit from accessing spatial information and maps. Andre and Smith [8] observe that disaster responders often require simple cartographic products, such as identifying impassable roads on a road network map, rather than products derived from advanced spatial analysis.

The role of IGIS in gathering and distributing spatial data during recent natural disasters like the Indian Ocean tsunami (2004) and Hurricane Katrina (2005) has been significant. However, it's crucial to interpret the success or failure of IGIS in this context considering its relatively young status. Following these disasters, IGIS platforms were established, integrating various spatial datasets such as coastlines, satellite imagery, damage maps, transportation networks, and population centers to provide a visual overview of the affected regions. Figure 3 displays images of the main interface of two such platforms.

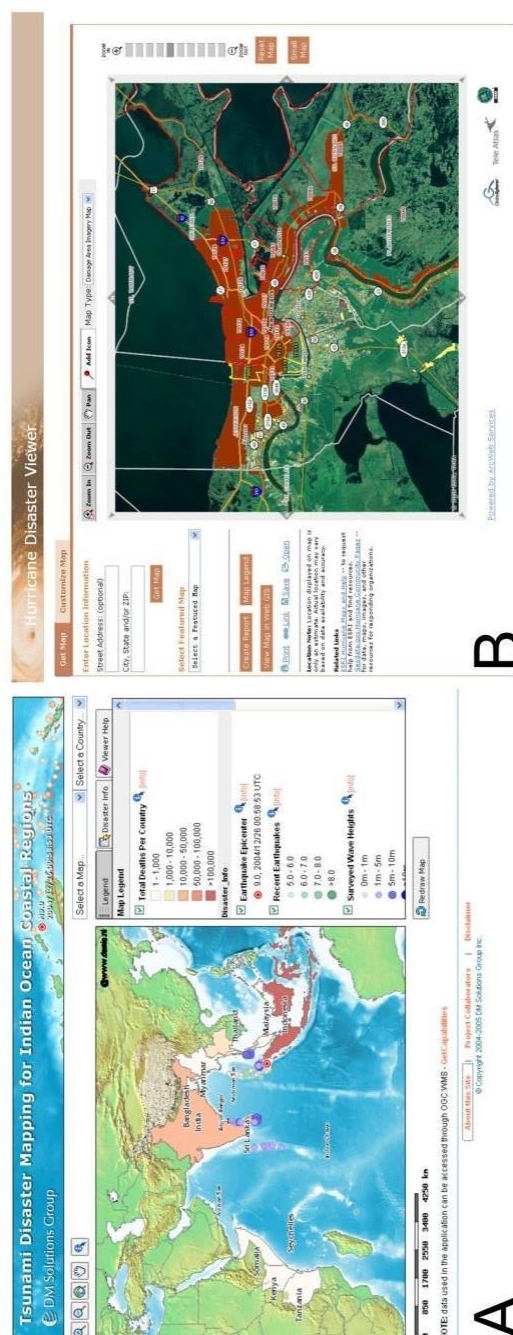


Figure 3: Examples of two IGIS-based natural disaster map viewers: a) South East Asia and Indian Ocean Tsunami Response Map Viewer (produced by DM Solutions Group, <http://www.dmsolutions.ca/showcase/>), and b) Hurricane Katrina Disaster Viewer (produced by ESRI Inc., Redlands California, USA)

While user-friendly map-based systems developed using IGIS can enhance access to relevant spatial information needed during disaster response, their design, development, and implementation demand substantial GIS/technical expertise and significant human and financial resources. However, in many developing countries, each of these requirements poses a challenge, potentially hindering the establishment of IGIS for disaster response. Interestingly, the two known IGIS platforms created to aid the Indian Ocean tsunami response were not developed by any affected developing country. Instead, one was created by a Canadian software development company (DM Solutions Group – <http://www.dmsolutions.ca>), and the other by the Pacific Disaster Center, based in Hawaii. Both possess considerable GIT resources and capabilities, enabling them to establish these IGIS platforms relatively quickly. This underscores the unlikelihood of GIT practitioners in developing countries having the expertise needed to develop an IGIS platform within a reasonable timeframe. Moreover, slow and

unreliable internet connections in many parts of the developing world further diminish the potential for accessing information through IGIS platforms.

Overall, developing an IGIS for disaster response necessitates exceptional GIT skills and substantial spatial data, which may vary in scale and format. Presently, the GIT requirements and skills associated with creating IGIS exceed those of disaster managers in developing countries. Therefore, attempting to implement IGIS may not be the most prudent use of their limited resources.

2.5 Geospatial Information Technology Software

In our examination of geospatial information technology (GIT) in natural disaster management, we have covered various applications and obstacles. However, we are yet to delve into the specifics of GIT software, including the distinctions between commercial and free and open source (FOS) software, and how these differences impact adoption in developing countries. Focusing on this topic, we will now delineate the key disparities between commercial/proprietary software and FOSS, and analyze their implications from the perspective of developing countries. Additionally, we will briefly explore the domain of FOS GIT software. Despite documented drawbacks and challenges associated with FOSS, the potential advantages far outweigh any drawbacks, making FOSS a viable model to consider [65] [66].

2.5.1 Free and Open Source Software (FOSS)

While some argue that "free" and "open source" software are not precisely identical, their similarities are significant enough that, for the purposes of this paper, they are treated as interchangeable. Although there are philosophical and legal distinctions between them, they are largely inconsequential to the average software user [67] [68]. While there are several criteria that a software package must satisfy to qualify as FOSS, three fundamental features encapsulate the essence of the semiofficial "Open Source Definition" (<http://www.opensource.org/docs/osd>):

- *"The source code must be distributed with the software or otherwise made available for no more than the cost of distribution.*
- *Anyone may redistribute the software for free, without royalties or licensing fees to the author.*
- *Anyone can modify the software or derive other software from it, and then redistribute the modified software under the same terms,"* [69].

Licensing agreements like the General Public License (GPL) outline the rights users possess over the software product (<http://www.gnu.org/licenses/gpl.html>). Further insight into the various FOSS licensing models is provided by Wu and Lin [70] as well as Cook and Horobin [71].

What sets FOSS apart from proprietary or commercial software is that the source code is "free." "In this context free means freedom, not necessarily zero price," [69] although most are indeed available at no cost. Free software denotes that users have the liberty to run, view, copy, modify, and distribute the software, regardless of financial constraints. Consequently, users can enhance the source code by improving existing functionality or adding new functions. Conversely, proprietary software denotes ownership and has its source code closed – it cannot be viewed, modified, or redistributed, as stipulated in the EULA (End User License Agreement) that users must agree to before installation. Free, in terms of price, is arguably the most significant attribute of FOSS that distinguishes it from commercial software, which is typically sold for profit. Another characteristic of FOSS is its accessibility (downloadable) from anywhere with an Internet connection; this is generally not the case with commercial/proprietary software. Table 2 delineates some of the key distinctions between proprietary and FOS software products, highlighting their advantages and disadvantages. With certain types of software, including GIT software, there are also notable disparities in functionality and user-friendliness.

Table 2: Key differences between proprietary and FOS software

	Proprietary Software	Free and Open Source Software
Advantages	warranty of developing company on product (holds for every computer) components should work together well documented software regular release times for new versions. regular service packs customization at the API level	no licence fees unrestricted use (e.g., no limits for the number of installations) no update enforcement support of open standards support usually available from several providers customisation at source code level platform independent
Disadvantages	software price and maintenance fees training costs maintenance fees tied to specific licensed companies, software options and time period customised development can be difficult due to available resources of vendors support only as long as software company exists Some limitations on out-of-box functionality where vendor partner's are necessary for upgraded functionality reliance - retraining costs when software versions change (e.g., ESRI's ArcView3.2 to ArcGIS 8.x) or data models change at vendor's whim or development cycle	installation know-how necessary in many cases training costs interoperability issues between FOSS quality (but self-correcting if actively used) no responsible authority support can lack for some packages

The FOSS movement continues to gather momentum, having already garnered significant attention in various sectors. For instance, "Apache dominates the web server market, with over 65% of all active websites using it," [69]. Ramsey [72] attributes its success to a robust user community dedicated to maintaining the Apache platform. Corporate giants like IBM and HP, government agencies, and academic contributors all contribute to the Apache community. Other popular FOSS projects include office suites like OpenOffice, database systems such as MySQL, the Mozilla web browser, and the Linux operating system. As of February 2009, Sourceforge.net, the world's largest open-source software development website, boasted over 230,000 registered projects and over 2,000,000 registered users. In fact, most users can find an application that precisely meets their needs [70]. According to Wheeler [73], who offers quantitative data, FOSS "reliability, performance, scalability, security, and total cost of ownership are at least as good as or better than its proprietary competition, and under certain circumstances are superior," [74]. This evidence suggests that FOSS can, and already does, compete with certain commercial software domains.

While the FOSS model presents compelling arguments, it also comes with commonly cited drawbacks compared to commercial software. A significant challenge in adopting FOSS is the issue of software support and technical assistance. However, FOSS advocates are keen to highlight that support can often be found within the FOSS community, through user groups and "archives of past queries and answers available on the Internet," [31]. Moreover, installation and user documentation are typically available for more established FOSS products [68]. Additionally, "organizations that deploy FOSS freely offer advice to one another, sharing insights and lessons learned," [65], leading to solutions for many common problems being accessible at no cost. In instances where solutions cannot be found, there is a growing FOSS support and custom development industry that can be utilized.

Another concern surrounding FOSS pertains to its long-term sustainability. Fitzgerald [65] notes that "studies of Freshmeat.net and Sourceforge.net (two popular FOSS development websites) revealed that most projects have only one or two developers, and that follow-up studies reported no change in version number or size of code base for many listed projects several months later,". However, this type of analysis of the FOSS domain can be misleading, given the abundance of FOSS projects. It's not unexpected that most projects have only one or two developers, and that new versions are not released regularly, especially if the package serves its purpose adequately. This reflects the nature of the FOSS model, which encourages individuals or small teams to develop and share software. Ultimately, it falls upon potential FOSS users to evaluate individual products, weigh potential advantages and disadvantages, and select what best aligns with their requirements. Câmara and Onsrud [75] examined FOSS GIT and identified numerous differences - in terms of support, maturity, and functionality - between products led by a single individual, products produced by small teams, and corporate-led products. They conclude that corporate-led projects tend to exhibit higher quality, at least from these three perspectives.

2.5.2 Free and Open Source Geospatial Information Technology Software

Shifting our focus to the specific realm of FOS GIT software, there are grounds for optimism. Rather than concerns about its long-term viability, Steiniger and Bocher [68] highlight the growing interest and development of FOS GIT products. They note in their examination of FOS GIS (e.g., gvSIG, Quantum GIS, SAGA, uDig, GRASS, etc.) that:

- a. Four out of ten desktop projects surveyed receive governmental funding support;
- b. There's an uptick in the download rate of FOS GIS software; and
- c. There's a rising number of use cases of FOS GIS.

Moreover, Ramsey [72] underscores that "existing products are now entering a phase of rapid refinement and enhancement... (FOS) software can provide a feature-complete alternative to proprietary software in most system designs." Some commercial software manufacturers are even beginning to support FOS GIT initiatives, which is promising, particularly from a user support and longevity standpoint. In late 2005, the software industry behemoth Autodesk, in collaboration with the MapServer community and DM Solutions Group, announced its support for and promotion of open source web mapping (a form of IGIS) by establishing the MapServer Foundation [76]. "The Foundation is expected to provide a stable infrastructure for the now extended MapServer family's code base and its growing community," [76]. The FOS GIT software community is steadily expanding, and since 2006 has been led by the Open Source Geospatial Foundation (OSGeo) (<http://www.osgeo.org>). "Their mission is to support and promote the collaborative development of open geospatial technologies and data," [77]. The OSGeo hosts a growing number of software projects, publishes the OSGeo journal, established an education and curriculum committee, and organizes the annual Free and Open Source Software for Geospatial (FOSS4G) international conference [68]. The extensive list of links to FOS GIT-related software projects/products available at opensourcegis.org and freegis.org indicates an active development community. Some noteworthy GIT programs, offering a spectrum of functionality from basic data/map viewing to advanced spatial analysis and Internet GIS capabilities, include: Quantum GIS, DIVA-GIS, OpenEV, uDig, gvSIG, GRASS (Geographic Resources Analysis Support System), MapServer, and OSSIM (Open Source Software Image Map). Other programs focus on more specific tasks, such as data management, format processing, geostatistical analysis, and data visualization. Presently, the freegis.org website contains information and links to over 300 FOS GIT projects. Ramsey (2007) presents an excellent review of some of the more mature projects within the FOS GIT software domain, categorized by development/implementation languages, such as C, Java, and .Net. For a deeper dive into current FOS desktop GIS, in terms of organizations, software groups, and functionality, refer to Steiniger and Bocher [68].

3. Geospatial Database Development

A significant portion of the information essential for emergency readiness, response, recovery, and mitigation, which includes resource allocation, relies on geospatial data. Various information technologies are suitable for different stages of the disaster management cycle [78]. Picture a scenario where geospatial data is accessible to all authorized users promptly, with a user-friendly interface [79]. More precisely, technologies need to be developed to facilitate access to information, visually analyze, explore, and make informed decisions. Despite commendable efforts by numerous groups, the approach to delivering information for emergency management often fails to efficiently utilize the wealth of available data housed within various organizations. The availability and capacity of data are not consistently uniform or standardized for emergency managers. Data standards frequently vary, and users are sometimes unaware of data limitations, uncertainties, or presented with conflicting interpretations without means to assess source reliability. All these factors undermine the decision-making process during emergencies. Therefore, there's an urgent need to organize geospatial data and utilize location information to integrate diverse data sources, making them accessible to decision-makers. To enhance mitigation and preparedness for both natural and man-made disasters, there's a concerted effort towards developing and organizing comprehensive geospatial databases. In the spatial realm, the vision includes multiple digitized layers on scales of 1:50000 for the entire country, 1:10000 for multi-hazard prone districts, and 1:2000 for mega-cities, covering hazard zonation, transportation networks, settlements, natural resources, hazardous industries, and resource inventories, among others. While various government agencies have already developed a substantial amount of digital spatial data, it requires collection and compilation. These spatial datasets need dynamic linkage with corresponding non-spatial information such as socio-economic data and infrastructure to enhance decision-making efficiency and objectivity. Integrating geospatial data from diverse sources with varying formats, semantics, precision, and coordinate systems is a critical challenge. Additionally, there's a vision to analyze emergency trends, demographic patterns, economic profiles, infrastructure status, communication networks, and public utilities to facilitate sharing the database for disaster reduction and economic development, particularly in vulnerable areas. For hazard/emergency management, data requirements can be classified into core datasets and hazard/emergency-specific geospatial data. Geospatial data organization for emergency management entails identifying datasets, assessing their availability and gaps, consolidating diverse datasets onto a common platform with standardized protocols, and establishing mechanisms for data access and dissemination during emergency situations.

Core datasets encompass the fundamental information essential for addressing a wide range of emergency scenarios, irrespective of the specific type of emergency. Establishing and structuring these datasets requires adherence to distinct standards. These core datasets need to be developed/organized across three different scales: 1:50,000, 1:10,000, and 1:2000. The datasets at the 1:50,000 scale are utilized for initial assessments and overall planning for mitigation and relief efforts. At the 1:10,000 scale, the datasets are employed in executing relief and rescue operations in areas prone to multiple hazards. For mega cities, datasets at the 1:2000 scale are utilized in the implementation of relief and rescue operations. Hazard-specific datasets may be necessary to address particular emergency situations. These geospatial datasets are tailored to handle specific hazards or emergencies such as cyclones, floods, landslides, earthquakes, fires, structural collapses, etc. The standardization and organization of hazard-specific data play a crucial role in damage assessments, relief efforts, mitigation strategies, and life-saving rescue operations during emergencies. Through brainstorming sessions, a comprehensive list of database elements related to both core and hazard-specific data has been identified to address emergencies stemming from both natural and man-made disasters. Figure 4 illustrates the core and hazard-specific datasets.

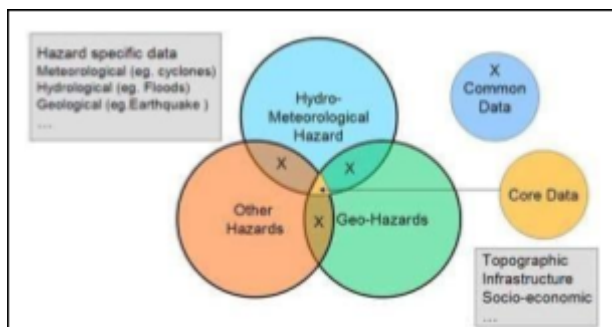


Fig.4: Core and hazard specific data sets.

Additionally, there is a plan to integrate real-time data from various measurement stations such as Automatic Weather Stations, in-situ sensors, etc., in addition to remote-sensing, aerial, and lidar data. Some datasets, like the spatial location of medical facilities, relief shelters, and civil supply warehouses, are currently unavailable and need to be generated using suitable technologies. Moreover, the volume of data to be organized is extensive and challenging to collect physically from diverse sources and convert into the required format for database organization, particularly in a large country like USA. Therefore, it is suggested to utilize web interfaces for data collection and organization wherever feasible.

3.1 Decision Support Tools

Decision support tools play a vital role in emergency management by providing timely information for effective decision-making. When facing threats like floods or cyclones, district officials need immediate access to scientific insights to minimize impacts. However, gathering basic information during an event is often impractical, and necessary data might not be available in the required format. Therefore, there's a crucial need to equip disaster management personnel with tools that facilitate decision-making based on scientific inputs. Spatial Decision Support Systems (SDSS) integrate GIS and Decision Support System technologies to assist decision-makers in spatially relevant problems. They serve as centralized databases accessible online, offering intelligent planning assistance and customizable report generation. Emergency response applications demand real-time data collection, fusion, and ingestion into process models for effective action planning, such as simulating flood scenarios to enhance evacuation preparedness. These tools enable incident managers to track events, predict outcomes, and generate actionable products like damage maps and simulated scenarios. Several such decision support tools have been developed, contributing to a conceptual database organization and service as illustrated in Figure 5.

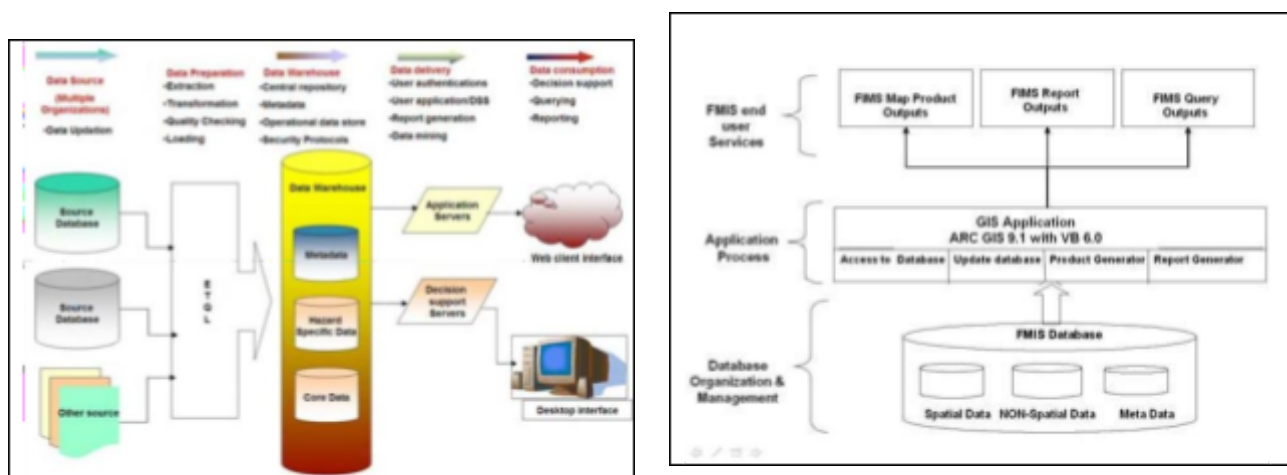


Fig. 5: Conceptual plan of database organisation and service

4. Selected Applications

4.1 Flood Management Information System

Louisiana, particularly areas around New Orleans faces recurrent flooding, prompting the government to establish a Flood Management Information System Cell (FMISC) in collaboration with the National Remote Sensing Agency (NRSA). The aim was to develop an information system to enhance flood management activities. NRSA created an operational Flood Management Information System (FIMS) tailored to the user's needs. FMIS's objectives include organizing data, ensuring secure access, visualization, querying, analysis, and output generation. It features a user-friendly Graphical User Interface (GUI) for easy visualization of the geospatial database and the creation of specific flood-related data products without extensive technical expertise. Developed using Arc Objects 9.1 in Visual Basic 6.0, FMIS operates on Windows OS and follows a desktop architecture with various modules: Data Visualization, Data Update, FMIS Data Products, and Report Tool. The system allows users to load and access datasets, update metadata, and generate standard flood data products like inundation maps and frequency maps. Additionally, a report generation tool creates reports in HTML format based on user inputs. FMIS products can be disseminated in PDF, JPG, and HTML formats through various media, including the internet. The system architecture comprises three main components: Database Organization and Management, Application Processing, and FMIS End-User Services. It utilizes ESRI Geodatabase for spatial data and Microsoft MS Access 2003 for non-spatial data management. FMIS operates in a standalone environment, requiring individual installation on machines with a complete copy of the database. Functional flow and GUI views are depicted in Figures 6 and 7 (a, b, & c), respectively.

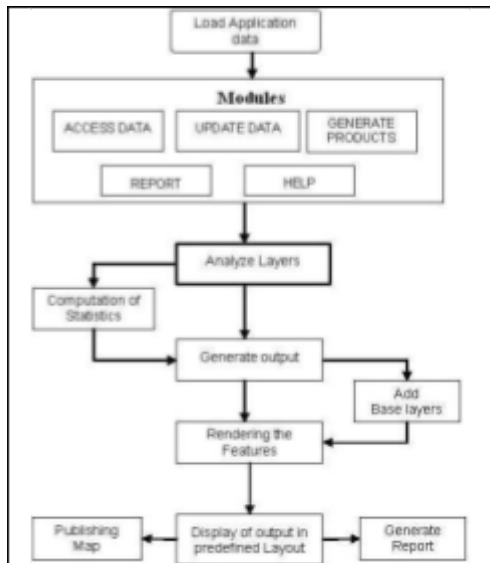


Fig. 6: FMIS Functional flow chart

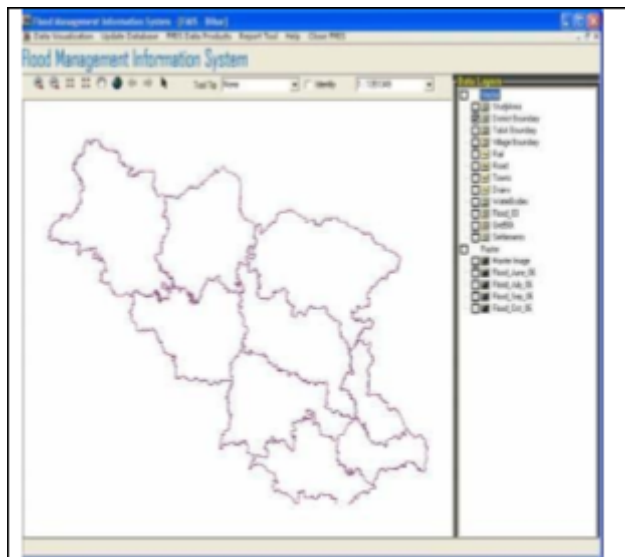
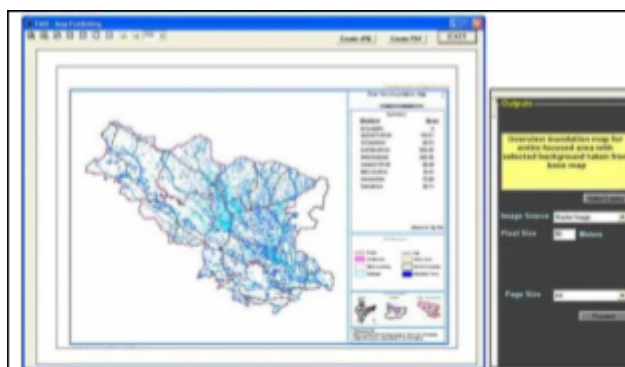


Fig. 7 (a) FIMS data view



4.2 Mobile-Based Applications

Real-time data collection and event monitoring are vital components of emergency management. Technologies such as Global Positioning System (GPS), wireless communication, and mobile computing facilitate the creation of spatial databases with essential attribute data, such as medical facilities and relief shelters. These advancements allow for the integration of geospatial data and location-based services into various applications. With the emergence of lightweight devices like Personal Digital Assistants (PDAs) equipped with GPS and wireless communication, mobile solutions have become ideal for capturing field information, including

photographs and geographic coordinates. A flood relief management prototype mobile application was developed to demonstrate this capability, as illustrated in Figure 8.

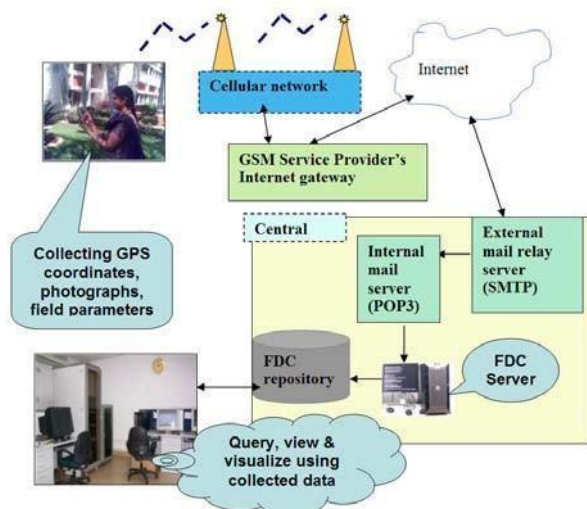


Fig. 8: Architecture of the mobile application.

4.3 Flood Relief Management Application

During flood disasters, relief and rescue operations, including evacuation, setting up relief camps, and providing medical aid, are top priorities. Timely access to reliable information is crucial for managing these activities efficiently. The information required during this phase is extensive and must be obtained quickly. Traditional data collection methods are time-consuming and not cost-effective. The flood management application addresses this challenge by allowing for the rapid collection of essential data from the field and transmitting it to a central server via wireless connectivity. The application includes features for capturing field photographs with location coordinates, facilitating data visualization on map servers. The collected data can then be ingested into databases for further analysis and decision-making support. Figure 9(a & b) illustrates some of the parameters collected through the application.

Parameter	Observations
Meteorological data	
Date	
Rainfall Source	CWC/IMD/State Govt/others(option)
Name of the gauge station-1	
Lat/Long	Lat: Long: Enter value
Accumulated rain	in mm
Rain rate	in mm/hr
Wind speed	in knots
Wind direction	E/W/N/S
Hydrological data	
Date & Time	
Name of the river	
Name of the gauge station	
Present water level	
Time of record	
Forecast level	
Danger level	
Breach of embankment	Yes/No
If Yes,	
Date of breach	
Lat/Long location of the breach	Lat: Long: Enter value
On which river	
Nearby Village/District	
Name of the embankment on which breach has occurred	
Length of the breach	
Flood Inundation details	
A previous year flood map has to be provided to them before readings are recorded	
Name of the district/village	
Affected by which disaster	☐ dropdown menu (Flood, Cyclone, Earthquake, others, specify)
When was it last affected	Date/month/year
When historic floods occurred	Enter year

Fig. 9 (a) list of some the parameters collected through the application

How many villages got affected	
List of villages affected	
What are the worst villages affected	
Did they go relief shelter	Yes/No
If Yes,	
Name of the relief shelter	
For how many days they were in the shelter	
If No,	
How did people in the village cope up	
For how many days flood waters have persisted (remained)	
Damages (Crop)	
What is the area affected	
Is there any crop damage	Yes/No
If Yes,	
What is the name of the crop	
How much is the damage	
Nature of damage	Rain/ standing water/after harvesting/othe
Damages (infrastructure)	
How many roads got affected	
Lat/long position	
Length of the roads	
Nature of damage	Motorable/Repairable/irreparable
Any alternate routes available for access	Yes/NO
If Yes,	
Lat/long position	
Railway	
Extent of damage to the railway	Moderate/ severe/not severe/over topping water
Did the trains stop moving	YES/NO
If Yes, for how many days the restoration took place	
Houses	
No of houses damaged	
Nature of damage	Full/Partial
Any compensation provided	
If so, how much	

Fig. 9 (b) list of some the parameters collected through the application

4.4 Web Application for Identification of Suitable locations for food shelters

It is important to identify suitable locations for detailed field investigation for identification of sites for construction of flood shelters. Basically these shelters are used for rehabilitating the victims of flood disasters. The basic criteria adopted in the development of the application are as follows:

- The location should be accessible through road within 2km.
- It should be located in a village / settlement
- The area should not be affected by an historic flood event
- It should be on a relatively high ground.

In order to meet the requirements, the fundamental database layers consist of the road network, settlement map, historical flood inundation maps, and elevation map. Users should have access to information regarding appropriate shelter locations for their province/districts. To ensure swift and efficient service online, minimal online data processing and integration were maintained. The application tool was developed within the ARC GIS environment. The tool automates the following tasks programmatically:

1. Creation of a 2km buffer zone using the road network, with extraction of villages/settlements within the buffer zone.
2. Consideration of historical flood inundations over the past decade, delineating areas inundated at least once and non-inundated areas.
3. Integration of selected settlements/villages and the road network with the flood inundations to extract non-inundated settlements/villages over the last 10 years.
4. Assignment of elevation data to each settlement.

The above information for selected districts/provinces was generated, and a web service was created for users/clients. A comprehensive web interface was designed, incorporating standard features such as pan, roam, zoom, location inquiry, and map navigation tools. Figure 10 illustrates the application web interface.



Fig. 10: Web Application for identification of suitable locations for flood shelters

The user can access the site via a web browser and choose the desired district from the drop-down menu. The corresponding map displaying suitable flood shelter locations will be presented, along with other topographical features retrieved from the database. Users can select the desired layers on the map and export/print the map at predefined scales. Additionally, a brief report/tabular statement can be generated, showing suitable locations alongside settlement names, geographic coordinates, elevation, and population details.

5. Conclusion

In light of the growing human population and the increasing evidence of climate change, which could worsen meteorological-related natural hazards, there is a growing concern that natural disasters may become more frequent and severe in the future. Therefore, it is imperative to leverage existing technology to reduce vulnerability to natural hazards and enhance preparedness for effective disaster response.

This article has examined the utilization of geospatial data processing in natural disaster management. GIT plays a crucial role in acquiring, interpreting, analyzing, mapping, and disseminating information throughout all phases of the natural disaster management cycle, including mitigation, preparedness, response, and recovery. Since disasters have spatial dimensions, GIT's spatial information and decision support capabilities are closely aligned with disaster management needs. GIT encompasses geographic information systems, remote sensing, global positioning systems, and Internet GIS, providing essential tools for planning mitigation strategies, conducting hazard and risk assessments, assessing vulnerability, managing vehicle dispatch and supply routing, conducting damage assessments, and mobilizing response resources.

However, despite the potential benefits of GIT, several implementation barriers exist, especially at the local administrative level, where robust disaster management initiatives are crucial. These barriers include financial constraints, inadequate spatial data availability, political or institutional instability, and a lack of local GIT knowledge and expertise. Until these barriers are addressed, the ability of GIT to enhance disaster management capacity at the local level will remain limited.

Many researchers have emphasized the significant opportunity that free and open-source software (FOSS) presents for developing countries. FOSS offers various attractive characteristics, including cost-effectiveness, freedom, accessibility, customizability, compatibility, and opportunities for software and technical capacity development. Given the cost challenges associated with proprietary/commercial GIT software, FOSS-based solutions offer a viable alternative, especially for developing countries. The growth of FOSS-based GIT has led to the emergence of mature, user-friendly software products that rival commercial alternatives in functionality. Therefore, FOSS-based GIT products can play a crucial role in improving GIT utilization in developing countries, particularly at the local level, by enhancing local GIT knowledge and skills and facilitating the development of spatial data infrastructures (SDIs) necessary for effective disaster management.

A significant portion of the information essential for emergency preparedness, response, recovery, and mitigation relies on geospatial data. Geospatial models play a crucial role in predicting the locations, impacts, timing, and durations of events, aiding jurisdictions in better preparation. Preparedness goals from a geospatial standpoint involve identifying data needs, creating datasets, and facilitating data sharing among agencies. This includes fundamental tasks like establishing framework data on infrastructure, hazards, risks, and asset locations for response and recovery purposes. Organizing geospatial data and integrating location information from diverse sources to make datasets accessible to decision-makers is imperative. However, integrating geospatial

information from various sources with differing formats, semantics, precision, and coordinate systems presents a significant challenge. Extending data models, query languages, indexes, and algorithms to handle complex geometric objects, particularly those that evolve over time, is essential. Geospatial data and tools should be integral throughout every phase of emergency management, from planning and response to recovery and future event mitigation. To enhance future emergency responses, substantial investments are needed in personnel training, agency coordination, and the sharing of data and tools.

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