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The Potential of Free and Open Source Geospatial Information Technology to Improve Local Level Capacity for Natural Disaster Management in Developing Countries

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THE POTENTIAL OF FREE AND OPEN SOURCE GEOSPATIAL INFORMATION TECHNOLOGY TO IMPROVE LOCAL LEVEL CAPACITY FOR NATURAL DISASTER MANAGEMENT IN DEVELOPING COUNTRIES

By
Sam Herold

A thesis submitted to
the Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the degree of

Master of Science, Geography

Department of Geography
UNIVERSITY OF OTTAWA

Your file Votre référence
ISBN: 978-0-494-58178-0
Our file Notre référence
ISBN: 978-0-494-58178-0

ABSTRACT

Disasters are deadly and destructive events, particularly in developing countries, where there is an immediate need to improve natural disaster management capacity, especially at the local level where hazard vulnerability can most effectively be reduced. Since disasters and vulnerability vary spatially, all phases of the disaster management cycle can be improved through the effective use of geospatial information technology (GIT). However, developing countries face many barriers to GIT implementation, and solutions that take these barriers into consideration are required. In general, developing countries lag behind in terms of technology use, and highly technical solutions are not practical to acquire, use and maintain by the local level disaster management practitioner community. This thesis proposes that free and open source software (FOSS) offers a feasible technical solution, and explores the significance of recent developments in this software domain from a GIT and natural disaster management perspective. Specifically, FOSS-based GIT can provide a core set of functionality for the development of critical framework spatial datasets required for the subsequent use of GIT during all phases of the natural disaster management cycle. Using gvSIG, a mature and user-friendly FOSS-based geographic information system, this thesis demonstrates how local level capacity in developing countries can be improved to ultimately reduce natural hazard vulnerability and disaster impacts.

ACKNOWLEDGEMENTS

This thesis would not have been possible without help and support from many people, not all of whom I can mention here.

First, I would like to gratefully acknowledge the love and support provided by my wife to be, Heather. Your unwavering encouragement will never be forgotten. No matter how discouraged I would get at times you were always able to put things in perspective.

Thanks to my supervisor, Dr. Mike Sawada, for your steady encouragement and confidence in my ability to write this thesis, and for your patience as I pursued my own research interests. I appreciate the advice, support and guidance you have given me over the years and this thesis would not have been possible without your help. You first sparked my interest in geomatics and for that I am forever grateful.

I would like to thank my parents for all the love and support they have given me, not only during graduate studies but throughout the duration of my academics.

I wish to acknowledge all my friends and fellow students who I have had the pleasure of working alongside in the Laboratory for Applied Geomatics and GIS Science (LAGGISS). Thanks to everyone for all the great advise and encouragement regarding my thesis, and for making my time in the lab that much more enjoyable. A special thanks to Zoran Reljic, Andrew Adamowski, Eric Seguin, Dan Cossette, Melanie Zahab, Melanie Carrier, Marian Kremer and Ruibo Han.

Last, but not least, I would like to acknowledge the financial, academic and technical support provided by the University of Ottawa, and in particular the Department of Geography.

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LIST OF ACRONYMS

CRS – Coordinate Reference System

DEM – Digital Elevation Model

EO – Earth Observation

EPSG – European Petroleum Survey Group (a code based coordinate reference system)

ESRI – Environmental Systems Research Institute

FOS – Free and Open Source

FOSS – Free and Open Source Software

GB – Gigabyte

GIS – Geographic Information System

GIT – Geospatial Information Technology

GLCF – Global Land Cover Facility

GPS – Global Positioning System

GRASS – Geographic Resources Analysis Support System

GUI – Graphic User Interface

ICT – Information and Communication Technology

IGIS – Internet Geographic Information System

MB – Megabyte

OS – Operating System

OSSIM – Open Source Software Image Map

RAM – Random Access Memory

RS – Remote Sensing

SDI – Spatial Data Infrastructure

SLWCS – Sri Lanka Wildlife Conservation Society

UN – United Nations

USB – Universal Serial Bus (data storage device)

UTM – Universal Transverse Mercator (map projection)

WGS – World Geodetic System (a coordinate reference system)

CHAPTER I

Introduction

1. INTRODUCTION

Natural meteorological and geological events such as severe storms, floods, earthquakes, volcanic eruptions and landslides have always occurred, threatening only existing flora and fauna. However, today, and as the human population continues to grow, such natural events frequently result in natural disasters. As such, natural events of unusual magnitude are called natural hazards. In fact, human vulnerability to natural hazards is rising, with more people living in low-lying coastal zones, seismically hazardous areas and concentrated urban environments (Burton *et al.*, 1993; El-Masri and Tipple, 2002; Briceño, 2004; Amendola *et al.*, 2008). Despite efforts to reduce the risk caused by natural hazards, such as the designation of the 1990s as the International Decade for Natural Disaster Reduction (IDNDR), the frequency and impact of disasters are expected to increase worldwide (IFRC, 2008).

Compared to developed countries, the impact of natural disasters in developing countries can be especially devastating. About 95% of deaths caused by natural hazards occur in developing countries (Bui *et al.*, 2000), and the loss of GNP due to disasters is 20 times that of developed nations (Alexander, 1995). Natural hazards tend to be more destructive in developing countries because of economic, political, social and cultural factors that increase vulnerability (Guinau *et* al., 2005). In Honduras, for example, Hurricane Mitch (1998) set the country's economic development back 20 years (IFRC, 2001). Natural disasters also jeopardize important social development goals such as addressing poverty, ensuring adequate food, water, and sanitation, and protecting the environment. The particular vulnerability of developing countries to natural disasters underscores the need to develop feasible solutions to reduce vulnerability, and in general improve overall disaster management capacity.

Although natural disasters cannot entirely be prevented, disaster losses (e.g. casualties, economic and environmental) can be minimized with effective disaster management – the process of mitigation, preparation, response and recovery. Geospatial information technology (GIT), and its ability to acquire, interpret, analyze, map and disseminate information, are essential in all areas of natural disaster management. GITs, including geographic information systems (GIS), remote sensing (RS), global positioning systems (GPS) and Internet GIS (IGIS) are currently being employed in a variety of ways to support all phases of disaster management (e.g. Rivereau, 1995; Cutter *et al.*, 2000; Rudyanto *et al.*, 2001; De La Ville *et al.*, 2002; Chen *et al.*, 2005; Köhler *et al.*, 2006; Dewan *et al.*, 2007). Figure 1.1 depicts the disaster management process with examples of relevant requirements/activities that can be assisted or fulfilled with the use of GIT. Since each phase is geographically related to where people, places, and things are spatially located (Gunes and Kovel, 2000), the entire disaster management process can be significantly enhanced through the effective use of GIT. GIT provides the basis for estimating and mapping risk, planning evacuation routes, determining suitable areas for shelters, identifying disaster victims, and assigning resources during recovery, among many other essential tasks (Goodchild, 2006).

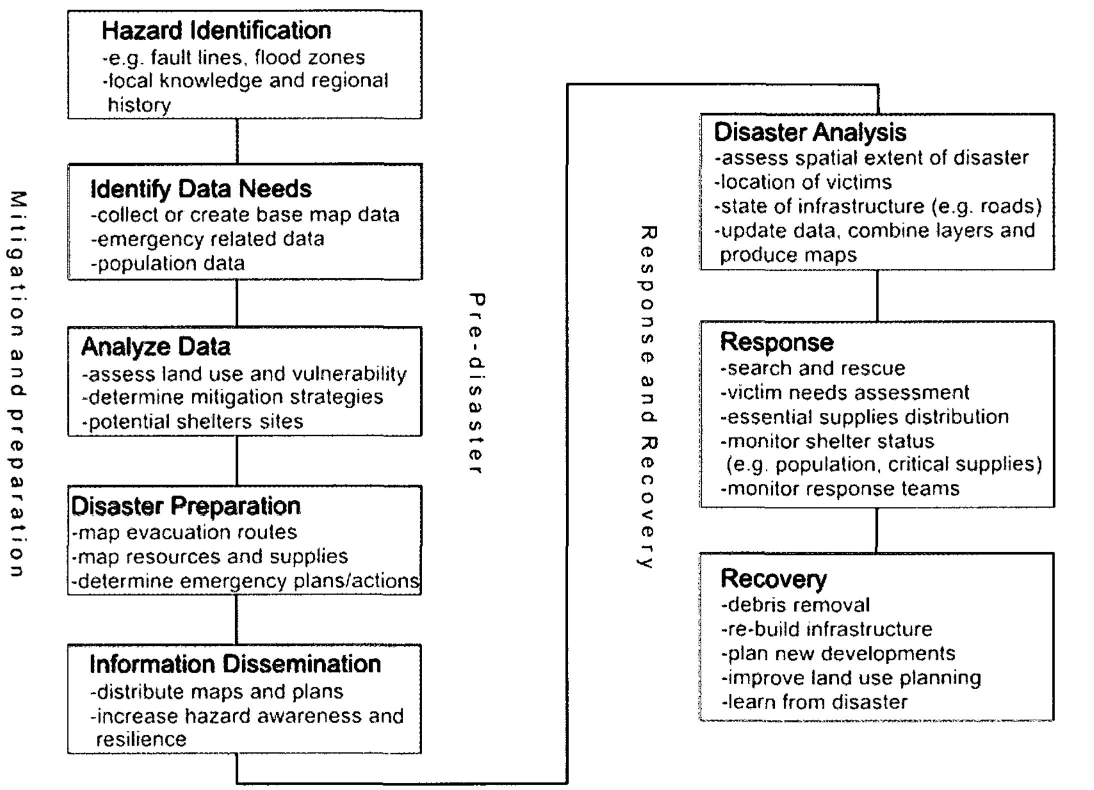

Figure 1.1. Natural disaster management process with examples of relevant requirements/activities that can be assisted or fulfilled with the use of GIT.

The value of GIS in disaster management, for example, arises "directly from the benefits of integrating a technology designed to support spatial decision making into a field with a strong need to address numerous critical spatial decisions" (Cova, 1999). However, for a variety of reasons there are dramatic differences between developed and developing countries in their ability to effectively implement GIT for natural disaster management purposes. These reasons are termed 'GIT implementation barriers', and include: (1) a lack of financial resources, (2) a lack of local expertise/knowledge, (3) institutional/political instability, and (4) a lack of spatial data (Coppock, 1995; Ramasubramanian, 1999; Britton, 2000; Brodnig and Mayer-Schönberger, 2000; Murgia *et al.*, 2002; Mohamed and Plante, 2002; Montoya and Masser, 2005; Pande, 2006; Osti *et al.*, 2008). Given the value of GIT in disaster management, an inability to implement GIT further increases vulnerability, and can exacerbate disasters.

There is no single solution to reduce all GIT implementation barriers in developing countries, and improve overall disaster management capacity. However, increasing attention is being given to free and open source (FOS) software (FOSS), particularly in terms of its ability to reduce software costs, improve computer and technical skills, and help develop local information and communication technology (ICT) knowledge (Rajani *et al.*, 2003; Hoe, 2006). Moreover, recent growth in the FOS GIT software domain is encouraging. For example, in terms of FOS GIS, Steiniger and Bocher (2008) emphasize the increasing interest and development of products, and Ramsey (2007) provides evidence that currently available FOS GIS offer feature-complete alternatives to proprietary software in most system designs. The comprehensive list of links to FOS GIT related software projects/products available at opensourcegis.org and freegis.org provides evidence of an active development community.

1.1. Research Design

The research undertaken in this thesis, and its design, is largely influenced by Wellar's (2005) paper titled "Significant Advances in Applied Geography from Combining Curiosity-Driven and Client-Driven Research Methodologies." It suggests that the most significant achievements in applied geography occur when curiosity-driven and client-driven research methodologies are combined. Tables 1.1 to 1.4, reproduced from Wellar (2005), are illustrative of the main differences between client-driven and curiosity-driven research domains, from the conceptualization of the research problem to assessing the research findings.

Table 1.1. Relating Client-Driven and Curiosity-Driven Research Domains: Some Basic Implications (1) (reproduced from Wellar, 2005).

Research Feature + Implication	Research Domain	
	Curiosity-Driven	**Client-Driven**
Source of Research Problem or Question	Derived from or prompted by the literature, personal experience, consultations, conversations, reflections, presentations, or (out of) "the blue".	Provided or specified by the person, agency, firm, or group needing an answer to a question or a solution to a problem.
+ Implication	Task of identifying significant, original problem or question invites encounter with unknowns and uncertainties in the search for truth; mind-expanding.	Task of understanding and addressing stated research problem or question requires getting into the head of the client (person, agency, firm, group): mind-focusing.

Table 1.2. Relating Client-Driven and Curiosity-Driven Research Domains: Some Basic Implications (2) (reproduced from Wellar, 2005).

Research Feature + Implication	Research Realm	
	Curiosity-Driven	**Client-Driven**
Execution of Research Project	Performed in accordance with conventions, regulations, etc., of associations, universities, departments, supervisors, etc., with an interest in how the yield from curiosity-based research is achieved.	Performed in accordance with the terms of reference, schedules, budgets, benchmarks, expectations set by the person, agency, firm or group that contracted for the research.
+ Implication	Allows and promotes shopping around in the search for best deals, lines of least resistance, best track records, opportunities to leverage, network, likelihood to get published, promoted, etc.	Requires attention to detail regarding documentation, procedures, protocols, precedents, agreements, specifics of deliverables and delivery mechanisms, liabilities, guarantees, remedial measures.

Table 1.3. Relating Client-Driven and Curiosity-Driven Research Domains: Some Basic Implications (3) (reproduced from Wellar, 2005).

Research Feature + Implication	Research Realm	
	Curiosity-Driven	**Client-Driven**
Research Report Recipient(s)	So-called "interested readers" usually are not known at start of project, may become known months, years or decades later if work is published and readers and beneficiaries identify selves via citations, correspondence, public pronouncements.	Sponsor of the project, and whoever or whatever the sponsor specifies as a recipient(s) of the research report.
+ Implication	Exposure to the openness, fluidity, competition, etc., of idea generation, circulation, and adoption-rejection.	Exposure to the need to have due regard for the output demand of the project sponsor.

Table 1.4. Relating Client-Driven and Curiosity-Driven Research Domains: Some Basic Implications (4) (reproduced from Wellar, 2005)

Research Feature + Implication	Research Realm	
	Curiosity-Driven	**Client-Driven**
Criteria for Assessing Value of the Research Finding + Implication	Emphasis is on adding to knowledge or ways and means of continuing to add knowledge, concerns about hypotheses and theories, validity, reproducibility, generalizability, etc.	Emphasis is on solving a known problem, answering a specific question for such purposes as improving operations, decreasing negative externalities, increasing benefits, decreasing costs, doing more with less, etc.
	Learning about the thoughts and thinking behind deeds and doing in ways that appeal to your preferences and abilities.	Learning about applying thoughts and thinking to deeds and doing in ways that are specified by the firm that retained your services.

The research undertaken here appears to be among the relatively few Master's level thesis that combine curiosity-driven and client-driven research approaches. The curiosity component is based on the hypothesis that free and open source software now provide a viable alternative to proprietary GIT software. The client component is founded with regard to the constraints and operational requirements of the disaster management practitioner communities that exist in developing countries (this group is the theoretical client).

Too often research on the application of GIT for natural disaster management fails to take into consideration the constraints and working environments of actual disaster managers (Cutter, 2003), who will only benefit from such research if it is accessible and if the methods and techniques can be realistically applied. Without regard for the operational requirements and constraints of the practitioner community, curiosity-driven research will only accidentally at best meet the needs of actual disaster managers and related personnel. Therefore, the work done by Wellar (2005) greatly helped structure the design of this research, and provided guidelines to ensure that both curiosity-driven and client-driven perspectives were considered in this thesis.

1.2. Thesis Motivation and Research Objectives

The primary motivation for this work is the growing indication/recognition that free and open source geospatial information technology (FOS GIT) can now provide viable alternatives to commercial GIT software. As was demonstrated in the introduction, GIT are fundamental during all phases of natural disaster management. Thus, FOS GIT offers considerable potential to improve natural disaster management capacity in developing countries, especially at the local level where GIT implementation barriers are most evident. Since disaster vulnerability is highly linked with overall community development practices, FOS GIS is seen as a technology that could also be used to improve resource management, landuse decisions and guide development patterns in a way that will ultimately reduce disaster vulnerability.

Additionally, FOSS are an excellent education and training tool that can be used to improve local knowledge of GIT, and to help develop the technical skill sets required for their successful application. In fact, building local technological and institutional capacity was identified at the 2005 World Conference on Disaster Reduction as one of the most important steps for developing countries to reduce disaster vulnerability, with specific reference to space technologies and geographic information systems (UN/ISDR, 2005). Furthermore, there is a pressing need to test simple and low cost methods that can improve disaster management capacity, methods which can be adapted to and immediately used by disaster management practitioners with a low level of specialization (Guinau *et al.*, 2005). We propose that currently available FOS GIT, and in particular FOS GIS, can help fulfill this need.

The primary objective of this thesis is to (1) determine and (2) demonstrate how currently available free and open source geospatial information technology software can be implemented at the local level in developing countries to improve natural disaster management capacity. The CENTRAL RESEARCH QUESTION underlying this objective is:

> **What currently available FOS GIT functionality exists that can be feasibly implemented by local level GIT practitioners in developing countries to improve disaster management capacity?**

The answer to this question is fundamental for the reduction of natural hazard vulnerability, and ultimately to the lessening of devastating impacts caused by natural disasters in developing countries.

To *determine how* currently available FOS GIT can be implemented at the local level in developing countries to improve natural disaster management capacity first requires a literature review that integrates the three research domains that can be seen in Figure 1.2. This review examines natural hazards and disasters, explores the concept of hazard vulnerability from a developing country perspective, describes the role of GIT in disaster management, and highlights and great potential that FOS GIT provide for developing countries. One finding of this review is that FOS GIT provides an effective alternative to proprietary GIT software for the creation/development of critical spatial datasets required to improve disaster management capacity at the local scale in developing countries, where data quantity and quality are a significant GIT implementation barrier.

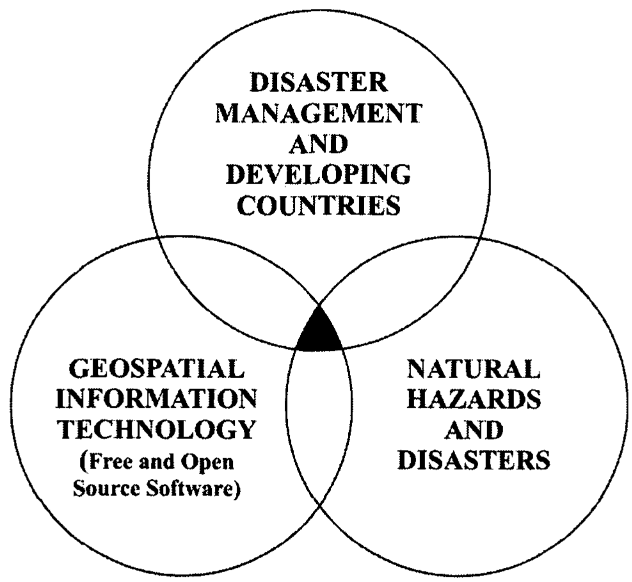

Figure 1.2. Venn diagram of the research domains that indicate the focal area of this thesis project.

The findings and conclusions drawn from the review paper are instrumental in answering the central research question and form the basis for the development of the second paper contained in this thesis. The second paper addresses the second objective of this thesis, which is to *demonstrate how* currently available FOS GIT can be implemented at the local level in developing countries to improve natural disaster management capacity. To successfully use GIT requires an adequate spatial data infrastructure (SDI) consisting of the type of data required for the effective application of GIT for disaster management purposes. Upon developing a set of what is termed 'framework spatial datasets' that are appropriate for local level use, it is subsequently demonstrated how these data can be created relatively easily using well-established methods and techniques supported by FOS GIS. Specifically, the demonstration is undertaken using Sri Lanka as a study area, a developing country that has experienced numerous natural disasters, and a FOS GIS called gvSIG. We illustrate the potential of gvSIG by demonstrating specific workflows, with screen shot examples, which can be used to create many of the framework datasets required to improve disaster management capacity at the local level in developing countries.

1.3. THESIS STRUCTURE

This thesis consists of four separate chapters and one appendix. Chapter I provides an introduction to this thesis and Chapters II and III can be read separately, as they are each independent manuscripts to be submitted to a refereed scientific journal. Chapter IV contains conclusions and recommendations for future research. Appendix I consists of a paper submitted at the 98th Annual Conference of the Canadian Institute of Geomatics, and does not directly relate to the objectives of this thesis but is thematically similar. The paper in Appendix I reflects the objectives of the initial research proposal for this thesis, which have since been modified based on conclusions drawn from the review paper that comprises Chapter II.

Chapter II is a detailed review of the application of geospatial information technology in the field of natural disaster management, with a focus on developing country perspectives. The review begins by exploring aspects of natural hazards, disasters and developing countries, with an emphasis on vulnerability issues and GIT implementation barriers. The broad use and role of GIT in natural disaster management is then reviewed. Also included in this review is an examination of the free and open source software model, GIT-based FOSS developments and related considerations for increasing local level GIT use in order to strengthen natural disaster management capacity in developing countries.

Chapter III is a direct result of the findings obtained in Chapter II. This paper demonstrates the current capabilities of FOS GIS and related functionality required for the development of spatial data needed to improve disaster management capacity at the local level in developing countries. Specifically, we describe how gvSIG, a FOS GIS, can be used for on-screen digitizing, editing/modifying existing spatial data, image/pixel classification, and for incorporating data collected using handheld GPS receivers. These methods are shown to be feasible for local level disaster management practitioners in developing countries to implement.

The overall significance of this thesis is in its offering of clear and concise pathways for FOS GIT use in developing countries with specific conceptual recommendations backed up with specific software capabilities. The research in this thesis is by necessity exploratory but represents a body of work that can not be found anywhere within the learned literature. FOS GIT is a very new field of study with capabilities existing for less than a half-decade. Only recently has FOS GIT been reviewed in the open literature and further research is required in all areas of its application.

As the author of the thesis I undertook the primary research and writing of all chapters. Critical discussions, editing and conceptualizations were made by my supervisor Dr. Michael Sawada. We received support for the development of the paper comprising Chapter III from Mr. Chandeep Corea, head of the GIS department of the Sri Lanka Wildlife Conservation Society (SLWCS[1]), who provided important data that was used and insight related to the use of GIT from a developing country perspective. Mr. Corea has made an invaluable contribution to this project, and will be offered a co-authorship on this paper upon the defence of this thesis. Discussion and contributions of committee members will be acknowledged through appropriate means either subsequent to or after the defence of the thesis itself.

[1] See http://gis.slwcs.org/

1.4. REFERENCES

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CHAPTER II

A Review of Geospatial Information Technology for Natural Disaster Management in Developing Countries

2.1. INTRODUCTION

Although the United Nations designated the 1990's as the International Decade for Natural Disaster Reduction (IDNDR), there was a global failure to reduce natural disaster impacts during that time (IFRC, 2001). Ultimately contributing to this trend are environmental degradation, rapid urbanization and social marginalization (McEntire, 1999), particularly in developing countries. The increasing number of disasters suggests that vulnerability to natural hazards is also rising and so equates to changing the geography of risk. By way of elaboration, more people are living in low-lying coastal zones, seismically hazardous areas and concentrated urban environments (Burton *et al.*, 1993; El-Masri and Tipple, 2002; Briceño, 2004; Amendola *et al.*, 2008). Vulnerable populations will be at increased risk, for example, as the geography and magnitude of hydrometerological hazards that are historically associated with some of the greatest disasters (Kondratyev *et al.*, 2002) change with global climate (Smith, 2004; IPCC, 2007). Defining the geography of risk is of a major concern in general and in particular in developing countries, where disasters jeopardize important social development goals such as addressing poverty, ensuring adequate food, water, and sanitation, and protecting the environment. Because natural disasters have the greatest overall impact in developing countries (Alexander, 1995; Bui *et al.*, 2000; IFRC, 2001), this is where geospatial information technologies (GIT) have the greatest potential to mitigate causalities.

The purpose of this paper is to examine the use of GIT for natural disaster management, with an emphasis on how these technologies can be effectively utilized at the local level in developing countries. Although natural disasters cannot entirely be prevented, disaster losses (including human, environmental and infrastructure/personal property) can be minimized with effective disaster management – the process of mitigation, preparation, response and recovery. The field of disaster management has greatly benefited from recent advancements in computers and related information technologies. Geospatial information technologies (GIT), including geographic information systems (GIS), remote sensing (RS), global positioning systems (GPS) and Internet GIS (IGIS) are currently being employed in a variety of ways to support all phases of disaster management. Since each phase is geographically related to where people, places, and things are spatially located (Gunes and Kovel, 2000), the entire disaster management process can be significantly enhanced through the effective use of GIT (Goodchild, 2006). Even though the natural processes (e.g. floods, earthquakes, landslides, etc.) that generate disasters might be fundamentally different, the techniques to assess and mitigate risk, evaluate preparedness, and assist response have much in common and can share and benefit from advances in geographic information science (GIScience) (e.g., data acquisition and integration; issues of data ownership, access, and liability; and interoperability) (Radke *et al*, 2000). We propose that currently available free and open source software (FOSS) can fulfil many GIT requirements needed to improve disaster management capacity at the local level. While FOSS can create additional challenges compared to commercial solutions (Camara and Onsrud, 2004), with a clear understanding of the barriers and benefits of FOSS from a developing world perspective, FOSS is a capable and effective alternative.

In the first section of this review, we begin by laying a set of brief contextual explanations and definitions of natural hazards and disasters while emphasizing their spatial components, and then describe some of the factors that differentiate developed and developing countries from a natural disaster vulnerability standpoint. Included in this section is a more detailed examination of the most commonly cited GIT implementation barriers faced by developing countries. This is followed by a brief review of the phases that comprise the disaster management cycle. In the next section, which forms the bulk of this paper, we review the extensive literature that describes and explores the many uses of GIT in the field of natural disaster management. We then examine GIT-based FOSS, highlighting its potential as well as limitations in terms of its ability to fulfil disaster management related requirements. Finally, we discuss and describe our vision of how FOSS can greatly improve the ability of local level disaster managers to implement GIT, and thus improve overall disaster management capacity and reduce vulnerability to natural hazards.

2.2. BACKGROUND

2.2.1 Natural hazards and disasters: an overview

To provide context for the pursuant issues, it is pertinent here to provide a brief overview of the relation between a natural hazard and a natural disaster. Natural hazards vary greatly in terms of frequency, duration, scale, impact, etc., and these differences partly determine the spatial data and technology needed to effectively mitigate, prepare for, respond to and recover from potential disasters that may result from their occurrence.

Simply put, *natural hazards* are unpredictable acts of nature, characterized by extremes in physical processes (Zerger and Smith, 2003). Examples of natural hazards include earthquakes, tsunamis, hurricanes, typhoons, droughts, wildfires, tropical storms and floods. The fundamental determinants of natural hazards are location, timing, magnitude and frequency (Alexander, 2000). The spatial scale and duration of natural hazards can vary greatly, which is important from a GIT perspective, and in particular from a data requirements perspective. Landslides, for example, have a local impact, whereas major floods can affect a large region. Earthquakes occur with little warning and last only a few seconds to minutes, while a drought may build up over a period of months over large regions and last even longer. Thus, a distinction can be made between "rapid-onset" natural hazards such as floods and earthquakes, or slower 'creeping crises' hazards like drought or disease (De Paratesi, 1989). However, Coppock (1995) points out that slowly developing hazards have more in common with natural resource management, at least from a mitigation perspective

McEntire (2001) describes *natural disasters* as the disruptive and/or deadly and destructive outcome of triggering agents when they interact with, and are exacerbated by, various forms of vulnerability. Simply put, when a hazard intersects the zone of human use there is the risk of disaster. The number of people affected by disasters resulting from natural hazard events of rapid-onset is increasing (Oloruntoba, 2005). In particular, hydrometeorological related natural disasters (i.e. floods, landslides/avalanches, forest/scrub fires, wind storms and waves/surges) have more than doubled since 1996 and caused over 90 percent of deaths from natural disasters during the 1990's (IFRC, 2001). *Herein, our main focus is on the role of GIT for mitigation of rapid-onset natural hazards that cause the risk of natural disaster.*

Large-scale disasters represent a complex and multidisciplinary problem for local disaster managers and related organizations, as well as International humanitarian/aid organizations. While many natural disasters are characterized by short reaction/response times, overwhelming damage to property and infrastructure, and a strain on the resources of the affected community, those less frequent large-scale natural disasters are much more deadly. Among the largest-scale globally predominant natural disasters with 50,000 victims or more, three hazard types can be singled out: earthquakes, tropical cyclones (with coastal inundation), and river floods (Kondratyev *et al.*, 2002). These types of natural hazards have caused the worst calamities both in the 20th century and the entire history of mankind, namely: the 1970 flood and cyclone in Bangladesh (300,000 victims), the 1976 earthquake in China (242,000 victims), and the 1931 flood in China (140,000 victims). The 2004 earthquake that occurred off the coast of Sumatra, Indonesia, and resulting tsunami that devastated many countries surrounding the Indian Ocean also ranks among the deadliest natural disasters in history, with 283,000 reported fatalities (Lay *et al.*, 2005).

2.2.2 Disaster vulnerability: developed vs. developing countries

Although natural hazards pose a considerable threat to all countries, historically, developing countries have been disproportionately affected (Briceño, 2004). About 95% of deaths caused by natural hazards occur in developing countries (Bui *et al.*, 2000), and the loss of GNP due to disasters is 20 times that of developed nations (Alexander, 1995). These alarming statistics cannot be attributed to a greater frequency of natural hazards in the developing world, but can be partly explained by differences in natural hazard vulnerability. The concept of vulnerability is complex – it depends on a number of parameters – and varies depending on the research orientation and perspective (for example, see Cutter, 1996; Morrow, 1999; Cutter *et al.*, 2000; Weichselgartner, 2001; McEntire, 2001 and Cutter *et al.*, 2003). Thus, there is no single accepted way to assess natural hazard vulnerability (Simpson and Human, 2008). However, regardless of how it is conceptualized or assessed, history shows that developing countries are more vulnerable to natural hazards than developed countries, and as a result experience a greater number of natural disasters.

Although location and proximity to natural hazards is certainly an important factor, many researchers propose that the scale of disaster impact is more a function of human vulnerability rather than of the physical magnitude of the hazard (Hewitt, 1995; Quarantelli, 1998; Smith, 2001). In this sense, natural disasters can more accurately be seen as social phenomenon, where the overall damage due to natural hazards is the result of both natural events that act as "triggers", and a series of societal factors (McEntire, 2001; Weichselgartner, 2001). Conceptualizing vulnerability in terms of societal factors as opposed to biophysical factors helps to explain the wide range of human impact that can result from events of comparable magnitude. For example, Montoya and Masser (2005) point out that the 1988 Spitak earthquake in Armenia (former USSR) and the 1989 Loma Prieta earthquake in California were of similar magnitude and affected populations of comparable size; however, the Armenian event killed 25,000 people whereas the California earthquake killed 63. Hurricanes Hugo in 1989 and Andrew in 1992 caused less than 50 deaths each in the U.S. On the other hand, cyclones in Bangladesh killed over half a million people in 1970 and another 140,000 in 1991 (Bui *et al.*, 2000). Clearly, the extent of human (or societal) vulnerability is a major factor that contributes to determining the scale of a disaster, but why are people in developing countries so vulnerable?

The vulnerability of a geographic area is determined by its natural and man-made environmental conditions, climatic patterns, and its political, social and economic ability to withstand and respond to natural hazard events (Jayaraman *et al.*, 1997). Hazards tend to be more destructive in developing countries where political, social and economic instability lead to poor organizational infrastructure and no adaptive capacity as compared to most developed countries. Henderson (2004), in examining the pervasive risk of natural disaster faced by developing countries, emphasizes that conditions of poverty, poor housing, lack of information about disaster risk, poor telecommunications, and inadequate physical infrastructure frequently exacerbate natural disasters. Insufficient disaster management resources, the absence of enforced laws and the shortage of trained experts all increase the difficulty in coping with natural disasters (Guinau *et al.*, 2005). For example, the high cost and skills required for the application of GIS technology has hindered its utilization for disaster management in developing countries (Rudyanto *et al.*, 2001). The lack of ability to effectively utilize relevant technology is a societal factor that contributes to increasing disaster vulnerability.

Developed countries have a greater awareness and understanding of the importance of natural disaster management. Bui *et al.* (2000) point out that they invest more in mitigation and prevention, and have more resources available to enforce legislation that may help reduce human vulnerability. In developed countries, insurance absorbs more than half of the economic losses from natural disasters, in contrast, less than 2% of the losses are insured in developing countries (Freeman and Pflug, 2003). However, as a general trend, in both developed and developing nations, disaster management becomes a more pressing concern only after the disaster has struck (Currion *et al.*, 2007). Perhaps the devastating impact of recent disasters, such as the Indian Ocean tsunami (2004) and Hurricane Katrina (2005), will encourage disaster managers in both the developed and developing world to focus more on mitigation and preparation, rather than response and recovery.

There are many factors that contribute to determining disaster vulnerability, and it is not our intention to discuss them all, but rather to demonstrate that the concept is pervasive within the disaster management literature, particularly from a developing countries perspective. In addition, since many of the factors that determine vulnerability vary spatially, vulnerability is well suited to be assessed using GIT. For example, McEntire (2001) considers vulnerability to be the dependent component of disaster that is determined by the degree of risk, susceptibility, resistance and resilience. Risk is created as a result of proximity to potential hazards, which varies spatially; resistance refers to the ability of buildings and the infrastructure to resist the strain exerted by natural hazards, which also varies from one area to another depending on building design, building codes and the materials used, among other factors. Susceptibility, which is a product of social, political, economic and cultural forces that determine the proneness of groups and individuals to be adversely affected by disasters, can also be analyzed in spatial terms. For example, characteristics such as age, gender, race and socioeconomic status are generally accepted to be influential components of social vulnerability (Cutter *et al.*, 2003), and these characteristics have a high degree of spatial variability, particularly within large urban areas. Such characteristics are typically captured in a census, and this information can be analyzed and mapped at varying scales using GIT, such as GIS.

Considering that assessing and understanding hazard vulnerability is a key component of disaster management, and that vulnerability varies spatially, it is well suited to be analyzed using GIT. Therefore, GIT must play a key role in any comprehensive and effective disaster management strategy, yet there are dramatic differences in GIT use between developed and developing countries. While each developing country is unique, there exists a common set of well-identified barriers that often limit the use of such technology, thus increasing vulnerability to natural disaster. These common barriers include:

1. *A lack of financial resources*

   Generally, using geospatial technology is not cheap, and requires a substantial investment in computer software/hardware, spatial data, and human resources (education and training). In many cases disaster management responsibilities and duties are decentralized to local governments without being accompanied by the necessary funds (Montoya and Masser, 2005). Considering that local governments have to provide many essential services (e.g. health, education and infrastructure services such as water, electricity and sewage, to name a few), they are often not predisposed to purchasing off-the-shelf commercial GIS software due to other demands for funding (Renyi and Nan, 2002). It is difficult to justify spending limited budgets on technology to enhance disaster mitigation and preparation when other more basic and fundamental societal issues remain unresolved. In addition, without the ability to purchase or collect the necessary data, software alone has no benefits. Thus, limited finances are a major barrier to the implementation of GIT in many developing countries. If GIT is going to play a role in local level natural disaster management financially feasible solutions are required such as FOSS.

2. *A lack of local expertise/knowledge (human/technical resources)*

   To effectively use GIT requires considerable technical knowledge and skills, typically obtained through education and training, as well as practical experience. Mohamed and Plante (2002) emphasize the lack of local expertise and capacity to operate and maintain a GIS as a major barrier in developing countries. Similarly, Murgia *et al.* (2002) point out that local level managers in developing countries are "hardly aware of the possibilities of GIS." In contrast, in most developed countries, there are established GIT communities that have been built up over time. Such communities are an important resource for individual practitioners to acquire new knowledge, methods or techniques, discuss ideas and/or obtain support. In some developing countries, the next closest practitioner may be hundreds of kilometres away or in another country, and not available via the Internet or telephone (Britton, 2000). This suggests that local disaster management organizations would experience difficulty in trying to find local personnel who could effectively manage the various GIT components/aspects of a holistic natural disaster management strategy. When GIT has been implemented at the local level in developing countries it is often the result of externally sponsored/funded technology development programs, rather than through the gradual building of local GIT capacity (Britton, 2000). Local workforce development and capacity building projects are essential for sustained GIT implementation and maintenance that does not rely on external support or funding.

3. *Institutional/political instability*

   Disaster management is dependent on the functional and effective operation of institutions, whether formal or informal, and at the local level where it matters most (Pande, 2006). The effectiveness of GIT and the ability to convert information into action also depends on the existence of supporting organisations, which are generally lacking in developing countries (Coppock, 1995). Political barriers have also been cited as obstacles to local level GIT use (Montoya and Masser, 2005). High resolution census data, for example, contains a wealth of information that could be utilized in a variety of GIT-based natural disaster management related applications (e.g. vulnerability assessment, risk mapping, evacuation planning, response prioritization, etc.), yet this data is inaccessible in some developing countries for security reasons. Furthermore, governments in developing countries can be unstable, and political terms can be short. According to Murgia *et al.* (2002) politicians have their own circle of supporters who will be appointed in public institutions, and thus political instability is expanded to institutional instability. Considering institutional instability, Ramasubramanian (1999) suggests that GIS implementation in developing countries is likely to be more successful if it relies on the capacity of empowered individuals and groups rather than solely on organisational structures.

4. *A lack of spatial data*

   Accurate and comprehensive spatial data play a critical role in all phases of disaster management, and are required for effective GIT use, yet in many developing countries reliable spatial data are a scarce resource (ESRI, 2006; Dewan *et al.*, 2007a). Murgia *et* al. (2002) suggest part of the problem is weak national data providers such as mapping agencies, census organizations and cadastres, and that many projects that have been initiated are stand-alone and lack continuity due to a lack of funding, are not embedded in stable institutions or are politically misused. Also, governments in developing countries tend to have a very conservative approach in terms of data and information management (Shrestha, 1994). For example, among the most common obstacles to be found in Asia are official restrictions on geospatial data for security reasons as well as the rigidity and compartmentalization of government bureaucracies, which consider certain types of information as their property (Brodnig and Mayer-Schönberger, 2000). In Costa Rica, for example, there is restricted access to census tract level data (Montoya and Masser, 2005). Additional factors that contribute to the lack of spatial data include: (1) the remoteness of many areas; (2) the lack of technical capacities to collect and assess bio-physical and socio-economic data; and (3) competing priorities in the fledging economies (Shrestha, 1994; Brodnig and Mayer-Schönberger, 2000). Montoya and Masser (2005) emphasize the need to identify or develop cost-effective data collection methods for producing spatially referenced information in developing countries. The role of spatial data in all areas of natural disaster management cannot be underestimated; in fact, Mansourian *et al.* (2004) propose the development of a spatial data infrastructure (SDI) as a framework to facilitate disaster management.

Aside from the barriers to GIT implementation just described, Ramasubramanian (1999) also identifies cultural and language barriers in terms of GIS implementation in developing countries (for more on specific GIS implementation issues in developing countries see Ramasubramanian (1999)). Given the aforementioned barriers, disaster managers in developing countries are unable to utilize GIT in the same ways as developing countries, which in effect, further increases their vulnerability to natural disasters. However, recent growth in the domain of free and open source software (FOSS), and in particular GIT-based FOSS, provides new opportunities that were previously unavailable. For example, the cost alone of commercial GIT software (such as GIS) can prevent it from being used at the local level in developing countries (Ranyi and Nan, 2002); with FOSS, the issue of cost is eliminated. For this reason, and others that will be described later in this paper, FOSS is increasingly being recognized within the disaster management literature as a good fit for developing countries.

2.2.3 Disaster management and the role of GIT

Disaster management can be understood as a cycle (Figure 2.1) which includes an effort to mitigate against, prepare for, respond to, and recover from a disaster (Montoya, 2002). The core components of this cycle are also commonly referred to within the emergency management literature (e.g. Cutter, 2003), and often in conjunction with natural disasters (Cova, 1999). Thus, emergency and disaster management are closely linked; after all, a disaster clearly constitutes an emergency, but in this paper it will be referred to as the disaster management cycle.

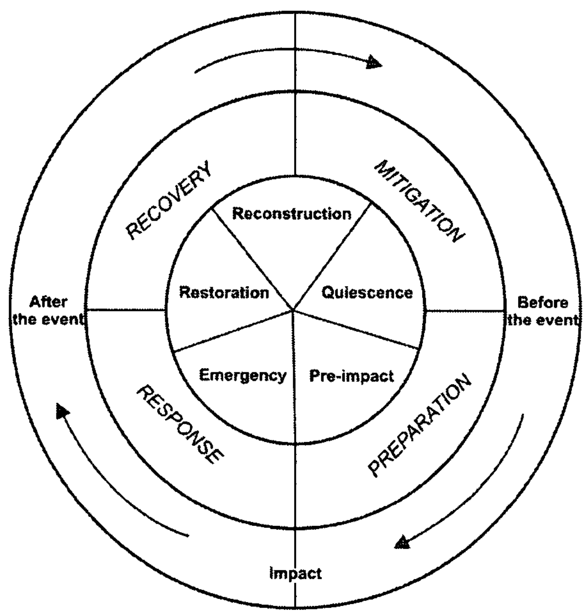
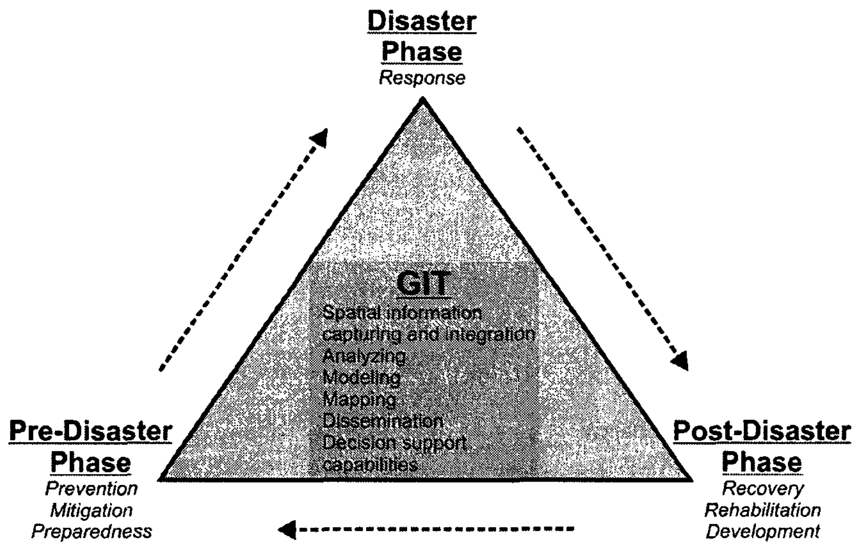


Figure 2.1. Disaster management cycle (source: Alexander, 2000).

Mitigation refers to efforts that aim to eliminate or reduce the risk to humans and/or property caused by natural or man-made hazards (e.g risk assessment, insurance, engineering standards, land use management, public education, etc.). Preparedness refers to activities necessary to the extent that mitigation measures have not, or cannot, prevent disasters. This involves developing operational capabilities for responding to a sudden disastrous situation. In this phase governments, organizations, and individuals develop plans to save lives and minimize potential disaster damage. This includes emergency planning, training exercises, implementing hazard warning systems, evacuation procedures and stock-piling of critical supplies. In addition, preparedness measures also seek to enhance disaster response operations. Response refers to those actions taken just prior to, during, and immediately after a disaster that save lives, reduce property damage or improve recovery. The most important aspect of this phase involves providing emergency assistance for 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. Recovery (often used in conjunction with the word 'relief') includes those activities that (1) restore vital life support systems and (2) return the area/population to a pre-disaster state. The former can be seen as part of the short-term recovery plan while the latter as part of the long-term, which may continue for a number of years after a disaster. Reconstruction is closely linked with mitigation, and is undertaken in ways that aim to reduce vulnerability and improve preparedness, thus disaster management occurs in a cyclical fashion as depicted in Figure 2.1.

Geospatial information technology (GIT), and its ability to acquire, interpret, analyze, map and disseminate information, are essential in all areas of natural disaster management. The value of GIS, for example, arises "directly from the benefits of integrating a technology designed to support spatial decision making into a field with a strong need to address numerous critical spatial decisions" (Cova, 1999). GIT provides the basis for estimating and mapping risk, planning evacuation routes, determining suitable areas for shelters, identifying disaster victims, and assigning resources during recovery, among many other essential tasks (Goodchild, 2006). It follows then, that GIT must play a key role in any comprehensive and effective disaster management strategy. Figure 2.2 incorporates GIT within the disaster management cycle to emphasize the central role it plays during all phases.



(modified from Hussain *et al.*, 2005)

Figure 2.2 A disaster management cycle incorporating GIT.

Disaster management is complex, and involves the participation and collaboration of many institutions/organisations/agencies operating at international, national, regional and local levels. Such institutions/organisations/agencies use a range of GIT depending on their specific information requirements, financial resources and technical capabilities. While a strong national disaster management initiative is important, Henderson (2004) emphasizes that disaster management capabilities should be decentralized to the regional or local level given the wide variations in demographic, socioeconomic, cultural and infrastructural conditions within regions and local areas of a nation. Regional and local authorities involved in disaster management should ideally have the capacity to effectively utilize GIT, yet even in developed countries limited financial resources can prevent such utilization within this administrative level (Laben, 2002). Theoretically, this approach is increasingly being recognized to be more effective than the centralized approach, but as Montoya and Masser (2005) note, local authorities are often not provided with the necessary financial resources to develop and implement effective policies and plans, which should incorporate GIT. Laben (2002) emphasizes that it is extremely important to have GIT alternatives available that can be used by all levels of the emergency and disaster management communities.

2.3. GEOSPATIAL INFORMATION TECHNOLOGY AND DISASTER MANAGEMENT

Geospatial information technology are essential for disaster management. GIT is used for many disaster management functions, including hazard and risk assessment (Ramli *et al.*, 2005; Dewan *et al.*, 2007b), vulnerability assessment (Cutter *et al.*, 2000; Weichselgartner, 2001; Kienberger and Steinbruch, 2005), vehicle dispatch and supply routing (Dong, 2005), damage assessment (Rivereau, 1995; Zhang *et al.*, 2002; Chen *et al.*, 2005) and resource mobilization (Goodchild, 2006), among many others essential tasks. In this section we examine the use of GIS, remote sensing and Internet GIS in the area of natural disaster management.

2.3.1 Geographic information systems (GIS)

A GIS is an "organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, up-date, manipulate, analyze, and display all forms of geographically referenced information" (ESRI, 1993, pp. 1-2). GIS a key component of any effective and comprehensive disaster management strategy, and are used to display, integrate, map, analyse, and model data and information derived from satellites, and other spatial data sources (Kumar *et al.*, 1999). GIS function primarily as a support tool to help answer essential questions and make informed, timely and appropriate decisions that can help save lives. Perhaps the greatest strength of GIS are their ability to integrate a wide range of data types, including geographic, social, economic, and political data into a single system (Dash, 1997).

However, to utilize GIS not only requires the software, but also hardware, data and trained personnel. Thus, a GIS capability involves not only the software itself, but the necessary spatial and descriptive (attribute) data, computer hardware and personnel who can effectively utilize it (Dash, 1997; Montoya, 2002). As a result, the use of GIS for disaster management varies widely between individual countries, and within disaster related organizations and institutions at different levels of government (Laben, 2002). These differences in GIS capability are clearly reflected in the wide range of literature that examines and describes the use of GIS for natural disaster management. This section of the paper will review the GIS and disaster management literature in order to identify examples of GIS capabilities (software, data, hardware, and level of expertise required) that are feasible for implementation in developing countries. These are all important considerations that will be emphasised and further discussed later in this paper

Since there are distinct differences between using a GIS for pre- or post-disaster management activities, this section has been divided in half, one half that deals with pre-disaster GIS use and another that examines post-disaster use. However, before these sections are presented it is first necessary to discuss the importance of spatial data, since it is the primary input for GIS and is required for their use.

2.3.1.1 The importance of spatial data

The success in utilizing GIS depends largely on the availability of spatially-referenced data; the quality of which is determined by locational precision, the characteristics of the attribute data, and by the extent to which standards are adopted that allow for data transfer (Coppock, 1995). The importance of good quality spatial data for use with GIS to assist disaster management cannot be underestimated. There are several types of spatial information that are useful for disaster management related decision making – the type, scale and complexity of such data depend on the type, scale and stage of the disaster (De La Ville *et al.*, 2002), as well as on the GIT capabilities of the implementing institution/organization. As an example, Table 2.1 describes some of the various types of spatial data/information applicable for disaster management that can be utilized in a GIS environment.

Over the years, developments in spatial data collection and use have led to the concept of spatial data infrastructure (SDI). A SDI includes "technologies, policies, standards, and human resources to acquire, process, store, distribute, and improve utilization of geo-spatial information" (Musinguzi *et al.*, 2004). Generally speaking, the success of disaster management largely depends on the availability, dissemination and effective use of information, much of which is spatial (Venkatachary *et al.*, 2002). Accordingly, then, there is a relationship between GIS, SDI and the extent to which spatial information is utilized for disaster management related purposes.

Table 2.1. Crucial Spatial Data for Disaster Management (adapted from Gunes and Kovel, 2000).

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

Most developed countries are at various stages of developing national SDIs, and their success can be linked to high levels of technology, availability of funds, trained personnel and political support (Musinguzi *et al.*, 2004). These factors that contribute to successful national SDI development are lacking in most developing countries, and as a result, there are vast differences in spatial data quality and quantity between developed and developing countries. As well, without a national SDI there is no effective mechanism for coordinating data collection efforts or for sharing spatial data among agencies or departments. This often results in duplication of data and is a waste of human/financial resources. Limitations in accessing and sharing spatial data are particularly problematic for disaster managers, whose spatial data needs typically cut across departmental/agency boundaries (Rego, 2001). However, some developing countries are making progress, including Sri Lanka, for example, who just this year (2008) initiated a national SDI (see www.survey-dept.slt.lk/). Their policy statement makes specific reference to disaster management, and how a SDI is required to reduce existing inefficiencies.

While there are distinct differences between developed and developing countries in terms of the quality and quantity of currently available spatial data, efforts are being made to improve the current situation. Nebert (2004: p.6) points out that "many national, regional, and international programs and projects are working to improve access to available spatial data, promote its reuse, and ensure that additional investment in spatial information collection and management results in an ever-growing, readily available and useable pool of spatial information." Although such initiatives may not be part of a formal SDI policy, they undoubtedly help the global GIS community and others who may use spatial data.

The internet has also drastically increased access to spatial data, as numerous websites now offer free access to a wide range of data (e.g. political/administrative boundaries, roads, hydrology, digital elevation, landcover, etc.). However, despite the rapid growth in available spatial data there has been little attention paid to aspects of its quality, including currentness, lineage, locational accuracy, completeness, and overall usefulness (Engler and Hall, 2007). This is unfortunate, because the quality of spatial data is particularly important when it is used for disaster management, when lives are potentially at risk. Although satellite imagery is an essential type of spatial data for disaster management, and is abundantly available online, its discussion is reserved for subsequent sections, and spatial data in the present context refers to vector data only.

Scale can also limit the usefulness of online spatial data. Currently, data available for developing countries is most often at the national scale. Generally speaking, such data is inappropriate for regional or local level use for a variety of reasons, including locational inaccuracy and a lack of attribute information. Even if the scale of the data is appropriate, some data may require additional time investments to clean, correct, or add the relevant attribute data before they can be effectively utilized. In addition, problems can arise when trying to combine data from disparate sources due to variations in coordinate systems and map projections. Engler and Hall (2007) emphasize that, in many cases, it may be better to create or purchase the required data elsewhere, as there may be to much work to be done or uncertainty associated with using data freely available from the internet.

Spatial data are essential in all areas of disaster management, yet good quality spatial data may be hard to come by, especially at the local level in developing countries. To improve and increase the use of GIS for disaster management will require a substantial effort in data collection, one that can be facilitated with an effective SDI policy. Rego (2001) stresses that the development of spatial databases should be built bottom up from the lowest administrative unit in country (e.g. the sub-district or district). The district databases would then feed into the state/provincial database and then into the national database. A bottom-up approach to spatial database production is especially relevant for local-level GIT use in developing countries.

2.3.1.2 Pre-disaster

A GIS has much to offer in the pre-disaster management phases of mitigation and preparedness. To effectively mitigate and prepare for a disaster requires not only detailed knowledge/information about the expected frequency, character, and magnitude of hazardous events in an area, but also the vulnerability of the people, buildings, infrastructure and economic activities in a potentially dangerous area (Rego, 2001; Van Westen and Hofstee, 2001). This information forms the cornerstone of preparedness planning and helps determine appropriate mitigation strategies. A GIS allows for the synthesis and analysis of such data/information to help determine risk levels, assess vulnerability, model scenarios, plan evacuation routes, determine resource requirements, and create a variety of useful information products to aid decision-making. Some specific examples of GIS use in the pre-disaster phases are particularly relevant for developing countries and so we elaborate upon these as cases of effective GIT implementation in pre-disaster management.

Van Westen and Hofstee (2001) present a case study that used GIS to create a spatial database of buildings, land parcels, roads and other infrastructure by digitizing from aerial photographs. Subsequently, a field team of investigators collected specific attribute information about each digitized land parcel and building, using a pre-determined checklist for the collection of data. For example, landuse of the parcel (residential, industrial, commercial, etc.), building material, building age, number of floors and whether previous hazard damage had occurred were among the attribute data collected. The resulting database, when combined with historical data on previous disasters, such as flood depth, was used to generate a variety of vulnerability and risk maps. The database and maps that can be generated serve as a basis for future development and planning that takes into account both biophysical and human vulnerabilities. This study was conducted for the city of Turrialba, Costa Rica, which has a population just over 30,000. Data collection and analytical methods are relatively simple to repeat, making this an excellent example of the type of GIS use that is practical for local level disaster managers in developing countries.

Cutter *et al.* (2000) present a county level "hazards-of-place" (see Cutter, 1996) based GIS method for assessing hazard vulnerability in spatial terms. Using twelve environmental threats and eight social indicators (e.g. age, race/ethnicity, income levels, gender, building quality, etc.) this study demonstrates how a GIS can be used to integrate both biophysical and social factors that contribute to hazard vulnerability. Social characteristics of the population are available from most national censuses, and census data is often used in a GIS to map human vulnerability to various natural hazards. The research methodology and conceptualization of hazard vulnerability provides a template for others to follow, and helps fill a void in the literature on spatial analytical approaches to vulnerability assessment. If vulnerability to natural hazards can be identified appropriate steps can then be taken to reduce the social and economic impacts of potential disasters. However, the authors acknowledge that implementing this approach at the local level may pose challenges in terms of availability of funds for training and data acquisition. Furthermore, results are based on a data intensive methodology, and while this approach is possible in developed countries, it is unlikely feasible in most developing counties due to a lack of detailed spatial data, in addition to other GIS implementation issues previously described. However, it seems likely that this methodology could be simplified (for example, use fewer indicators) and still produce useful hazard vulnerability information.

Guinau *et al.* (2005) used a GIS to create a hazard susceptibility map to help mitigate landslide risk. The methodology applied focussed solely on the biophysical factors that cause landslides. The authors digitized present and past landslides from aerial photographs to create a landslide inventory, which was then overlaid on terrain data, such as lithology, slope, soil characteristics and landuse. Analysis of terrain conditions in areas affected by landslides made it possible to determine zones with similar characteristics, and through further analysis the delineation of low, medium and high susceptibility zones. Perhaps most important about this study is that it demonstrates a relatively simple GIS-based methodology to assess landslide vulnerability that is feasible for developing countries.

Dewan *et al.* (2007a) integrated GIS and remote sensing techniques to analyze the flood hazard and risk levels in Dhaka, Bangladesh. A major impediment was the unavailability of data in a digital format, and as a result, a number of the required data layers had to be created. Flood-affected frequency and flood depth were estimated from multi-date SAR data (from RADARSAT), based on previous flood events. Land-cover was generated using a combination of approaches and data sources, including on-screen digitization from high resolution remotely sensed imagery, recently produced topographic maps, field surveys and the use of hand-help GPS units. A geomorphic map was also developed using a LANDSAT TM of 1999, in conjunction with available paper maps and field investigation. Elevation data in the form of a DEM was obtained from the Institute of Water Modeling (IWM), Bangladesh. All the vector data layers were then converted to raster at identical resolutions. Using a relatively simple procedure, that involved assigning a weighted score to each data type (to represent varying significance) and the use of GIS overlay functionality, the authors were able to create maps depicting flood hazard potential and flood risk zones. The data collection methods, analytical techniques and general approach used in this study demonstrate innovative and adaptive use of GIT in the context of a city-scale hazard assessment for developing countries.

Uncontrolled and informal housing development is a recurring problem in cities in developing countries (Thomson and Hardin, 2000), and such development practices contribute to increasing natural hazard vulnerability. To resolve this problem, Thomson and Hardin (2000) used GIS and satellite imagery (Landsat TM) to identify potential low income housing sites in the eastern portion of the Bangkok Metropolitan Area, where flood risk is a concern. Location, infrastructure, land cover, and natural environment factors were used to assess the characteristics appropriate for public housing sites. Due to a shortage of spatial data, all GIS coverages required were derived from satellite imagery or input from map sources, including land use, land parcels, roads and drainage. To derive land cover, for example, required a combination of techniques, including unsupervised (to identify spectral clustering) and supervised classification based on local knowledge, and the use of aerial photographs for verification. Major roads were digitized on-screen in the GIS based on the satellite imagery, and the remaining data were generated using a variety of low-tech methods, including visual image interpretation (and digitization) and field work. Using basic GIS functions, such as overlay and buffering, a final map was produced that identified sites possessing appropriate criteria for low-income housing: non-built, greater than 25 hectares, within 1 km of a road, and least prone to flooding. The map can be effectively utilized at large and medium scales (e.g. 1:20,000 – 1:50,000), and the analysis methods and techniques are considered feasible for cities in developing countries, in terms of available data and required skill sets. A better understanding of suitable locations for potential housing sites could help guide development in ways that reduce natural hazard vulnerability.

Knowledge of the spatial characteristics of hazards and vulnerability before a disaster strikes enables disaster management authorities and emergency workers to identify areas that are likely to be most affected, and thus focus their resources in the most effective way. Such knowledge is critical to the development of effective mitigation and preparation strategies that will ultimately help reduce the devastating impacts that can result from natural disasters.

2.3.1.3 Post-disaster

In the immediate aftermath of a natural disaster, and in the days and weeks that follow, a GIS is valuable. Disaster responders, emergency personnel, aid workers and anyone involved in the response and relief effort need timely and up-to-date information, such as the extent of damage and location of potential victims, the location of critical facilities (e.g. shelters, hospitals, air strips, etc.), available resources (e.g. food, water, blankets, medical supplies, etc.), infrastructure conditions (e.g. damaged roads/bridges/utility lines, etc.), and evacuation or supply drop off points. Much of this information is spatial and is thus well suited to be compiled and analyzed in a GIS, and then disseminated as maps. However, using GIS post-disaster is much different, and poses greater challenges than using it pre-disaster, since time becomes a critical factor (Goodchild, 2006). Immediately following a disaster, information must be quickly collected, analyzed and assembled into useful information products that can assist response efforts. Thus, to the extent possible, GIS data should be collected and/or analysed in advance of an event, rather than having to put it all together during the aftermath (ESRI, 2006). Bottlenecks in information flow and dissemination can mean the difference between life and death. Therefore, having a database of the most critical and useful spatial data before a disaster strikes is essential. It allows for quick updates of the data to reflect ground conditions and reduces the time it takes to produce critical information products required by disaster responders and related emergency response personnel.

Following the initial response period, and once the situation has stabilized, a GIS can be used to further analyze disaster impacts and help plan the rehabilitation process in a way that reduces potential vulnerabilities. Development of this fashion is termed "invulnerable development" (McEntire, 2001). The following few examples demonstrate the value and necessity of GIS during the post-disaster management phases.

Impact analysis is one fundamental use of GIS in the post-disaster phase. Impact analysis can assist response efforts by identifying those areas most in need, and can help guide reconstruction efforts in a way that will minimize the potential for future disasters; for example, through improved land-use planning that takes into account local hazard vulnerabilities. In conjonction with IKONOS panchromatic images, De La Ville *et al.* (2002) used GIS to evaluate the distribution of landslide erosion scars and their effects on several urban areas situated among six mountain catchments in Venezuela. The GIS was used to analyze and map the distribution of scars and deposition zones, and to study the factors (e.g. slope, geology, land cover, etc.) that contributed to causing the various types of mass movements. All the information derived from this study was used by the corresponding government agencies as the basis for the preparation of reconstruction plans for the affected areas.

Following the Indian Ocean tsunami of 2004, and after evoking the International Charter on Space and Major Disasters to acquire pre- and post-disaster high resolution satellite imagery, Magsud *et al.* (2005) used a GIS for rapid damage assessment of buildings in Galle, Sri Lanka. The GIS was used primarily to combine different data types and to support a visual analysis of building damage. QuickBird multi-spectral imagery and a 1:5000 scale vector layer of buildings (obtained from the Survey Department) were overlaid in a GIS to accurately identify construction that existed prior to the disaster. In addition, a ground survey of 81 buildings was undertaken that identified the level of damage following the disaster (completely destroyed, partially damaged mainly inside, partially collapsed with roof intact, and slightly damaged). A high precision GPS was used in conjunction with ground photographs to accurately record the location and building damage, respectively. This allowed for a comparison between the damage level in the photographs and satellite imagery. Results indicate that heavily damaged buildings can easily be identified, but partial damage, particularly if the roof was still intact, was difficult to determine from the satellite imagery alone. The mapped results clearly show the location of destroyed buildings, which is valuable information that could be used to prioritize response operations. With an adequate amount of technically trained personnel, the authors' propose that a near real time damage assessment could be possible. The analytical methods and data inputs used in this study are relatively simple, yet effective, and are therefore considered appropriate/suitable for disaster managers in developing countries.

In general, GIS are well suited to provide valuable information to assist disaster response operations. For example, they can be used to determine the extent of a disaster and estimate damage (Ranyi and Nan, 2002), organize resource inventories and their geographic distribution (Hussain *et al.*, 2005), monitor shelter/refugee camp status and the state of transportation infrastructure (Gunes and Koval, 2000) and integrate disparate spatial data sources that may be required to guide response (Amdahl, 2001). As such, GIS can help with search and rescue, providing medical services, debris removal, sheltering, and infrastructure repairs. However, a large number of spatial data layers are required for planning and coordinating such operations, and without them the value and usefulness of a GIS decreases substantially, possibly to a point where it may no longer be required. Therefore, to some extent, the usefulness of GIS following a disaster hinges upon the existence of the required base datasets (e.g. roads, critical facilities, population density).

Finally, Zerger and Smith (2003) emphasize that the suitability of GIS for planning verses real-time applications is quite different. Results from a test scenario indicated that the utility of GIS for real-time decision making is questionable owing to a number of practical and implementation impediments, including a lack of training and the need for temporal resolution rather than spatial detail. Using GIS for pre-disaster management functions, such as vulnerability assessment or evacuation route planning, poses fewer challenges than trying to use the technology post-disaster, when time is critical and ground conditions may be constantly changing. Nevertheless, assuming there is adequate data and personnel to effectively utilize GIS, few would question its ability to assist disaster response and recovery operations.

2.3.2 Remote Sensing

The potential of remote sensing (RS) to provide critical earth observation information for disaster management (e.g. hazard assessment, disaster mitigation, preparedness, response and recovery) has repeatedly been emphasized (e.g. Rivereau, 1995; Jayaraman *et al.*, 1997; Mansor *et al.*, 2004; Becking, 2004; Chen *et al.*, 2005)), and is reflected in over 400 scientific articles between 1972 and 1998 (Showalter, 2001). For instance, remotely sensed imagery can answer questions such as: what did/does the area look like pre-/post-disaster? RS data can show the land cover and topographic features in an area and can illustrate infrastructure and population density (Becking, 2004). Showalter (2001) provides an in-depth review of the use of RS in hazard and disaster research, and concludes that the technique is primarily used to detect, identify, map, survey and monitor existing hazards and/or their effects; secondary goals of RS focus on damage assessment, improved planning, or the provision of data for disaster management functions. Simonovic (2002), in examining the repeat frequency, spatial resolution, and types of sensors on-board, provides insight into the suitability of specific satellites to different natural disasters. Multispectral scanners (optical sensors) and radar collection systems are probably the two most widely recognized RS capabilities that are used in support of disaster management (GDIN, 1997).

The applicability of remote sensing for disaster management is perhaps best exemplified in the case of flooding, and many researchers address its use for this disaster type. Satellite imagery can be used to assess the extent of past flood events (Dewan *et al.*, 2007a) and aid in the development of flood hazard potential maps. Zhang *et al.* (2002) and Jayaraman *et al.* (1997) highlight the potential of RS technology to drastically assist flood response and relief operations by providing inundation mapping and damage assessment. Disasters resulting from floods are a logical choice for RS analysis because: (1) floods generally cover large areas, and thus occur at spatial scales much greater than the spatial resolution of most satellite imagery (Showalter, 2001), and (2) water has a unique spectral reflectance which makes it clearly discernable from other ground features. In contrast, earthquakes, for example, may cause significant damage to buildings and infrastructure, but without high resolution imagery or change detection capabilities it can be difficult or impossible to identify.

Remotely sensed digital elevation data (often termed DEM (digital elevation model) or DTM (digital terrain model)) are a digital representation of surface topography and are frequently used in the study of natural hazards. DEMs are a critical data input for assessing landslide susceptibility (Guinau *et al.*, 2007), delineating flood risk potential

(Dewan *et al.*, 2007b), flood hazard mapping (Sanyal and Lu, 2003; Dewan *et al.*, 2007a) and for a variety of coastal hazard (e.g. tsunami, storm surges, etc.) and disaster assessment purposes (for example, see Chen *et al.*, 2005). DEMs are also commonly used to derive new data that is required for specific types of disaster management related analysis or visualization. The types of new datasets that can be generated include, but are not limited to: slope, aspect, contour lines, flow direction, flow accumulation, watersheds, hillshade, and many others. The most important factors that determine the suitability of a DEM for any particular disaster management related application are the spatial resolution and vertical accuracy.

The potential of remotely sensed data to assist disaster management is very clear, however, there are some limitations and potential obstacles, including image resolution, repeat frequency (temporal resolution) and the suitability of particular sensors. Perhaps the most significant obstacle facing the use of satellite imagery for a number of disaster management requirements is low pixel resolution. In large urban centers, satellite image resolution can be less than 1 meter, but in more remote areas and many parts of the developing world, only 15-30 meter Landsat or ASTER imagery are publicly available (Nourbakhsh *et al.*, 2006). Low image resolution can limit the range of potential uses of RS data, including using it as a source to create digital datasets of basic, yet fundamental information for disaster management. For example, Rüdenauer and Schmitz (2005) used supervised classification techniques and found that Landsat 7 ETM+ data (30m resolution) could be used to identify and separate out settlements, but that the detection of linear features such as roads, railways and waterways was unsatisfying. Integrating the panchromatic band (15m resolution) into the analysis failed to significantly improve results. Thus, while Landsat imagery can be used to identify settlements it cannot be used as a source to accurately derive other spatial features on the ground.

Repeat frequency is also an important consideration, as time becomes a critical factor in post-disaster use of RS imagery, some satellites may not be available within an appropriate/suitable time frame (San Miguel-Ayanz *et al.*, 2000). For example, repeat frequency can vary from 12 hours (NOAA) to 35 days (ERS) (Simonovic, 2002). In addition, Cutter (2003) points out that the pre- and post processing time for remote sensing images may negate their use in immediate response activities. Even if they are able to pass over a disaster affected region, cloud cover and the time of day (day vs. night) can constrain the use of optical sensors for image acquisition (Coppock, 1995). Therefore, the type of sensor onboard a particular satellite as well as the atmospheric conditions will partly determine the suitability of satellites for a given disaster related requirement. Even partial cloud cover can be a significant obstacle that limits the use of optical imagery. In cloudy conditions satellites employing radar systems are required, but they too have their limitations (see Simonovic, 2002) and are at times not suitable for acquiring the type of information that may be required. Shadows can also be a limiting factor in both optical and radar imagery. Magsud *et al.* (2005) found that shadows prevented the visual identification of damaged buildings using high resolution QuickBird imagery following the Indian Ocean tsunami. The same authors also note that intact roof tops can be deceiving, as initially certain buildings appeared to be damage free, but upon ground truthing the building was essentially hollowed out, with the roof top and support beams being the only remnant. Accordingly, caution must be used when drawing initial conclusions based on visual imagery analysis, and ground truthing should be considered before any significant actions are taken.

Recognizing the importance of high resolution satellite imagery in disaster management, many major space agencies and satellite operators signed the International Charter on Space and Major Disasters by the year 2001. This multilateral agreement stems from the fact that no single operator or satellite can match the data-related challenges of natural disaster management. The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters (Space Agencies, 2005). The charter has been successfully evoked on numerous occasions by countries all around the world - from Ecuador to India to Russia - providing indispensable high resolution imagery for no fee. For example, in the aftermath of the Indian Ocean tsunami several agencies and private companies provided RS imagery for response and relief work (ESRI, 2006). DigitalGlobe provided 60-centimeter QuickBird images, which are the highest resolution commercial satellite images currently available.

Although developing countries cannot send satellites into orbit, opportunities do exist for acquiring high resolution remotely sensed imagery for disaster management purposes. However, Magsud *et al.* (2005) point out that once satellite data are received by the coordinating office it is then up to the authorized user to effectively use the data - there are few mechanisms in place to help countries in need of support to use the data. In developing countries this can pose a problem because potential data users are not fully aware of the capabilities of GIS and remote sensing, and they require additional assistance in order to put the data to good use. Moreover, the International Charter does not provide free imagery for pre-disaster GIT operations.

In sum, RS technology acts as a tool to gather spatial information that can support many disaster management functions, especially when combined with other spatial data (points, lines and polygons) in a GIS. Satellite imagery is critical for natural disaster response in remote and inaccessible regions, or regions where primary (or basemap) geospatial data are non-existent or difficult to collect. In such regions, satellite imagery often offers the best means of obtaining the necessary information (Kerle and Oppenheimer, 2002). This is particularly true in many developing countries which tend to lack digital spatial data (Brodnig and Mayer-Schönberger, 2000; ESRI, 2006).

2.3.3 Internet GIS

Internet GIS (IGIS), the integration of GIS and the Internet, has quickly evolved over the last decade and has achieved significant recognition within the disaster and emergency management community for two main reasons. First, GIS provides a way to centralize and visually display critical information relevant to a disaster, since most of the data requirements are of a spatial nature and can be located on map (Johnson, 2000). Second, the Internet provides an ideal medium for multiple users with a range of backgrounds and skill sets to access spatial information and mapping capabilities. Radke *et al.* (2000) emphasize that data acquisition and integration may be the single largest contribution area needed for emergency and disaster response – IGIS can help address both these issues. During the response phase, access to pertinent spatial data/information is among the most essential requirements (Jayaraman *et al.*, 1997; Amdahl, 2001). Disaster managers, local authorities, aid workers and the public need up-to-date data/information to enable quick and effective decision making in the immediate aftermath of a disaster. Organisations such as the Global Disaster Information Network (GDIN) provide evidence of the importance and value of disaster-related information, as well as the need to be able to obtain and share it effectively.

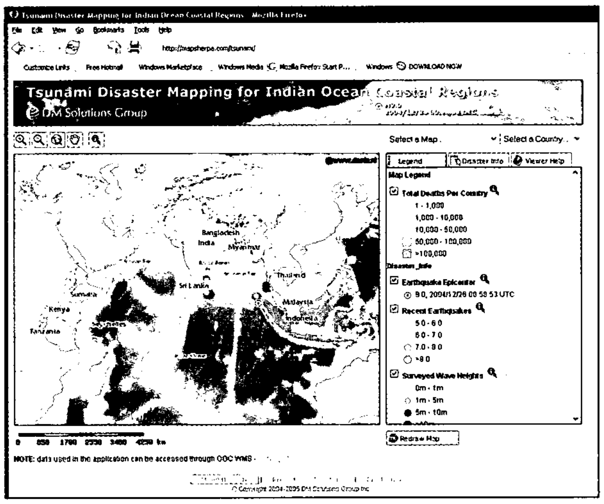
The integration of GIS and the Internet first began in the early 1990's (Plewe, 1997), and grown rapidly since that time. This growth is partly attributable to advancements in computer and information technology and the building of spatial data infrastructure (SDI) worldwide (Yang *et al.*, 2005). In this section we briefly define and describe the capabilities of Internet GIS, discuss the implications of this relatively new technology on the field of disaster management, and examine its potential from a developing countries perspective.

Like other newer fields, there is no general agreement on the terms used to describe GIS-based programs on the Internet. They are commonly referred to as Internet GIS, Web-based GIS, distributed GIS and On-line GIS, among others. Peng and Tsou (2003) help to better differentiate between these terms and classify the various types of applications. The term 'Internet GIS' (IGIS) will be used henceforth herein and is defined as network-based geographic information services that can utilize wired or wireless internet to access geographic information, spatial analysis tools and GIS Web services (Peng and Tsou, 2003). It is worth noting here that although the term GIS is included with "Internet", IGIS focus mainly on displaying geographic information (in map form) as well as data dissemination tasks but tend to lack comprehensive GIS capabilities common to most desktop software. Kraak (2004) points out that most IGIS applications currently in use are limited to (interactive) mapping (with zoom, pan, measure distances, identify spatial features, etc.), although some offer basic GIS functions such as address matching, proximity searches, and routing. However, more recent advancements are allowing for the development of Internet distributed GIServices with the capabilities to interact with multiple and heterogeneous systems and servers that support more advanced GIS functions (Dragićević, 2004). Such capabilities are reflected in the rapidly developing standards for web-based GIS services (www.ogc.org).

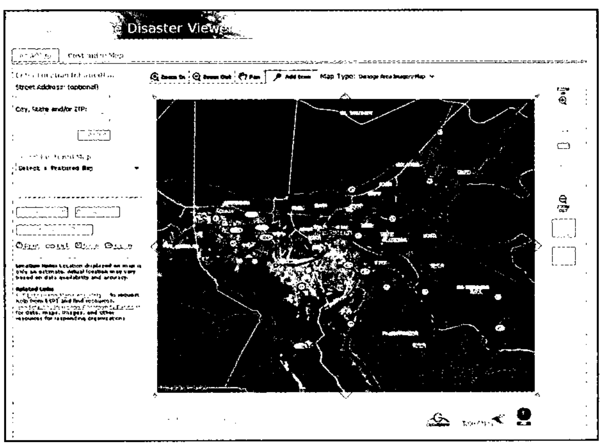
The characteristics and capabilities of IGIS offer considerable potential in the field of disaster management, particularly during the response phase when access to spatial information is a key requirement (Radke *et al.*, 2000). Disaster impacts can significantly alter the landscape (natural and built environments), and often vary across organizational, sociological, political, and geographic boundaries. This is especially true following large-scale disasters. Information about the disaster zone needs to be disseminated to many stake-holders involved in the response, at local, regional, national and international levels, both public and private (GDIN, 1997). Much of this information is spatial, such as the location of the most devastated towns or villages, the location of supply drop-off points and the extent of in-tact transportation networks. IGIS are well suited to fulfil these information requirements since (1) they allow for the integration of various spatial datasets and (2) they can be accessed from any location with an Internet connection.

The often ad-hock nature of disaster response involves people and organizations (local to international) that require spatial information relevant to their own logistical operations. Comfort (2000) reports that during disaster response there are often dynamic and spontaneous actions taken by responding organizations and individual groups of people. These types of efforts are encouraged, but could be more effective and better coordinated with an improved spatial awareness of the disaster zone, achieved through the use of appropriate spatial information and maps accessed using IGIS-based Web sites. Becking (2004) states that obtaining geographic awareness is one of the most important steps in effectively understanding a disastrous situation, and being able to make appropriate decisions. Traditionally, geographic information has been distributed using paper maps, which are costly to produce and difficult to update and distribute to all parties involved.

Experience has shown that a top-down approach to data sharing is not entirely effective (Radke *et al.*, 2000), as disaster responders must gain access to a number of department managers and organizations, their unique maps and data. Knowing which data is where and how to effectively access it can be a significant problem. Furthermore, this type of approach often results in duplication of efforts. For example, following the Indian Ocean Tsunami many agencies created damage maps at almost the same time (ESRI, 2006). An alternative option is to utilize current IGIS architectures to create a disaster information system with wide accessibility, which allows multiple users to access relevant spatial data/maps provided by a variety of organizations through distributed servers/sources. An IGIS-based mapping system that is intuitive, user-friendly and easy to access could help provide geographic awareness to disaster responders, many of whom have limited or no GIS experience but could certainly benefit from access to spatial information and maps. Andre and Smith (2003) note that disaster responders often require simple cartographic products (for example, the location of impassable roads identified on a road network map) as opposed to products derived from advanced spatial analysis.



South East Asia and Indian Ocean Tsunami Response Map Viewer (produced by DM Solutions Group)



Hurricane Katrina Disaster Viewer (produced by ESRI)

Figure 2.3. Examples of two IGIS-based natural disaster map viewers.

Experience to date indicates that IGIS has played a key role in the collection and dissemination of spatial information during the disaster response and recovery of recent natural disasters, including the Indian Ocean tsunami (2004) and Hurricane Katrina (2005). However, the success/failure of IGIS in that regard must be interpreted within the context of the very young IGIS field. With that caveat in mind, following these natural disasters IGIS sites were established that integrated a large number of spatial datasets, including coastlines, satellite imagery, damage maps, transportation networks, population centers and other data intended to provide a visual overview of the regions impacted by the disasters. Figure #3 shows images of the main interface of two such sites.

The user friendly map based information systems created using IGIS can clearly increase access to relevant spatial information required during disaster response. However, their design, development and implementation require substantial GIS/technical knowledge and significant human and financial resources. As demonstrated earlier, in many developing countries each of these requirements represents a challenge, and could prevent them from creating IGIS for disaster response. In fact, the two known IGIS sites created to assist with the Indian Ocean tsunami response were not created by any developing country that was affected by the disaster; one was created by a Canadian software development company (DM Solutions Group) and the other by the Pacific Disaster Center, which is based out of Hawaii. Both have significant GIT resources and capabilities, and were able to establish these IGIS sites in a relatively quick period of time. This is an important point, as it is unlikely that GIT practitioners in developing countries have the expertise required to effectively develop an IGIS site in a reasonable time frame. In addition, Internet connections in many parts of the developing world can be slow and patchy (Nourbakhsh *et al.*, 2006), which reduces the potential for accessing information using IGIS sites.

In general, the ability to develop an IGIS for disaster response requires excellent GIT skills and a large amount of spatial data, which may exist at differing scales and in varying formats. Currently, the GIT requirements and skills associated with creating IGIS are beyond those of disaster managers in developing countries, and we suggest that trying to implement IGIS may not be the best use of their limited resources.

2.4. GEOSPATIAL INFORMATION TECHNOLOGY SOFTWARE

We have reviewed many uses and barriers of geospatial information technology (GIT) to natural disaster management. However, there has been no discussion regarding specific aspects of GIT software, including the difference between commercial and free and open source (FOS) software (FOSS), and the implications of these differences for adoption within developing countries. Turning our attention to that issue, we now discuss the main differences between commercial/proprietary software and FOSS, and explore the significance of these differences from a developing country perspective. We also briefly discuss the FOS GIT software domain. Although there are some well documented drawbacks to using FOSS, and challenges to overcome, the potential benefits that can be gained far outweigh any downside, and thus FOSS should be considered a viable model (Fitzgerald, 2004; Hoe, 2006).

2.4.1 Free and Open Source Software (FOSS)

While some consider "free" and "open source" software to be something close but not identical, they are similar enough that for the purposes of this paper they are considered the same. We can lump them together because for the general software user the difference is negligible, although philosophical and legal differences do exist (see Rajani *et al.*, 2003; Steiniger and Bocher, 2008). Although there are a number of criteria that a software package must meet to be considered FOSS, three essential features capture the essence of the semiofficial "Open Source Definition[2]":

- 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. (Weber, 2004)

[2] The full definition can be accessed at www.opensource.org/docs/osd

Licensing agreements such as the General Public License (GPL) define the rights users have over the software product[3]. Wu and Lin (2002) and Cook and Horobin (2006) provide further information about the various FOSS licensing models.

What makes FOSS different than proprietary or commercial software is that the source code is "free." In this context free means freedom, not necessarily zero price, although almost all are available at no cost. Free software implies that the user has the freedom to run, view, copy, modify, and distribute a piece of software, irrespective of financial limitations. Thus, users can improve the source code, by either enhancing its existing functionality or by adding new functions. In contrast, proprietary software indicates ownership, and has its source code closed – it cannot be viewed, modified or redistributed, as is stated in the EULA (End User License Agreement) that you must agree to prior to installation. Free, as in price, is perhaps the most significant characteristic of FOSS that differentiates it from commercial software, which is inherently sold for profit. Another characteristic of FOSS is that it can be accessed (downloaded) from anywhere with an internet connection; this is typically not true of commercial/proprietary software. Table 2.2 outlines some of the key differences between proprietary and FOS software products, in terms of advantages and disadvantages. With certain types of software, including GIT software, there are also considerable differences in terms of functionality and ease of use, two aspects that we address in a companion paper (Chapter III).

[3] See www.gnu.org/licenses/gpl.html

Table 2.2. 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)	no licence fees
	components should work together	unrestricted use (e.g. no limits for the number of installations)
	well documented software	no update enforcement
	regular release times for new versions.	support of open standards
	regular service packs	support usually available from several providers
	customization at the API level	customisation at source code level
		platform independent
Disadvantages	software price and maintenance fees	Installation know-how necessary
	training costs	Training costs
	maintenance fees tied to specific licensed companies, software options and time period	Interoperability issues between FOSS
		Quality (but self-correcting if actively used)
	customised development can be difficult due to available resources of vendors	No responsible authority
		Support can lack for some packages
	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 (ArcView3.2- ArcGIS 9.2) or data models change at vendor's whim or development cycle	

The FOSS movement is continually gaining momentum, but has already garnered significant attention in some areas. For example, Apache dominates the web server market, as over 65% of all active web sites use it (Weber, 2004). Ramsey (2007) points out that its success can be linked to a powerful user community that "shares an interest in maintaining Apache as a top-drawer web server." Corporate mainstays such as IBM and HP, government agencies and academic contributors are all part of the Apache community. Other FOSS projects that have become very popular include office suites such as OpenOffice, database systems like MySQL, the Mozilla Web browser, and the Linux operating system. Currently (March 2008), there are over 173,000 registered projects and over 1,817,000 registered users at Sourceforge.net, the world's largest open source software development web site. In fact, most users can find an application that will exactly meet their specific needs (Wu and Lin, 2001). According to Wheeler (2007), who provides 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. This evidence suggests that FOSS can, and already is, rivaling certain commercial software domains.

Although a strong case can be formed for the FOSS model, it also has some often cited disadvantages compared to commercial software. For starters, software support and technical assistance is a major issue facing the adoption of FOSS. However, FOSS proponents are quick to point out that support may be found within the FOSS community, in the form of user groups and archives of past queries and answers available on the Internet (Ramli *et al.*, 2005). Installation and user documentation is also common among the more mature FOSS products (Steiniger and Bocher, 2008). Furthermore, organizations that deploy FOSS freely offer advice to one another, sharing insights and lessons learned (Fitzgerald, 2004). As a result, solutions for many typical problems can often be found at no cost. When they cannot, there is a growing FOSS support and custom development industry that can be utilized in such circumstances.

Another concern about FOSS relates to its long-term survival. Fitzgerald (2004) reports 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. This sort of vague analysis of the FOSS domain can be deceiving, since there are so many FOSS projects it is not surprising that most have only one or two developers, and that new versions are not coming out regularly, particularly if the particular package is sufficient for its purpose. That is the nature of the FOSS model, as it encourages individuals or small teams to develop and share software. It is up to potential users of FOSS to examine individual products, consider potential advantages and disadvantages, and choose what best fits their needs. Câmara and Onsrud (2004) examined FOSS GIT and identified many differences that exist - 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 be of better quality, at least from these three standpoints.

2.4.2 Free and Open Source Geospatial Information Technology Software

Turning our attention now to the specific domain of FOS GIT software, there is reason for optimism. As opposed to questionable long-term survival, Steiniger and Bocher (2008) emphasize the increasing interest and development of FOS GIT products. They point out in their overview of FOS GIS (e.g. gvSIG, Quantum GIS, SAGA, uDig, GRASS, etc.) that:

a. Four out of ten desktop projects examined receive governmental funding support;
b. There is an increase in the download rate of FOS GIS software; and
c. There is an increasing number of use cases of FOS GIS

Furthermore, Ramsey (2007) points out 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 starting to back FOS GIT initiatives, which is encouraging especially from a user support and longevity perspective. In late 2005 the software industry giant Autodesk, in association with the MapServer community and DM Solutions Group, announced that it would support and promote Open Source Web mapping (a form of IGIS) through the creation of the MapServer Foundation (Schutzberg, 2005). The Foundation is expected to provide a stable infrastructure for the now extended MapServer family's code base and its growing community.

The FOS GIT software community is steadily growing, and since 2006 has been spearheaded by the Open Source Geospatial Foundation (OSGeo) (www.osgeo.org). Their mission is to support and promote the collaborative development of open geospatial technologies and data (OSGeo, 2008). The OSGeo hosts an increasing number of software projects, publishes the OSGeo journal, founded an education and curriculum committee, and presents the annual Free and Open Source Software for Geospatial (FOSS4G) international conference (Steiniger and Bocher, 2008).

The comprehensive list of links to FOS GIT related software projects/products available at opensourcegis.org and freegis.org provides evidence of an active development community. Some notable GIT programs, which offer a range of functionality from simple data/map viewing to more 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. Currently, the freegis.org website contains information and links to over 300 FOS GIT projects. Ramsey (2007) provides 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 more in-depth overview of current FOS desktop GIS, in terms of organizations, software groups and functionality, see Steiniger and Bocher (2008).

2.4.3 FOSS and Developing Countries

From the perspective of developing countries the FOSS model is a particularly good fit, for reasons that include: cost, freedom, accessibility, customizability, compatibility, capacity development and reducing the overall so-called digital divide (Hoe, 2006). The lower cost of FOSS is definitely the most significant factor that makes it attractive to developing countries (Rajani *et al.*, 2003). Hoe (2006) states that "the ability to obtain FOSS without licensing fees has proven to be very beneficial to the users in these regions as this makes information and communications technology (ICT) more affordable to them." The software that comprises the commercial GIT domain is particularly expensive. Table 2.3 provides a few examples of some popular commercial GIS and RS software applications and their general price ranges.

Table 2.3. Approximate costs of selected commercial GIS/RS software (the wide price ranges reflect possible variations in licence type, software options, purchasing agreements, etc.).

Application	Price range (USD)	Software
High end GIS/RS	$10, 000 to $50, 000	ArcGIS (ArcINFO) Genasys ENVI ERDAS Imagine ER-Mapper
Low end GIS/RS	$1, 000 to $3, 000	MapInfo ArcGIS (ArcView) ArcView extentions ERDAS Imagine Essential

Even the most basic and required proprietary software necessary for many computing needs, such as Windows XP and MS Office, can be too expensive to purchase in a developing country (Roets *et al.*, 2007). With that in mind, it is not surprising that the highest software piracy rates occur in developing countries such as Vietnam, China and Indonesia, with piracy rates of 97, 94 and 89 percent, respectively (Rajani *et al.*, 2003). In some cases "it is common for a new computer to be pre-installed with pirated copies of whatever proprietary software the customer wants" (Weerawarana and Weeratunge, 2004). This evidence demonstrates that users in developing countries most often don't, and perhaps more importantly, cannot afford to pay for computer software. Although piracy is very common, it actually devalues the economic benefits of FOSS by falsely reducing the price of proprietary software (Weerawarana and Weeratunge, 2004). The zero cost of FOSS should be considered a major advantage over proprietary software in the case of developing countries, and could also help reduce their reliance, and inadvertent support and encouragement, of the illegal software market.

The freedom to access and study the source code is another fundamental advantage of using FOSS. As a result, the choice to use FOSS is not only a software choice, but also a means of acquiring knowledge about the software itself. In developing countries this is important for capacity building of the local population, and can help them better understand and deploy new technologies successfully (Hoe, 2006). Mohamed and Plante (2002) emphasize that local workforce development and capacity building are critical for system maintenance and operation over the long run. In addition, using FOSS can contribute to the development of the local ICT industry (of which GIT is a part of), as support, development and maintenance contracts can be provided by local businesses that offer FOSS services (Cook and Horobin, 2006). This will, in tern, provide more jobs in the FOSS industry, attract trained professionals, and help stimulate the local economy.

The freedom to customize the source code is also important from a developing country perspective. Krakowski (2006) points out that proprietary software developed within the Western world is designed to fit well with Western culture. As a result, it may not be well-suited for use in other regions of the world, where local customs and practices may be quite different. With FOSS, applications can be tailored to meet the specific needs of the users, and take into account cultural variations and social practices that deviate from industrialized societies. Similarly, the majority of people in developing countries do not understand English, yet proprietary software is often only available in English (Nonogaki *et* al., 2004; Hoe, 2006). Clearly, interface and documentation language represents a major obstacle to users who do not understand English; however, FOSS can be adapted to meet local language needs and in doing so helps to tackle the digital divide. For example, Ubuntu is an African adjusted Linux distribution that attempts to resolve language problems (Krakowski, 2006). GNOME 2.22 – the default desktop environment of Ubuntu – offers support for 46 languages. Similarly, multi-language capabilities have been incorporated in recent versions of GRASS and Mapserver (Nonogaki *et al.*, 2004; Raghavan *et al.,* 2006) and gvSIG is available in more than ten languages. Additional efforts need to focus on translation of online help files, manuals and so on.

Another advantage of FOSS is that they usually do not require the newest or best computer hardware in order to function efficiently and correctly. In contrast, and especially in the GIT software domain, proprietary companies are continually releasing new versions that demand the newest and most advanced hardware. In developing countries most users do not have access to powerful, high-end computers with the most current hardware available (Caldeweyher *et al.*, 2006). Therefore, even if they could purchase sophisticated GIT software they would also require computers with sufficient

RAM and CPU power to take advantage of the advanced capabilities that are offered in most commercial GIT packages.

A couple of final remarks about the potential of FOSS for developing countries relate to accessibility and unlimited installations. First, FOSS can be downloaded (accessed) from anywhere with an Internet connection; and where the Internet is unavailable FOSS can be delivered on a CD or provided via a data storage device such as a USB or external hard drive. This makes computer software accessible to potential users who would have absolutely no ability to purchase or otherwise obtain such software. Second, the freedom to install FOSS on as many computers as is desired is another fundamental benefit not offered by proprietary software. If a single use license is purchased from a proprietary company only one computer can legally run the software, and multi-use licenses are expensive and considered unaffordable for most software users in developing countries, even governments (Roets *et al.*, 2007). This limits the accessibility of the software, preventing it from being installed and used on more than one computer. In an office environment, for example, this is likely to represent a significant problem.

In sum, the literature that addresses issues related to FOSS and its adoption in developing countries, in terms of advantages and disadvantages, is diverse and abundant. The preceding discussion is meant to provide only a brief overview of some well acknowledged and commonly discussed advantages that FOSS provide and elaborate on those specific to GIT. We acknowledge that there are many more advantages to FOSS in general for the developing world that are beyond the scope of this paper to discuss and so recommend reviews by Rajani *et al.* (2003) and Weerawarana and Weeratunge (2004), or Cook and Horobin (2006) who examine FOSS from a public administration (government) perspective.

2.5. DISCUSSION

Considering that disasters are spatial phenomenon, it would be reasonable to assume that GIT are being effectively employed throughout all phases to assist the disaster management process. While this is true in the case of developed countries, the same cannot be said for developing countries. The use of GIT for disaster management in developing countries is limited by a number of well documented barriers, including: a lack of financial resources (Renyi and Nan, 2002), a lack of local GIT expertise/knowledge (Mohamed and Plante, 2002), institutional/political instability (Pande, 2006), and a shortfall of spatial data (Murgia *et al.*, 2002; ESRI, 2006). The degree to which each of these GIT implementation barriers limits the use of GIT varies between developing countries, and within each country depending on the administrative level.

We have examined the literature and discussed various aspects of research on natural hazards and disaster management. Developing countries are highly vulnerable to natural disasters, a vulnerability that could be addressed partially through GIT. However, there are numerous barriers to GIT implementation in the developing world. We reviewed the application of GIT in natural disaster management and focused on describing the significant potential for GIS, RS and IGIS to assist the disaster management phases. We discussed the concept of FOSS, and argued that they have reached a stage a maturity that makes FOSS a viable alternative model over commercial software, especially in developing countries. The FOS GIT software domain is steadily growing and there are already many mature projects that currently offer a range of functionality (Raghavan *et al.*, 2006; Steiniger and Bocher, 2008).

Given the continued growth of FOS GIT, we propose that its current availability offers increasing potential to the local level disaster management practitioner community in developing countries. In this section we discuss why and how FOS GIT can, and should, be implemented at the local level in developing countries in order to improve disaster management capacity, and propose future research needs in this area.

The cosmopolitan existence of FOSS is a relatively new phenomenon, as are the applications that are emerging. Currently, within the literature that addresses FOS GIT, there appears to be very little that examines its use in the specific research domain of natural hazards and disaster management, and this finding may be related to the fact that the entire FOS GIT domain is quite new compared with proprietary GIT software. Table 2.4, containing search results from the SCOPUS database, provides quantitative evidence of the difficulty in finding literature that applies FOS GIT in the field of natural disaster management in developing countries. Although the concepts of GIT have existed for decades, and are now reflected in a large commercial GIT software market, those concepts have only recently been transformed into capabilities within FOS GIT, with the exception being GRASS. However, GRASS was originally developed by the U.S. Army Corp of Engineers in the early 1980s and is currently used in academic and commercial settings around the world, and by numerous government departments (e.g. USGS and NASA)[4]. As a result of its long use and development (which is now multi-national) history it has evolved into a sophisticated and powerful raster/vector GIS, used for geospatial data management and analysis, image processing, graphics/map production, spatial modeling, visualization and much more. Although GRASS is very powerful, its main drawback is its unfriendly user environment, as it functions primarily through command line operations which can be a challenge for non-expert users (Ramli *et al.*, 2005; Steiniger and Bocher, 2008).

Furthermore, a key word search of 'hazard' and 'disaster', independently, of all presentation titles from the FOSS4G 2006 and 2007 (www.foss4g2006(2007).org/) conference yielded only three that contained 'hazard' and one that contained 'disaster.' This is surprising given the increasing frequency of natural disasters and the critical role that GIT plays within the various management phases. However, although very few presentation titles include the word 'hazard' and/or 'disaster', it is likely that many of the topics discussed do contain recent research or software development relevant to the study and/or management of natural hazards and disasters. For example, addressing how FOS GIS software can contribute to SDI development is relevant to disaster management, since the required spatial data are often lacking, although an explicit connection may not necessarily be made. Coppock (1995), in a study of GIS and natural hazards research, makes an analogous point, explaining that GIS and natural hazards are multidisciplinary

[4] See http://grass.itc.it/intro/general.php

fields, and that much of what has been written appears in the literature of those disciplines.

Table 2.4. Literature themes search results from Scopus[5].

LITERATURE THEMES	ADVANCED SEARCH PHRASES USED (in: title-abstract-keyword)	# of RESULTS
Natural Hazards and Disasters	((“disaster*” OR "natural disaster*" OR "natural hazard*" OR “environment* hazard*” OR "flood*" OR "earthquake*" OR "storm*" OR "hurricane*" OR "tsunami*" OR "landslide*")) + *“hazard*” (which includes hazards that are not of natural origin)*	**254,109** ***459, 881***
Natural Hazards and Disasters + Disaster Management	(("disaster*" OR "natural disaster*" OR "natural hazard*" OR "environment* hazard*" OR "flood*" OR "earthquake*" OR "storm*" OR "hurricane*" OR "tsunami*" OR "landslide*") AND ("disaster* manage*" OR "hazard* manage*" OR "mitigation" OR "prepare*" OR "respon*" OR "relief"))	**54,283**
Natural Hazards and Disasters + Disaster Management + Geospatial Information Technology (GIT)	(("disaster*" OR "natural disaster*" OR "natural hazard*" OR "environment* hazard*" OR "flood*" OR "earthquake*" OR "storm*" OR "hurricane*" OR "tsunami*" OR "landslide*") AND ("disaster* manage*" OR "hazard* manage*" OR "mitigation" OR "prepare*" OR "respon*" OR "relief") AND ("geo* info* sys*" OR "GIS" OR "geoinfo*" OR "3S" OR "geospatial" OR "geo* info* tech*" OR "remote sens*" OR "RS" OR "earth observation*" OR "EO" OR "satellite" OR "spatial*"))	**4,994**
Natural Hazards and Disasters + Disaster Management + Geospatial Information Technology (GIT) + Developing Countries	(("disaster*" OR "natural disaster*" OR "natural hazard*" OR "environment* hazard*" OR "flood*" OR "earthquake*" OR "storm*" OR "hurricane*" OR "tsunami*" OR "landslide*") AND ("disaster* manage*" OR "hazard* manage*" OR "mitigation" OR "prepare*" OR "respon*" OR "relief") AND ("geo* info* sys*" OR "GIS" OR "geoinfo*" OR "3S" OR "geospatial" OR "geo* info* tech*" OR "remote sens*" OR "RS" OR "earth observation*" OR "EO" OR "satellite" OR "spatial*") AND ("develop* countr*" OR "develop* region*" OR "develop* nation*" OR "transition* countr*" OR "third world" OR "less develop*" OR "East* Europe" OR "Africa" OR "Asia" OR "South America" OR "Central America" OR "China" OR "India" OR "Pakistan" OR "Indonesia" OR "Malaysia" OR "Thailand" OR "Bangladesh"))	**769**
Natural Hazards and Disasters + Disaster Management + Geospatial Information Technology (GIT) + Developing Countries + Free and Open Source Software (FOSS)	(("disaster*" OR "natural disaster*" OR "natural hazard*" OR "environment* hazard*" OR "flood*" OR "earthquake*" OR "storm*" OR "hurricane*" OR "tsunami*" OR "landslide*") AND ("disaster* manage*" OR "hazard* manage*" OR "mitigation" OR "prepare*" OR "respon*" OR "relief") AND ("geo* info* sys*" OR "GIS" OR "geoinfo*" OR "3S" OR "geospatial" OR "geo* info* tech*" OR "remote sens*" OR "RS" OR "earth observation*" OR "EO" OR "satellite" OR "spatial*") AND ("develop* countr*" OR "develop* region*" OR "develop* nation*" OR "transition* countr*" OR "third world" OR "less develop*" OR "East* Europe" OR "Africa" OR "Asia" OR "South America" OR "Central America" OR "China" OR "India" OR "Pakistan" OR "Indonesia" OR "Malaysia" OR "Thailand" OR "Bangladesh") AND ("open source" OR "OS" OR "open source software" OR "OSS" OR "free software" OR "FS" OR "free and open source" OR "FOS" OR "free and open source software" OR "FOSS" OR "F/OSS" OR "free/libre and open source software" OR "FLOSS" OR "open source software/free software" OR "OSS/FS" OR "FOSS4G" OR “GRASS” OR “gvSIG” OR “Quantum” OR “SAGA” OR “uDig” OR “ILWIS” OR “JUMP” OR “DIVA” OR “KOSMO”))	**15**

[5] Scopus is the largest abstract and citation database of research literature and quality web sources (www.info.scopus.com)

While a review of the application of FOS GIT in the area of natural hazards and disaster management is desirable, the lack of available literature (see Table 2.4) makes this task nearly impossible. However, when you remove the FOSS component, there is an abundance of literature that utilizes proprietary GIT software, as was demonstrated in the previous section on GIT and disaster management, and in Table 2.4. More common from the FOSS perspective is literature that emphasizes the great potential it offers in areas such as disaster management, without going into any more detail about specific applications or examples of successful usage. Thus, further research is required regarding the current capabilities of FOS GIT, and more specifically, how they can be used by the disaster management community in developing countries. Again, we emphasize that sufficient time has not elapsed to allow for the creation of a literature base in this research area, yet strongly believe that more and more examples of successful FOSS implementation will undoubtedly emerge in the coming years. This belief is based on the increasing interest in FOSS and overall growth of the user and development communities, through initiatives such the OSGeo and websites like opensourcegis.org and freegis.org.

Among the broad set of Millennium Development Goals that the United Nations established in 2000, one stands out: "Make available the benefits of new technologies, especially information and communications technologies[6]." GIT are with the domain of ICT, yet peppered throughout this chapter are a number of barriers that can limit GIT implementation in developing countries. We propose that FOSS can reduce some of these barriers, and in doing so, can also help in achieving the development goals established by the UN.

Primarily, FOSS eliminates the need to purchase expensive software licenses and makes GIT accessible to anyone, including local level disaster managers operating on very small budgets. This point is of fundamental importance when considering that in many cases disaster management responsibilities and duties are decentralized to local governments

[6] See http://www.un.org/millenniumgoals

without being accompanied by sufficient funding (Montoya and Masser, 2005). Second, there exists a lack of local expertise and knowledge that is required to implement and maintain the use GIT. FOS GIT software could be used to learn about the technology itself, and the potential ways in which it could be used for natural disaster management purposes. Raghavan *et al.* (2006) emphasize that previous FOS GIT technology transfer was an arduous task for novice users, but recent developments in the availability of packaged solutions, such as FWtools (see maptools.org), and commercial support have helped reduce implementation obstacles. In addition, many FOS GIT software products are available as a single executable file, and once downloaded, are installed in the same manner as proprietary software (e.g point and click). Albeit, some software versions designed for Linux or other FOSS operating systems do require specific installation instructions and a certain amount of computer knowledge. Furthermore, that FOSS can be an effective educational/training tool is an idea that is widely acknowledged, given that they can be accessed at no cost and experimented with in whatever way users see fit. Local workforce development and capacity building projects are essential for sustained GIT implementation and maintenance that does not rely on external support or funding.

In general, disaster management is dependant on the functional and effective operation of institutions, whether formal or informal, and at the local level where it matters most (Pande, 2006). However, government instability is common in developing countries, which leads to institutional instability (Murgia *et al.*, 2002), which can result in a lack of commitment to address disaster management requirements, such as providing adequate technology and training. As a result of this instability, Ramasubramanian (1999) suggests that GIS implementation in developing countries is likely to be more successful if it relies on the capacity of empowered individuals and groups rather than solely on organisational structures, such as public institutions. To some extent, FOS GIT could be harnessed to empower such groups, and allow them to benefit from technology without having to rely only on institutional initiatives and financial support.

Lastly, and perhaps most importantly, FOS GIT offers considerable potential to help build spatial data infrastructures required to fulfil basic disaster management mitigation and preparation planning, and following a disaster, speed response and recovery efforts. It has already been shown that many essential disaster management requirements hinge upon the existence of required spatial datasets, such as critical facilities, transportation infrastructure and population distribution (location of towns and villages), yet many of these key datasets are missing in developing countries. Especially for assessing the situation in more remote regions, which are frequently only reached days or even weeks after an event, a detailed inventory of settlements and infrastructure may save many lives and speed up recovery (Kerle and Oppenheimer, 2002). Montoya and Masser (2005) emphasize the need to identify or develop cost-effective data collection methods for producing spatially referenced information in developing countries. Mansourian *et al.* (2004) propose the development of a SDI as a framework to facilitate disaster management, and many currently available, and user friendly, desktop FOS GIS (see Steiniger and Bocher, 2008) have the necessary functionality to assist the SDI development process.

Many of the barriers to successful GIT implementation in developing countries can potentially be addressed with FOSS. Currently, there are many basic FOS GIT software available and others are undergoing rapid development (Raghavan *et al.*, 2006). However, there still remains a need to identify particular software products, establish feasible methodologies and workflows, and in general document specific examples of FOSS usage. While few would argue against the potential of FOSS, there exists a research agenda with the aim of clarifying the exact role of FOS GIT during each of the phases of the disaster management cycle. Regardless, a lack of attention to the aforementioned GIT implementation barriers in any decision on whether to adopt GIT will significantly increase the risk of system failures, a matter of some significance in any environment characterized by a lack of financial, technical and human resources (Sliuzas, 1999).

This review suggests that the successful application of GIT in natural disaster management requires significant spatial data inputs of high quality, advanced GIT knowledge and technical skills, and/or advanced functionality primarily offered by expensive proprietary software. Each of these requirements constitutes significant obstacles from a developing country perspective, especially at any administrative level other than national. Another noteworthy fact is that the use of proprietary GIT typically requires significant computing resources. This represents a huge obstacle in developing countries, which often do not have access to modern (i.e. less than 2-3 years old) computer hardware (Caldeweyher *et al.*, 2006). GIS users in developing countries are likely unable to take advantage of advanced spatial analysis and data visualization features prevalent in current proprietary GIS software. In comparison, FOS GIS software generally require less processing power, and are more suitable for users who do not have modern computers. Thus, while advanced GIT usage is feasible in developed countries and within academic/research environments (including some in developing countries), for the typical disaster management practitioner in developing countries this type of high end GIT software usage is unachievable (Cutter, 2003).

Although we have argued that currently available FOS GIT have great potential, we do acknowledge that proprietary GIT software, at this point, offer superior overall functionality and provide advanced analytical and visualization capabilities that are beyond what current FOS GIT software can provide, with GRASS being a possible exception. However, GRASS is notoriously difficult to use and requires an advanced GIT skill set, and as a result, it is not suitable for use at the local level in developing countries where such expertise is in short supply, and where an inability to successfully use the software may result in frustration and discouragement. To avoid such a result, we suggest that simpler FOS GIT software could be implemented and utilized more successfully, and at the same time provide sufficient functionality to improve current disaster management GIT requirements at the local level. In addition, combining a number of FOS GIT software together can extend the functionality in the long term. GIT usage must not be over ambitious in the early stages and should focus on the core requirements needed to improve existing disaster management capabilities. Osti *et al.* (2008) make a similar point, and suggest that low-tech systems, which are less cost intensive and can be handled by the local population, are of high interest in the context of developing countries.

Within the hazard and disaster management literature that addresses developing countries and GIT implementation issues there are a couple additional topics that deserve mentioning: the participatory approach (e.g. PGIS) and the concept of traditional/indigenous environmental knowledge. Both of these topics are also partly embedded within the technology transfer literature, and although not within the scope of this paper, we will briefly touch on these two topics since FOSS has a potentially large role to play.

With technology transfer there is a tendency to assume that development occurs when less developed countries adopt the technologies and methods of the more advanced countries (Britton, 2000). However, this approach is increasingly being recognized as ineffective (Heeks, 2002; Brewer *et al.*, 2005). Although GIT implementation successes are often reported in popular magazines or trade journals, their sustainability is seldom documented, and failures are not reported or glossed over to avoid criticism (Ramasubramanian, 1999). Heeks (2002) explains that the introduction of GIS in developing countries has been problematic, as they are seen to incorporate a number of assumptions and requirements that derive from Western rationalism. One way to possibly improve the success of technology transfer initiatives is through participatory approaches. Within the GIT domain, GIS has garnered considerable attention from a participatory standpoint and thus will be used as an example. In terms of developing countries, Abbot *et al.* (1998) define PGIS as "an attempt to utilise GIS technology in the context of the needs and capabilities of communities that will be involved with, and affected by, development projects and programmes." A central objective of the participatory approach is to capture local knowledge and combine it with more traditional spatial information, and to facilitate GIS production and use which are community-based. Creating GIT environments that pull in new ideas, and possibly new spatial methods and techniques, rather than having them pushed in from the outside, appears to be a more effective solution (Britton, 2000). Developing countries could benefit from international development programs that focus on capacity building in the area of participatory GIT-based FOSS implementation. Knowledgeable practitioners in developing countries could then further build local capacity, especially with FOSS, which have been shown to be a good fit for developing countries. If appropriately utilized, Rambaldi *et al.*, (2006) emphasize that participatory approaches could exert profound impacts on community empowerment, innovation and social change.

Kienberger and Steinbruch (2005) applied a PGIS approach in Mozambique, in which the main objectives were to acquire spatial data of the communities through GPS surveys, to better visualize certain aspects of the community to assist disaster risk committees, and to identify secure locations in the case of floods. Results indicate that the participatory approach was suitable for the collection of spatial information and to capture the perception of the local people regarding disasters. A follow up of this study revealed that in some communities, and without outside/donor influence, maps were also used at meetings to discuss issues with a spatial relevance.

Generally speaking, participatory approaches can help build local capacity to understand and implement GIT to improve disaster management capabilities. Using a participatory approach local knowledge about natural hazards - their location and frequency - can be ascertained from community members and represented spatially within a GIS. For example, using a GPS coordinates of the location of previous floods can be captured, along with elevation data. Within the GIS the flood point locations can be analyzed in conjunction with elevation data (e.g. a DEM or contour lines), and potential flood scenarios can be considered and prepared for accordingly. Combing locally derived hazard knowledge with other spatial data such as transportation infrastructure, critical facilities and towns/villages within a GIS environment will help the local population to be more prepared for and help mitigate potential disaster impacts. Ultimately, the goal is to reduce disaster vulnerability, and this can be achieved with a better spatial understanding of the relationship between natural hazards and the elements at risk (e.g. people, infrastructure, etc.) (Montoya and Masser, 2005).

In the past, there has been unwillingness to use 'non-scientist' or 'indigenous knowledge' as data. However, there is growing recognition of the importance of indigenous knowledge, and the need to better understand how it can be combined with Western knowledge to reduce natural hazard vulnerability (Pande, 2006; Mercer *et al.*, 2007). Local communities in developing countries rely heavily on their environment; they depend on the subtleties of ecological cycles and patterns, and have accumulated a body of wisdom commonly referred to as 'traditional environmental knowledge' (TEK) (Brodnig and Mayer-Schönberger, 2000). "TEK is in essence a geographical information system derived from and embedded in the close relationship of local people with their land and natural resources...with members of the community serving as repositories for different types and categories of data..." (Brodnig and Mayer-Schönberger, 2000). Raghavan *et al.* (2006) propose that FOS GIT could help local practitioners incorporate spatial knowledge, and thus integrate TEK with technology use. Such an approach could prove valuable for natural disaster management, since local knowledge of environmental hazards and traditional coping strategies could be very useful.

2.6. CONCLUSION

As the human population continues to grow, and considering recent evidence of climate change that might exacerbate meteorological related natural hazards in particular, there is reason for concern that natural disasters may occur in the future with increasing frequency and consequence. As a result, there is an immediate need to utilize available technology to reduce natural hazard vulnerability and in general to be more prepared to effectively respond to disasters when they occur.

This article has reviewed and examined the use of geospatial information technology (GIT) in the field of natural disaster management, with an emphasis on developing countries where natural hazard vulnerability is high and disaster impacts can be particularly devastating. The ability of GIT to acquire, interpret, analyze, map and disseminate information, are essential during all phases of the natural disaster management cycle – the process of mitigation, preparation, response and recovery. Since disasters are spatial phenomenon there is a strong relationship between disaster management requirements and the spatial information and decision support capabilities offered by GIT. In this context, GIT includes geographic information systems, remote sensing, global positioning systems and Internet GIS. Among numerous other tasks, GIT provides a basis for planning mitigation strategies, hazard and risk assessment/mapping, vulnerability assessment, vehicle dispatch and supply routing, damage assessment, and response resource mobilization. Consequently, by using GIT, it is possible to identify and mitigate risk, be better prepared for and respond to disasters, and recover from disasters. However, we have also identified and described a number of GIT implementation barriers that are especially relevant to the application of GIT at local administrative levels, where a strong disaster management initiative is required. These barriers include, but are not limited to: (1) a lack of financial resources, (2) a lack of spatial data, (3) political/institutional instability and (4) a lack of local GIT knowledge/expertise. Thus, until at least some of these barriers are overcome the level of ability for GIT to improve overall disaster management capacity at the local level will remain low.

Many researchers have highlighted the particular opportunity that free and open source software (FOSS) now provides for developing countries that were previously unavailable. Attractive characteristics of FOSS from a developing country perspective include: cost, freedom, accessibility, customizability, compatibility, and software/technical capacity development opportunities. The cost aspect is especially significant from a GIT perspective, as proprietary/commercial GIT software are expensive and a lack of financial resources is currently a very significant GIT implementation barrier. Recent growth and development in the GIT-based FOSS domain has resulted in the emergence of many mature, very capable and user-friendly software products that in some cases offer functionality that is comparable with commercial GIT software. As a result, we propose that GIT-based FOSS products can be used to improve the use of GIT in developing countries, especially at the local level. Specifically, GIT-based FOSS provide opportunities to improve local GIT knowledge and related skill sets required for their effective application in the field of natural disaster management. Additionally, the current capabilities of GIT-based FOSS allow for the development of spatial data infrastructures that are required by the disaster management practitioner community to successfully implement GIT, for purposes such as hazard and risk assessment. Considering the lack of available spatial data in developing countries, which is a GIT implementation barrier, the development of SDIs will represent a major step forward. However, future research is required that identifies specific GIT-based FOSS and functionality that can be effectively implemented at the local level in developing countries to improve overall natural disaster management capacity.

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CHAPTER III

A FOSS Based Approach Using gvSIG for the Development of Framework Spatial Datasets for Local Level Natural Disaster Management in Developing Countries

3.1. INTRODUCTION

Disasters caused by natural hazards are often deadly and destructive events that significantly impact social, economic, cultural and environmental systems. Although natural hazards pose a considerable threat to all countries, developing countries are disproportionately affected by disasters (Briceño, 2004; Guinau *et al.*, 2005). Natural disasters cannot entirely be prevented, but disaster losses can be minimized with effective disaster management – the process of mitigation, preparation, response and recovery. Since each management phase has a geographic component that relates to where people, places, and things are located (Gunes and Kovel, 2000), the entire disaster management process can be significantly enhanced through the effective use of geospatial information technology (GIT) such as geographic information systems (GIS), remote sensing (RS), and global positioning systems (GPS). For example, among numerous other tasks, GITs provide the basis for hazard and risk assessment (Rego, 2001; Ramli *et al.*, 2005; Dewan *et al.*, 2007b), vulnerability assessment (Cutter *et al.*, 2000; Weichselgartner, 2001; Kienberger and Steinbruch, 2005), vehicle dispatch and supply routing (Dong, 2005), damage assessment (Rivereau, 1995; Zhang *et al.*, 2002; Chen *et al.*, 2005) and resource mobilization (Goodchild, 2006). Consequently, by using GIT it is possible to identify and mitigate risk, be better prepared for and respond to disasters, and recover from disasters.

Few would dispute the potential benefits of GIT throughout the disaster management process; however, to implement GIT requires software, computer hardware, spatial and descriptive (attribute) data, and personnel who can effectively utilize it (Dash, 1997; Montoya, 2002). In developing countries it can be a challenge to meet such requirements (Rabindra *et al.*, 2008), and as a result, there are dramatic differences in the ability to implement GIT, not only between developed and developing countries, but also within different administrative levels (Laben, 2002). Many of the barriers to GIT implementation are common within the information and communication technology (ICT) domain in general, and we will elaborate on them in subsequent sections.

To overcome, or at least help break down some of the barriers to GIT use, many have suggested adoption of free and open source software (FOSS) (e.g. Rajani *et al.*, 2003; Ramli *et* al., 2005; Roets *et al.*, 2007). The growth of established projects and the advent of new projects in the FOS GIS domain now provide considerable opportunities that a few years ago did not exist (Steiniger and Bocher, 2008). However, aside from capable software, an essential prerequisite to using GIS is spatial data, yet in developing countries spatial data are often of poor quality or non-existent (Brodnig and Mayer-Schönberger, 2000; ESRI, 2006; Dewan *et al*, 2007; Osti *et al.*, 2008). As a result, there exists a need to develop or identify cost-effective data collection methods for producing spatially referenced information in developing countries that can be effectively utilized for disaster management purposes (Montoya and Masser, 2005).

One goal established at the 2005 World Conference on Disaster Reduction (www.unisdr.org/wcdr) is to strengthen local-scale disaster management capacity. In this context, local scale implies the lowest government level (e.g. district) and municipal administrative units that may exist, such as city, town or village. One way to achieve this is through the development and improvement of relevant and large-scale databases, in conjunction with the development of scientific, technological and technical capacities needed to research, analyze and map natural hazards, vulnerabilities and disaster impacts (UN/ISDR, 2005). FOS GIS can provide a technological framework with which a number of these goals can be addressed. In this article we describe the key spatial or framework datasets needed to improve disaster management capacity at the local level in developing countries. We then demonstrate how currently available FOS GIS contain the required functionality or capabilities necessary to develop the framework datasets. Recent desktop FOS GIS provide a great opportunity for the transfer of a relatively simple, well-established, and effective set of GIS concepts and capabilities to local level disaster management practitioners in developing countries. While FOSS in general are recognized as having great potential for the developing world, there is a paucity of literature that describes exactly how specific software products can be used to improve disaster management capacity, and this article attempts to help fill that gap. Describing the framework datasets and demonstrating how they can be easily developed using currently available FOS GIS provides one example of how local level disaster management capacity can be enhanced in developing countries. However, before proceeding, we first provide pertinent background information on the disaster management cycle in order to justify the choice of framework datasets and subsequent FOS GIS workflows presented.

3.2. BACKGROUND

3.2.1 Natural hazards and disasters

Natural hazards vary greatly in terms of frequency, duration, scale, impact, etc., and these differences have implications for the spatial data and GIT required during each unique disaster management phase. Examples of natural hazards include earthquakes, tsunamis, hurricanes, typhoons, droughts, fires, tropical storms and floods. However, a distinction can be made between "rapid-onset" natural hazards such as floods and earthquakes, or slower 'creeping crises' hazards like drought or disease (De Paratesi, 1989). Our focus is on rapid-onset natural hazards, as Coppock (1995) points out that those developing slowly generally have more in common with natural resource management, at least from a mitigation perspective. Moreover, Oloruntoba (2005) emphasizes that the number of people affected by disasters resulting from natural hazard events of rapid-onset is increasing.

Unlike natural hazards, disasters are more difficult to define, given their varying magnitude, temporal and spatial dimensions and varying social and economic impacts. McEntire (2001) describes natural disasters as the disruptive and/or deadly and destructive outcome of triggering agents when they interact with, and are exacerbated by, various forms of vulnerability. When a hazard intersects the zone of human use there is the potential for a disaster. Rapid onset hydro-meteorological related natural disasters have more than doubled since 1996 and caused over 90 percent of deaths from natural disasters during the 1990's (IFRC, 2001). Our focus is on using FOS GIT capabilities to reduce the impact of natural hazards at the local scale in developing countries.

3.2.2 Disaster management

Disaster management can be understood as a cycle which includes an effort to mitigate against, prepare for, respond to, and recover from a disaster (Montoya, 2002). The core components of this cycle are also commonly referred to within the emergency management literature (e.g. Cutter, 2003), and often in conjunction with natural disasters (e.g. Cova, 1999). Thus, emergency and disaster management are closely linked; after all, a disaster clearly constitutes an emergency. Geospatial information technology (GIT), and its ability to acquire, interpret, analyze, map and disseminate, are essential in all areas of natural disaster management. GIT provides the basis for estimating and mapping risk, planning evacuation routes, determining suitable areas for shelters, identifying disaster victims, and assigning resources during recovery, among many other essential tasks (Goodchild, 2006). The value of GIS, for example, arises "directly from the benefits of integrating a technology designed to support spatial decision making into a field with a strong need to address numerous critical spatial decisions" (Cova, 1999). Figure 3.1 incorporates GIT within the disaster management cycle to emphasize the central role it plays during all phases.

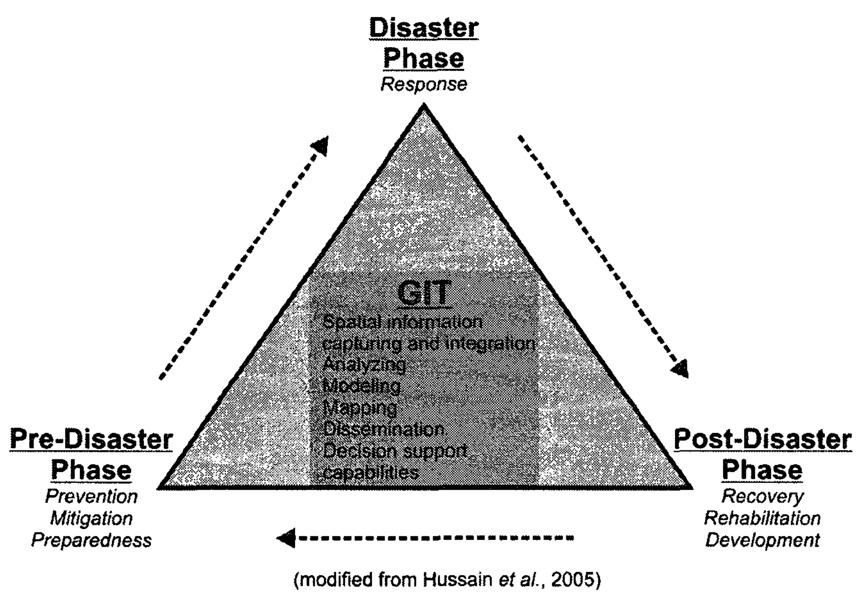

Figure 3.1. A disaster management cycle incorporating GIT.

However, to effectively implement GIT for disaster management purposes requires a sufficient amount of spatial/attribute data, which are typically not available in developing countries (Osti *et al.*, 2008). Thus, to increase the potential of GIT use for disaster management in the context of developing countries requires a substantial effort and investment in spatial data creation. In fact, Mansourian *et al.* (2004) propose the development of a spatial data infrastructure (SDI) as a framework to facilitate disaster management. Laben (2002) emphasizes that it is extremely important to have technological alternatives available that can be used by all levels of the emergency and disaster management communities, and we propose that FOS GIT provides this alterative, compared to proprietary GIT, in terms of building local level SDIs.

3.2.3 Developing countries and disaster vulnerability

Natural disasters tend to be much more deadly and destructive events when they occur in developing countries. About 95% of deaths caused by natural hazards occur in developing countries (Bui *et al.*, 2000), and the loss of GNP due to disasters is 20 times that of developed nations (Alexander, 1995). These alarming statistics can be partly explained by differences in natural hazard vulnerability. The concept of vulnerability is complex – it depends on a number of parameters – and varies depending on the research orientation and perspective (for example, see Cutter, 1996; Morrow, 1999; Cutter *et al.*, 2000; Weichselgartner, 2001; McEntire, 2001 and Cutter *et al.*, 2003). However, it is generally acknowledged that vulnerability to natural hazards is rising in developing countries, where more and more people are occupying low-lying coastal zones and seismically hazardous areas, becoming concentrated in urban environments, and cultivating land of marginal productivity that is subject to recurrent natural hazards (McEntire, 1999; El-Masri and Tipple, 2002; Briceño, 2004; UN/ISDR, 2005). In addition, poverty, poor housing quality, a lack of information about disaster risk, inadequate physical infrastructure, and poor telecommunications frequently exacerbate natural disasters in developing countries (Henderson, 2004).

An inability to implement GIT further increases hazard vulnerability. The primary barriers to GIT implementation at the local level in developing countries are: (1) a lack of financial resources, (2) a lack of local expertise/knowledge, (3) institutional/political instability, and (4) a lack of spatial data (Coppock, 1995; Ramasubramanian, 1999;

Britton, 2000; Brodnig and Mayer-Schönberger, 2000; Murgia *et al.*, 2002; Mohamed and Plante, 2002; Montoya and Masser, 2005; Pande, 2006; Osti *et al.*, 2008). Such barriers themselves can be exacerbated by disasters that jeopardize important social development goals such as addressing poverty, ensuring adequate food, water, and sanitation, and protecting the environment. Thus, developing GIT implementation solutions that are feasible in the context of developing countries, with respect to these barriers, could improve disaster management capacity and facilitate a reduction in natural hazard vulnerability.

3.2.4 Free and open source software and geospatial information technology

Although there are a number of criteria that a software package must meet to be considered FOSS, three essential features capture the essence of the semiofficial "Open Source Definition[7]":

- 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. (Weber, 2004)

From the perspective of developing countries, the FOSS model is a particularly good fit, for reasons that include: cost, freedom, accessibility, customizability, compatibility, capacity development and a general narrowing of the digital divide (Hoe, 2006); although the lower start-up costs aspect is definitely the most attractive factor (Rajani *et al.*, 2003). This is especially understandable in the context of GIT software, which can be very expensive. For example, Table 3.1 provides a price list of some popular high end and low end GIT software products.

[7] The full definition can be accessed at www.opensource.org/docs/osd

Table 3.1. Approximate costs of selected commercial GIS/RS software (the wide price ranges reflect possible variations in licence type, software options, purchasing agreements, etc.).

Application	Price range (USD)	Software
High GIS/RS	$10,000 to $50,000	ArcGIS (ArcINFO) Genasys ENVI ERDAS Imagine ER-Mapper
Low GIS/RS	$1,000 to $3,000	MapInfo ArcGIS (ArcView) ArcGIS extensions ERDAS Imagine Essential

Accessibility is another important characteristic of FOSS, as it can be downloaded from anywhere with an internet connection. This is typically not true of commercial/proprietary software which must be purchased before being obtained.

From a FOS GIT perspective, the software community is steadily growing, and since 2006 has been spearheaded by the Open Source Geospatial Foundation (OSGeo) (www.osgeo.org). The comprehensive list of links to FOS GIT related software projects/products available at opensourcegis.org and freegis.org provides evidence of an active development community. Moreover, a recent review of FOS GIS by Steiniger and Bocher (2008) found that:

a. four out of ten desktop projects examined receive governmental funding support;

b. there is an increase in the download rate of FOS GIS software; and

c. there is an increasing number of use cases of FOS GIS

Some notable FOS GIT programs, which offer a range of functionality from simple map viewing and data editing to more advanced spatial analysis, image processing 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. While alone, many FOS GIS do not have the capability of their commercial counterparts, together the functionality of many commercial applications can be reached. For a more in depth review and analysis of notable FOS GIT programs and their development platforms/implementation languages (e.g. C, Java and .Net) see Steiniger and Bocher (2008) and Ramsey (2007), respectively.

In the past, simply installing FOS GIS was an onerous task for beginners and required installing and configuring several libraries and related packages (Raghavan *et al*, 2006), yet with the recent availability of pre-packaged solutions, such as FWTools (see maptools.org), and single executable installation files (e.g. gvSIG, Quantum GIS) the installation process is now in many cases identical to or easier than many commercial packages. In particular, the often complex licensing applications/models that plague commercial software are non existent with FOSS. This is very important considering the lack of GIT knowledge/technical skills available at the local level in developing countries. This potential user group of FOS GIS that is composed of the practitioner community require software products that are relatively easy to install and subsequently utilize. In addition, the more mature FOS GIT products typically provide detailed user manuals which demonstrate the software capabilities and provide usage examples.

A final comment relates to the overall differences between FOS GIS and proprietary GIS functionality. Based on our own experience we concur with Caldeweyher *et al.* (2006), who states that only a few FOS GIS projects "have reached a level of sophistication and feature richness comparable to that of their proprietary counterparts, yet none combining true ease of use, analysis capabilities and simple publishing of maps." That said, the current capabilities and functionality offered by currently available FOS GIS are sufficient for a number of purposes, including the development of spatial data infrastructure required to assist and improve the disaster management process.

3.3. FRAMEWORK SPATIAL DATASETS

To implement GIS technology requires software, computer hardware, spatial and descriptive (attribute) data, and personnel who can effectively utilize it. In this section we focus solely on the spatial and descriptive attribute data requirement, and describe what we consider to be 'framework datasets' essential to the success of the disaster management process. Cutter (2003) identifies the development of baseline data to support GIS science applications in disaster management as a key topic that needs to be addressed in order to improve overall disaster management capacity, emphasizing that data quality, quantity and integration issues continue to plague the practitioner community. Currently, a huge disparity exists between the spatial data infrastructure (SDI) of developed and developing nations, and until the situation improves, the potential to implement GIT to assist local disaster management will remain low.

From the perspective of a local disaster or emergency management practitioner there are numerous spatial questions that need to be addressed before, during and after a disaster. Where should potential shelters be located? What towns or villages exist that may be impacted by various natural disaster types, and where are they located? Where can we get fresh drinking water for displaced populations? What is the best location for supply drop off zones and what transportation infrastructure exists? Answering these questions is essential for effective disaster management, and can be achieved through the viewing and analysis of relevant spatial data and relations that basic FOS GIS functionality, including data overlay, spatial querying and thematic mapping currently offer.

Our proposed framework datasets are intended as a guideline to help determine the most essential spatial data required for a holistic natural disaster management approach. Even though the natural processes (e.g. floods, earthquakes, landslides, etc.) that generate disasters might be fundamentally different, the techniques to assess and mitigate risk, evaluate preparedness, and assist response have much in common (Radke *et al*, 2000). Many of these techniques, such as vulnerability assessment, hazard mapping, evacuation planning, and damage assessment rely heavily on spatial data, and are impossible to implement without them.

Table 3.2 provides a list of 5 general spatial data categories and examples of each, along with a rational for their inclusion as framework datasets. While many of the framework databases already exist and are put to use for disaster management in developed countries, such data are not readily available in developing countries (ESRI, 2006) except at national spatial scales (e.g., 1:1,000,000). The selection of framework datasets within Table 3.2 was made based on the key categories of the Canadian Geospatial Data Infrastructure (CGDI) framework datasets (http://cgdi.gc.ca/en/resourcelibrary/keyStudiesReports) and their intersection with those datasets specified as fundamental for local level natural disaster management within the open literature. We selected the CGDI framework as an ideal model because it is a globally recognized standard that can be utilized at multiple spatial scales and these datasets support the majority of geomatics applications. Furthermore, the framework datasets include only those that can be developed prior to a disaster, and we acknowledge that other essential spatial data may need to be created post-disaster to further assist response and relief efforts.

Others have proposed the development of SDI as a framework to facilitate disaster management (e.g Mansourian *et al.*, 2004); however, this body of literature focuses on stressing the importance of spatial data throughout the disaster management process. Very limited information is presented that explains specifically what types of data are required during the various phases, and no authors, to our knowledge, have identified the most critical and feasible datasets needed for a holistic disaster management approach applicable at the local level in developing countries.

Table 3.2. Local level natural disaster framework spatial datasets and their rational (sources: Gunes and Kovel, 2000; Aloysius *et al.*, 2001; Rego, 2001; Balaji *et al.*, 2002; Cinque *et al.*, 2003; Cutter *et al.*, 2003; Papathoma and Dominey-Howes, 2003; Mansourian *et al.*, 2004; Kienberger and Steinbruch, 2005; ESRI, 2006; Dewan *et al.*, 2007).

Data Type	Rational
Hazards - potential hazard locations - rivers - fault lines - steep slopes - low lying coastal areas - extent/location of know hazards/disasters - flood plains – previous landslides - storm surge heights - previous earthquake epicenters	An understanding of the location and magnitude of hazards is fundamental to the disaster management process. Spatial information about past disasters as well as potential hazards and their extent is required. A hazards spatial database combined with other data in a GIS has great potential to improve the decision making process through each phase. Data on hazards contributes to understanding risk, which is essential for developing disaster mitigation and preparedness strategies.
Population - location of cities and villages - dense landuse/human use - population characteristics (e.g. some may be available from census data) - demographics - gender - race - socioeconomic status - others	Disasters result when human societies intersect natural hazards. Knowing the location and other characteristics of a population, including human landuse characteristics, are crucial to effective disaster management. A spatial database representing the population can help create essential plans, assess risk and vulnerability, guide response efforts, and plan recovery strategies. Regardless of the type and resolution of the data (e.g. point locations vs area units) there are many potential uses that can assist and improve disaster management decision making. The complexity of use depends on the type, detail and quality of the data, and available financial, technical and human resources.
Transportation Infrastructure - roads - surface type (e.g. paved, gravel, dirt) - rail lines - bridges - construction material - walking paths - air strips - surface type (e.g. paved, gravel, dirt)	A database of transportation infrastructure is critical for pre-disaster planning and during disaster response. Knowing the potential ways to get in and out of a disaster zone, and the likelihood that they are still intact, is invaluable information that can save lives. Among many other essential tasks, transportation infrastructure data can be used to evaluate and plan evacuation routes, assess response access, determine the best relief supply drop zones or distribution points and plan rebuilding efforts.
Critical Facilities/Locations - hospitals - potential shelters - schools - power grids/utilities - emergency facilities - police - fire station - response resources - others locally derived - water access point (e.g. well) - points of high ground - relevant public buildings	Before, during and after a disaster strikes there are many locations, buildings or facilities that are important for disaster management. A locally derived database of such facilities/locations allows for the creation of maps that can help with the development of mitigation strategies, such as public awareness, assist the establishment of preparedness plans and priorities, and can help guide and speed up response efforts. For example, knowledge of where schools are located will help determine where children will be located in the immediate aftermath of a rapid onset natural disaster that occurs during the day. Similarly, knowledge of potential shelter sites will assist post disaster response since safe and secure locations have been already been identified.
Administrative Boundaries - provincial - district - county - city - village - ethnic region - other jurisdictional or locally relevant boundaries	Who is responsible for what and where are critical questions that determine potential roles and responsibilities before, during and after a disaster strikes. Therefore, all administrative or relevant jurisdictional boundaries are considered as framework datasets.

Finally, the framework datasets are intended as a guideline to help determine the most essential spatial data required for a holistic natural disaster management approach. The identified GIT implementation barriers previously described will determine the extent to which this data already exists or can be created and utilized effectively. Existing spatial data created at the national or regional scale may not be accurate enough for local level use or may not contain the required attribute detail, among other potential problems. Local disaster management practitioner communities are likely going to have to create much of the required data on their own in order to make use of available FOS GIT. However, this can have advantages, as it allows them the ability to incorporate local or indigenous knowledge into the development of their spatial databases for disaster management. There is growing recognition of the importance of local/indigenous knowledge in natural disaster management in developing countries, and there is a need to better understand how it can be combined with Western knowledge and related scientific approaches to reduce natural hazard vulnerability (Pande, 2006; Mercer *et al.*, 2007; Osti *et al.*, 2008). Combing locally derived hazard and environmental knowledge with other spatial data such as transportation infrastructure, critical facilities and towns/villages within a GIS environment will help the local population mitigate potential disaster impacts and be better prepared to effectively respond. Ultimately, the goal is to reduce disaster vulnerability, and this can be achieved with a better spatial understanding of the relationship between natural hazards and the elements at risk (e.g. people, infrastructure, the environment, etc.) (Montoya and Masser, 2005).

3.4. CREATING FRAMEWORK DATASETS USING FOS GIT FUNCTIONALITY

Since developing countries often do not have access to modern (i.e. less than 2-3 years old) computer hardware (Caldeweyher *et al.*, 2006), and to be consistent with the working environments that may exist in developing countries, a personal computer with modest hardware, by today's standards, was utilized to demonstrate the potential of FOS desktop GIS to create many of the required framework datasets. We define desktop GIS as "mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations" (ESRI, 2008). Specifically, a desktop PC with 256 MB of RAM, a 2.53GHz CPU, a 40GB hard drive, and Windows XP operating system was used. Although Windows is proprietary software, its use in developing countries is widespread due to software piracy (Rajani *et al.*, 2003), and knowledge of Windows is viewed as a valuable skill (Brewer *et al*, 2005). Furthermore, most FOSS projects offer multiple versions of their software that can run on either Windows or FOSS operating systems such as Linux, therefore, the use of Windows is justified even though it is not FOSS.

Although there are a number of FOS desktop GIS currently available that provide the necessary functionality to develop many of the framework datasets, the specific software used for example purposes is called gvSIG (www.gvsig.gva.es) (Diaz, 2007; Rico *et al.*, 2008; Bayarri and Anguix, 2008). It was selected for a number of reasons. First, gvSIG is probably the largest FOS GIS project in terms of financial and development resources (Steiniger and Bocher, 2008), and is therefore unlikely to become obsolete. Second, gvSIG supports many open and proprietary standards of geospatial data, is functional with Windows, Mac OS X and Linux, and contains full user documentation. Third, it has a simple to understand graphic user interface (GUI) containing menu operations, buttons and dialog boxes and is offered in over ten languages, thus supporting an international user community. Fourth, gvSIG offers many software extensions that greatly increase its overall functionality (e.g. Raster pilot, Network pilot, Publishing extension, etc.[8]). As a result, it has great potential to be used for a variety of analytical purposes to improve disaster management related decision making following the creation of the framework datasets. A discussion of such analysis capabilities that are pertinent and feasible for local level disaster managers remains a desirable task, yet is beyond the scope of this paper. Nonetheless, a familiarity with gvSIG established during spatial database development will certainly help facilitate its use with available extensions that increase its overall functionality.

[8] For a complete list of available extensions see: www.gvsig.gva.es/index.php?id=2009&L=2&K=1

There are many ways to create the types of spatial data described in Table 3.2, however, the four methods that are considered appropriate for developing countries at the local level are on-screen digitizing, using global positioning system (GPS) units for coordinate collection, modifying/editing pre-existing data sources and possibly image/pixel classification (although this requires more GIT knowledge and skill compared to the other techniques). Figure 3.2 graphically elaborates on these methods. We propose that these methods are simple enough to be used by local level disaster management practitioners with basic GIS training or experience.

An extremely useful and relatively easy to use command line utility with excellent documentation and usage examples is GDAL/OGR (GDAL for raster data/OGR for vector data). It can be used to convert data between formats, reproject data from one coordinate system to another (including datum transformations), and generate rasters from vector data or vice-versa, among many other useful data management tasks[9]. Thus, GDAL/OGR could be useful in the development and integration of the framework datasets. Consider a case where spatial data may already exist, but are in the wrong format or projection. This can result in data alignment problems or the inability to effectively integrate all data within a single FOS GIS. GDAL/OGR provides the necessary functionality to help overcome such obstacles, and is therefore considered an essential component of the FOS GIT toolkit.

To get a sense of the spatial data infrastructure (SDI) that may be available for local level disaster management practitioners in developing countries, we chose Sri Lanka as an example for two reasons. First, Sri Lanka has a history of impact by natural disasters, most recently, the 2004 Tsunami destroyed over 118,000 homes and; second, among developing nations, Sri Lanka has taken an exemplary role, recently initiating a national steering group to create a nationwide SDI through their Ministry of Estate Building and Estate Infrastructure Development (http://www.mnbd.gov.lk/index.php?page=dep_17). As such, the current state of affairs with regard to spatial data within Sri Lanka provides a

[9] See http://www.gdal.org/

strong case for a pre-national spatial data infrastructure within a country that critically needs disaster management at numerous spatial scales.

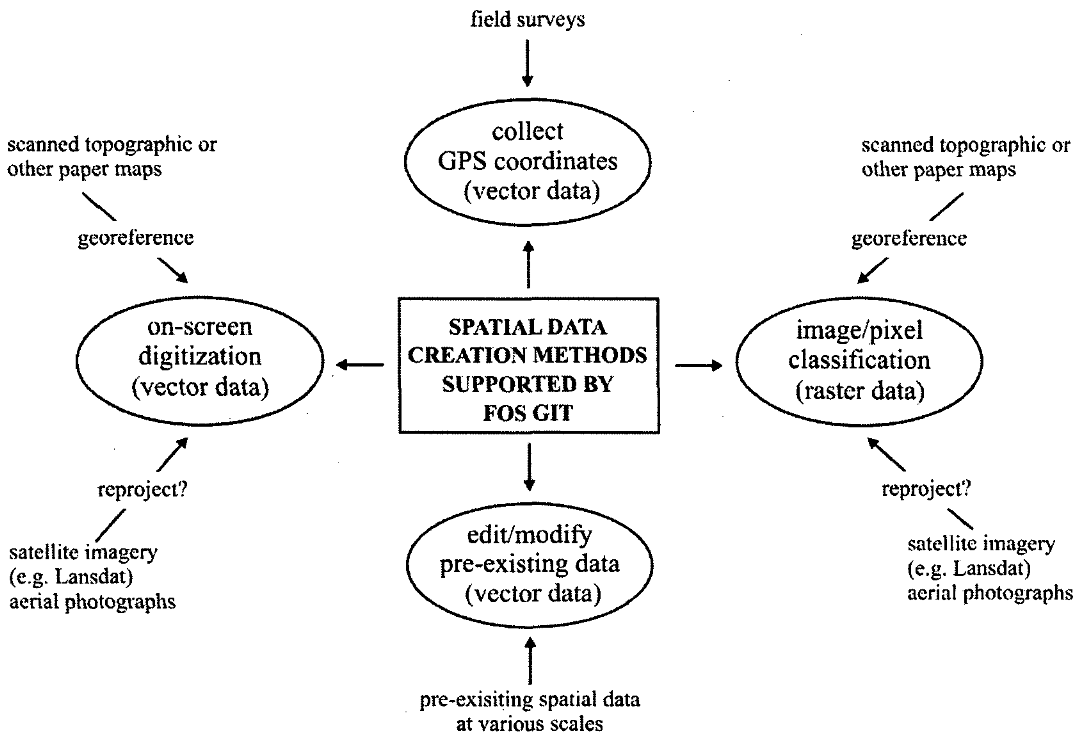

Figure 3.2. Feasible local level spatial data creation methods supported by FOS GIT.

A DVD of the SDI of the Sri Lanka Wildlife Conservation Society (SLWCS) was obtained. The SLWCS has been working to implement GIT technology at the local level in their conservation and resource management efforts[10]. As such, they have assembled a repository of currently available spatial data for various regions within Sri Lanka, including ad hoc satellite imagery and aerial photos. The SLWCS database is considered to generally resemble the type and quality of spatial datasets that may be obtainable by the local level disaster management practitioner community in developing countries.

An examination of SLWCS data revealed that they exist at varying source scales, projections, completeness, attribute detail, and coverage. The patchy nature of the currently available Sri Lankan datasets makes them difficult to integrate at a large scale

[10] See http://gis.slwcs.org/ for further information about the SLWCS GIS program

in any particular region (Chandeep Corea, head of the SLWCS GIS department, personal communication). As such, there is evidence that additional data collection efforts are required at the local level before GIS analyses can be successfully undertaken for planning and disaster management. In recognition of the need to work within existing data constraints and the requirement to produce new spatial data, the following data creation methods and gvSIG workflow examples illustrate a feasible approach for developing framework datasets, which is a prerequisite for local level disaster management related GIS implementation.

3.4.1 On-screen digitization

On-screen digitization is a relatively simple and well-established method for creating spatial data based on existing map sources or from remotely sensed imagery, such as satellite imagery or aerial photos. Figure 3.3 depicts the main steps involved in the on-screen digitization process.

To demonstrate the potential of FOS GIS for on-screen digitization of framework data, a 1:50 000 scale topographic map of Sri Lanka (Sheet 91) from 1985 is used that was provided by the SLWCS and covers a portion of the southern coast of the Matara district. Figure 3.4 shows a map of Sri Lanka and highlights the Matara district.

This topographic map can be used to digitize roads, rivers, lakes, towns, villages and urban areas, among other potentially relevant map features. The map had been divided into eight individual 150dpi jpeg images, and these were manually mosaiced using the Draw program available in OpenOffice, a popular FOSS cross-platform office application suite with functionality comparable with Microsoft Office[11] (Andrew, 2003). The fact that the map is over 20 years old is considered irrelevant, since the emphasis is on the process of creating spatial data as opposed to actually creating a usable and current database. It is up to local GIS practitioners to obtain the most relevant and up-to-date map/image sources available for their specific region/location.

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[11] See www.openoffice.org

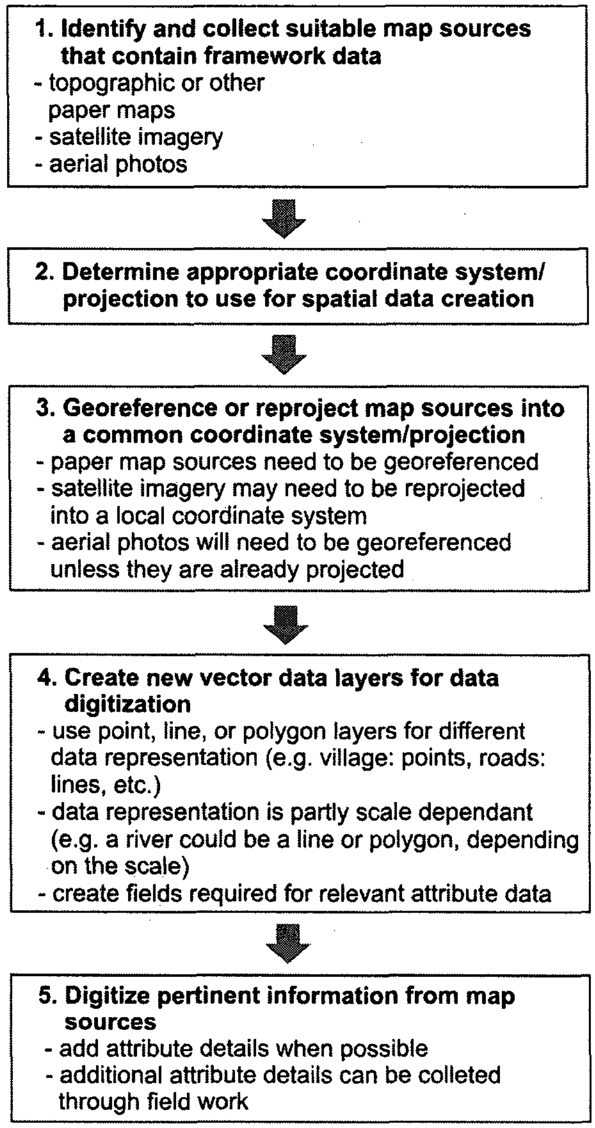


Figure 3.3. Primary steps required in the on-screen digitization process.

To use the mosaiced topographic map image in a GIS it first had to be georeferenced using a suitable map projection. WGS 84/UTM Zone 44 North (EPSG code 33624) was chosen because Sri Lanka is located in the center of this 6 degree zone. As well, this UTM WGS84 (Universal Transverse Mercator projection of the World Geodetic System 1984 speroidal surface) was selected because of its low within-zone deformation and because it is the most commonly accepted global mapping standard. A new view was created in gvSIG and the projection was defined. Figure 3.5 shows screen shots of the user friendly dialog box-based projection definition process in gvSIG. Different projections can be searched by EPSG code, by name or by area and custom projections can be specified by modifying specific parameters, such as the central meridian and standard parallels, by clicking the CRS (coordinate reference system) info button, as seen in number 3 of Figure 3.5.

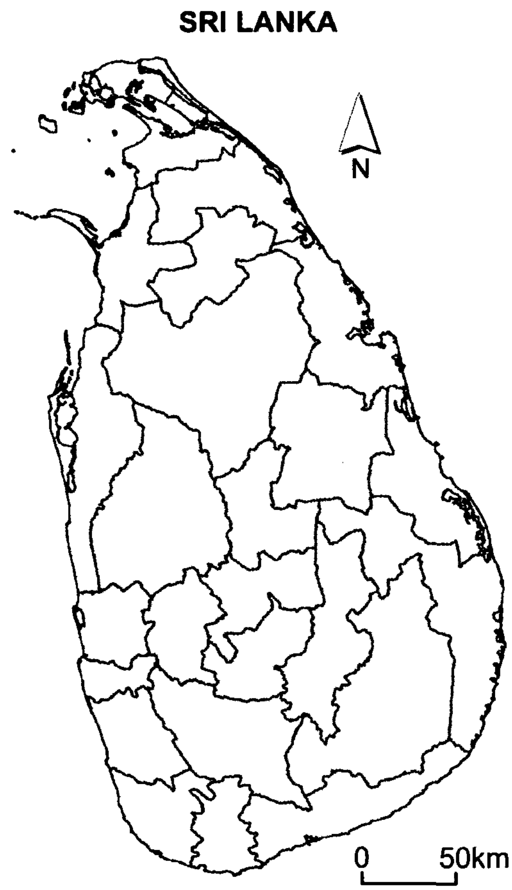
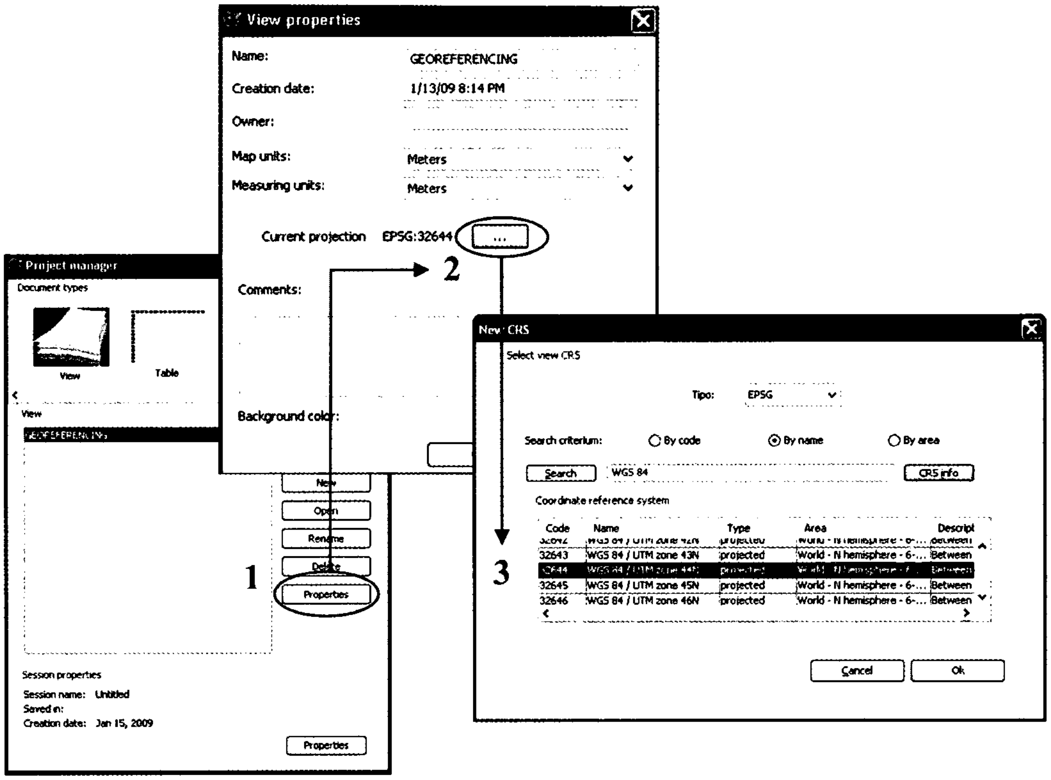


Figure 3.4. Map of Sri Lanka highlighting the Matara district.

Multispectral imagery was used as a basemap source to georeference the digital topographic map. All seven bands of a 30 meter resolution 2001 Landsat TM satellite image that covered the Matara district (p141r056) were downloaded for free from the Global Land Cover Facility (GLCF) website (http://glcfapp.umiacs.umd.edu) in geoTIF format. Bands 1, 2 and 3 were used to create a colour composite image for georeferencing purposes. Figure 3.6 shows a portion of the colour composite image and the Matara district boundary, as well as the raster properties dialog box which contains the functionality for assigning different bands to blue, green and red.



>Project manager >Properties >Current projection >Set to WGS 84/UTM Zone 44N

Figure 3.5. Defining the view/map projection in gvSIG.

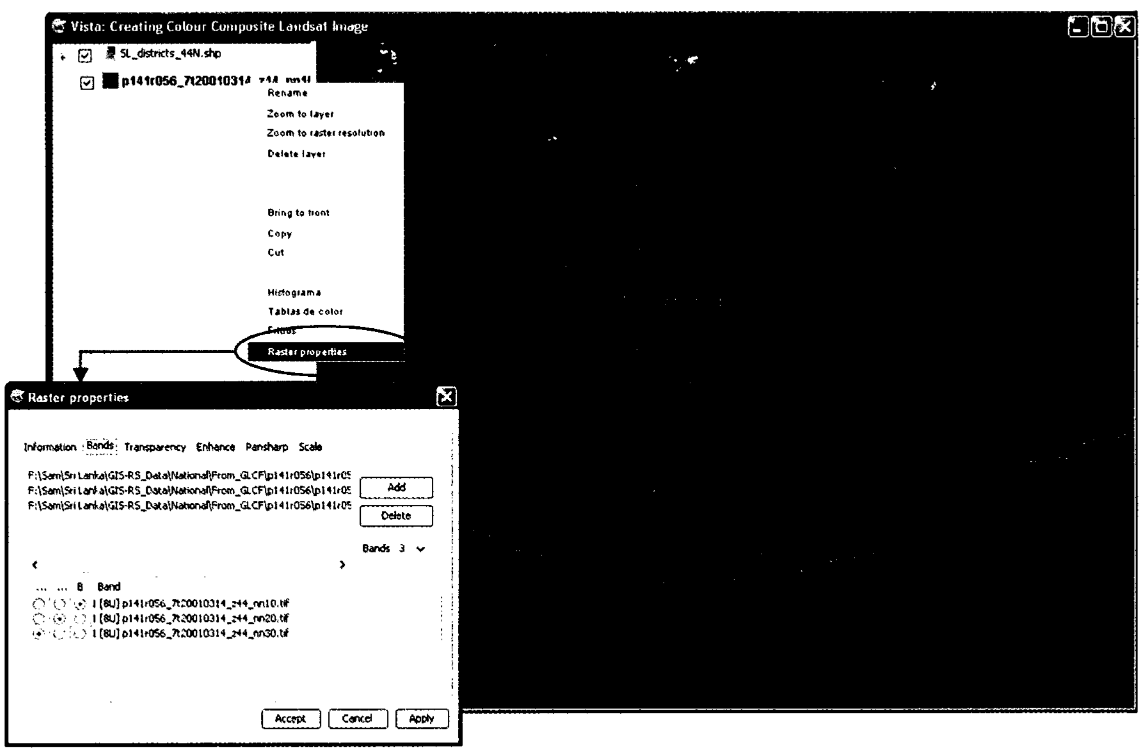
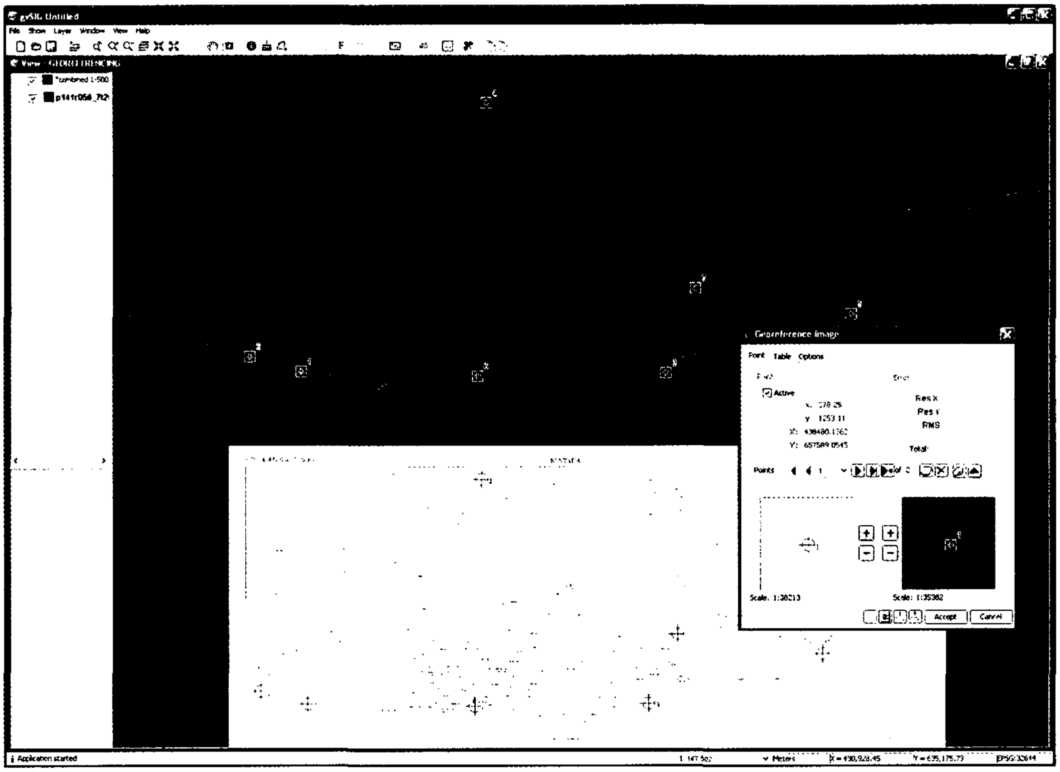


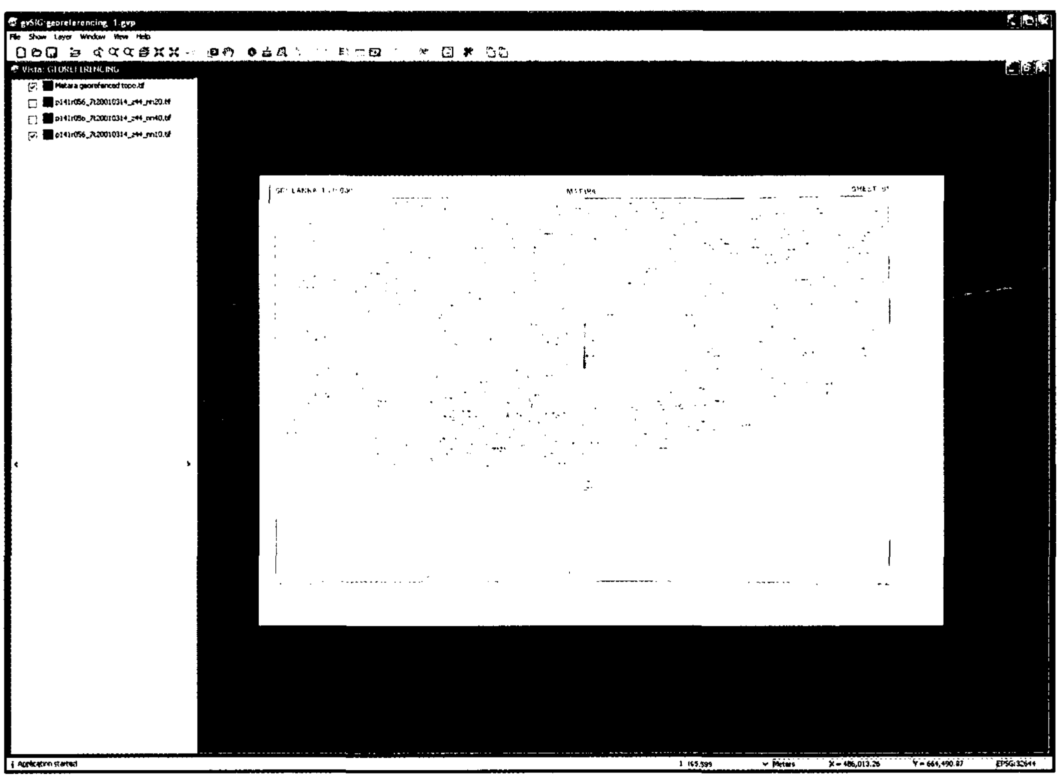
Figure 3.6. Colour Composite image in gvSIG covering the Matara district.

The topographic map was added to the view and georeferenced using control points from the map and Landsat colour composite. However, the resolution of the colour composite image is 30 meters and it was difficult to accurately identify ground features to use as control points. To improve the image resolution the panchromatic band (band 8-15 meter resolution) was used to pansharpen the image and significantly increase feature recognition. Pansharpening functions, including Brovey and HSL, can be accessed in the 'Pansharp' tab available in the raster properties dialog box which can be seen in Figure 3.6.

Coastal peninsulas and lakes were found to be the best type of ground features that could be identified on both the map and pansharpened Landsat image. The georeferencing function in gvSIG contains an excellent control point placement adjustment feature that can be seen in Figure 3.7. It provides two separate windows for corresponding control points in which the user can zoom in or out to visualize and make sure the placement of both control points is as accurate as possible. In addition, RMS errors for each point can also be viewed by selecting the 'Table' tab of the georeferencing dialog box (Figure 3.7), and points creating unacceptable errors can be removed or readjusted prior to rectification. In this case, using seven control points resulted in a total RMS error of 5.513 meters. It is important to note here that our intention is to highlight the capabilities of the gvSIG system for map registration purposes and not the judicial selection of control points for image rectification. There are a number of references recommended on the latter process (Kenney *et al.*, 2003; Hosny *et al.*, 2004; Shaker *et al.*, 2005).



a) selected control points on topographic map and pansharpened Landsat image, and georeferencing dialog box



a) rectified topographic map overlayed on the colour composite Landsat image

Figure 3.7. Screen shots of control point selection and georeferencing function in gvSIG (a), and resulting rectified topographic map (b).

Once topographic or other framework data relevant maps/images/aerial photos have been georeferenced new vector layers can be created for each unique type of data that is visible (e.g. administrative boundaries, roads, rivers, coast lines, critical facilities, towns, villages, etc.) and data digitization can begin. Using a set of drawing tools (e.g. point, polyline, ellipse, polygon, rectangle and others) different types of features can be represented accordingly by tracing them on-screen. A screen shot of the drawing tools toolbar, which is part of the editing toolbar can be seen in Figure 3.9. The spatial accuracy of the datasets created is complex but the main source is the base map scale upon which digitization is undertaken. For example, a map at a scale of 1:50 000 cannot be made more accurate by digitizing at a scale of 1:10 000 or higher (gvSIG clearly displays at all times the display scale). Therefore the digitized map accuracy is at best equal to the accuracy of the base map which is a function of the scale-induced level of generalization. That said, the user should digitize features at a display scale larger than the map base scale so that they may, as much as possible, approximate the center of mapped features. Errors induced by the digitizing process are well known and the reader is referred to a number of references that make these explicit (Thompson, 1981; Chrisman, 1987; Keefer *et al.*, 1988; Dunn *et al.*, 1990; Fisher, 1991; Keefer *et al.*, 1991; Fernandez *et al.*, 1991). In addition, error propagation is a significant issue here (Heuvelink *et al.*, 1989; Lanter and Veregin, 1992; Stanislawski *et al.*, 1996) and the error of registration is additive to any digitizing errors as the sum of the squared individual error terms. As time and resources permit, relevant attribute information can be collected, added and/or updated accordingly for each type of entity that is created using on-screen digitization methods.

3.4.2 Editing/modifying existing spatial data

The spatial information requirements of disaster management practitioners often overlap those of other government departments or organizations, and relevant data may already exist and be stored elsewhere. Rego (2001) points out that at the national scale in developing countries there are almost certainly existing databases for a wide variety of purposes. Thus, an attempt should be made to investigate potential data sources that may already exist in order to reduce the work required in the establishment of local scale framework data. However, additional work will likely be required in order to make the data useful at the local level, and it will have to be determined whether it is more efficient to modify existing data or to start from scratch. For example, national scale data may lack the positional accuracy, comprehensiveness and/or attribute detail required for local level (large scale) use. Figure 3.8 demonstrates these problems using a national scale roads layer obtained from the SLWCS.

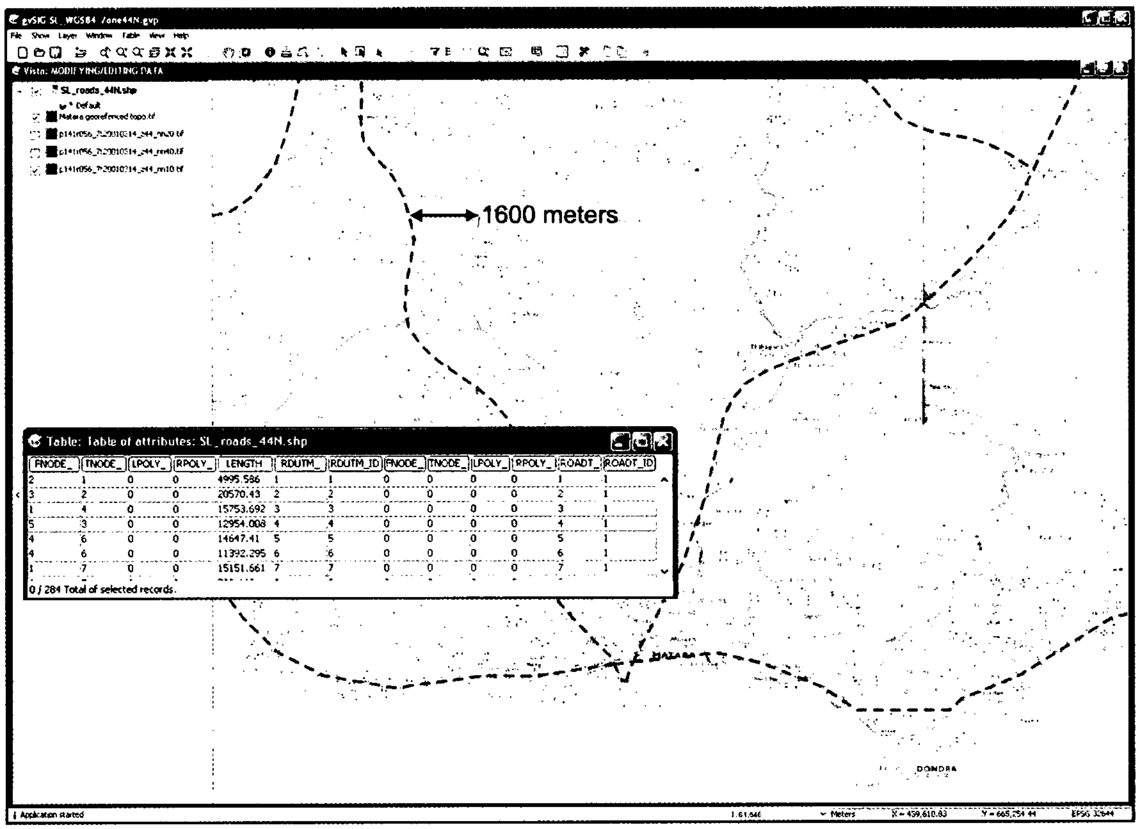
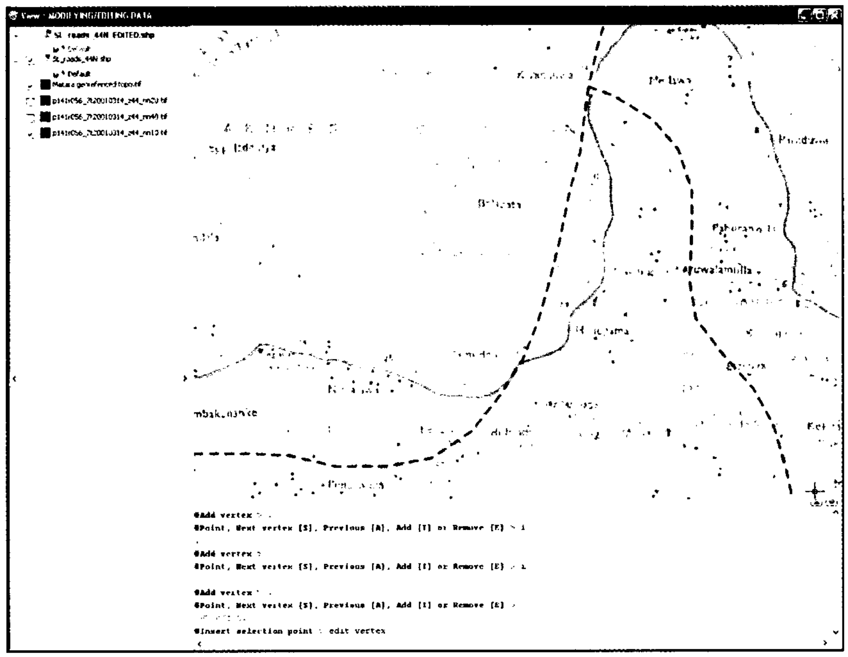


Figure 3.8. Example of the positional discrepancy due to two different scale-dependant levels of generalization of a national scale roads spatial data layer (purple dotted line) overlaid on the georeferenced topographic map of the Matara district in Sri Lanka. On the topographic map, roads are represented by red lines and the dotted purple lines depict roads based on the national scale data. In some cases the location of the road is off by more than 1600 meters, as indicated. The roads attribute table consists of many seemingly irrelevant fields (often populated with '0') which do not contain useful descriptive data, such as road name, number or surface type.

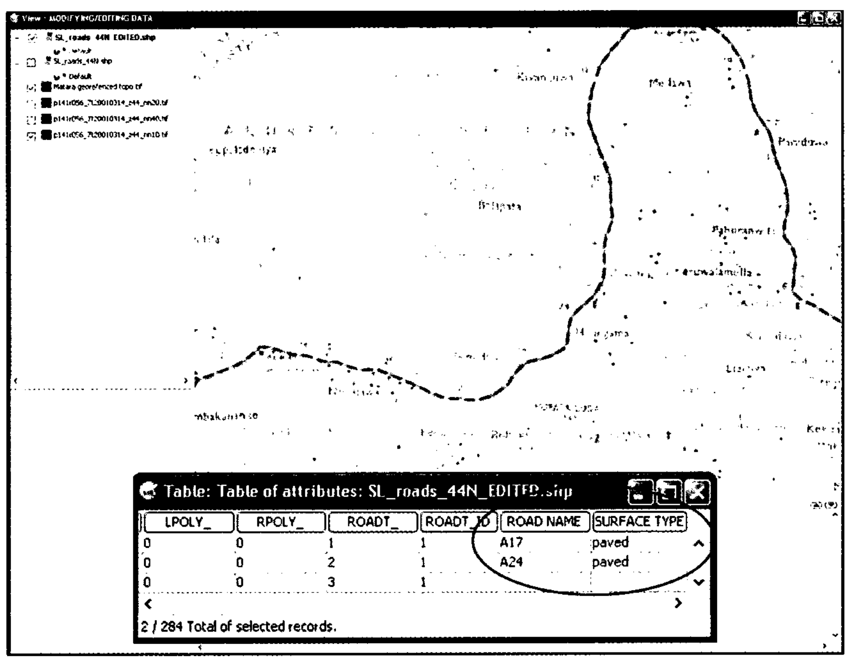
Figure 3.8 introduces a large discrepancy between datasets that is typical of source map scale dependant generalization and secondly to source accuracy. That is to say, the national scale dataset which is based on VMAP Level 0 (1:1,000,000) (NIMA, 1997) has a larger degree of generalization than the larger-scale topographic map (1:50,000). As such, the same features are clearly represented differently and in general, all other errors accounted for, the larger-scale topographic map is more accurate. A second clear source of discrepancy is the feature accuracy: there is greater error in the national level data which shows evidence of missing roads.

In order to make use of small-scale national level data geometry and attribute table editing functionality are required in a GIS software. Both capabilities exist in gvSIG. Figure 3.9 shows before and after screen shots that demonstrate the geometry and attribute table editing functionality used to adjust the position of the road and update the attribute table with new fields. The geometry editing was performed at a scale of 1:25 000. Using this functionality it is possible to modify existing spatial data sources to make them suitable for local level use. In addition, gvSIG also contains a reprojection function, which may be required in order to integrate data from disparate sources into a common coordinate system.

editing toolbar



a) before editing roads



b) after editing road geometry and adding new fields in the attribute table of the roads layer (new fields circled in red)

Figure 3.9. Before and after screen shot examples demonstrating the geometry and attribute table editing capabilities featured in gvSIG required for the modification of existing spatial data for local level use. This is an example of spatial data re-scaling and correction. In this case, new features are not created but simply modified and this is a time-saving step that also utilizes the schema constructed for the National level dataset.

3.4.3 Using GPS receivers for spatial coordinate collection

Using global positioning system (GPS) receivers is another feasible method of obtaining coordinates for many of the framework data required for disaster management related GIS use at the local level. GPS is required when spatial coordinates of required locations or objects cannot be obtained from available map sources or remotely sensed imagery. For example, using a low-end handheld GPS receiver, fairly accurate spatial coordinates representing locally deemed critical facilities, such as potential shelter sites, schools, or emergency resource stockpiles can be easily obtained through field observations and without the need for an accompanying topographic paper map. Rainham et al. (2008) provide a good overview of GPS error sources and accuracy assessment. In general, the coordinate accuracy retrieved from a hand-held unit will be less than 10 m, which equates to an accuracy better than coordinates taken from a 1:50,000 topographic map. GPS receivers can also be used to collect coordinate information based on the extent of previous disasters or known hazard locations. For instance, in the case of storm surges or tsunamis that have impacted low-lying coastal regions, where human population are often concentrated, historical locations of maximum wave run-up can be obtained based on local knowledge. Once this information is represented in a GIS with other framework data, local disaster management practitioners can study the spatial relations between potential disaster impacts and the elements at risk (e.g. villages, transportation infrastructure, schools, power stations, etc.). Additionally, if elevation data, such as a digital elevation model (DEM) or contour lines, can be obtained and incorporated into the GIS then potential disaster scenarios representing various wave run-up heights can be modeled and examined. Predicting and understanding potential disaster scenarios (e.g. their location or extent) and their spatial relationship with elements at risk is essential for establishing effective disaster mitigation and preparation strategies, and for determining response priorities. Figure 3.10 introduces the primary steps required for creating framework data using GPS coordinates.

FOS GIS provide the capability to create spatial and descriptive attribute data based on GPS coordinates, and this functionality will be demonstrated using gvSIG with the example of schools. In the event of a rapid-onset hazard, such as a tsunami, that might occur during the day when children are in school, knowing their locations and the number of students/teachers can help guide response efforts and possibly save lives. Knowledge of the building materials and construction design, which can be included in the attribute table, will also help in the assessment of response priorities. In fact, the collection of this data pre-disaster will allow for the creation of maps that can display vulnerability differences between schools. For example, using gvSIG, vulnerability levels can be assigned a numeric rank, and each school can then be displayed using a unique colour that corresponds to the vulnerability ranking. Spatial patterns of school vulnerability can then be visualized, providing valuable information that can be used throughout the disaster management process, from the development of mitigation strategies to response prioritization.

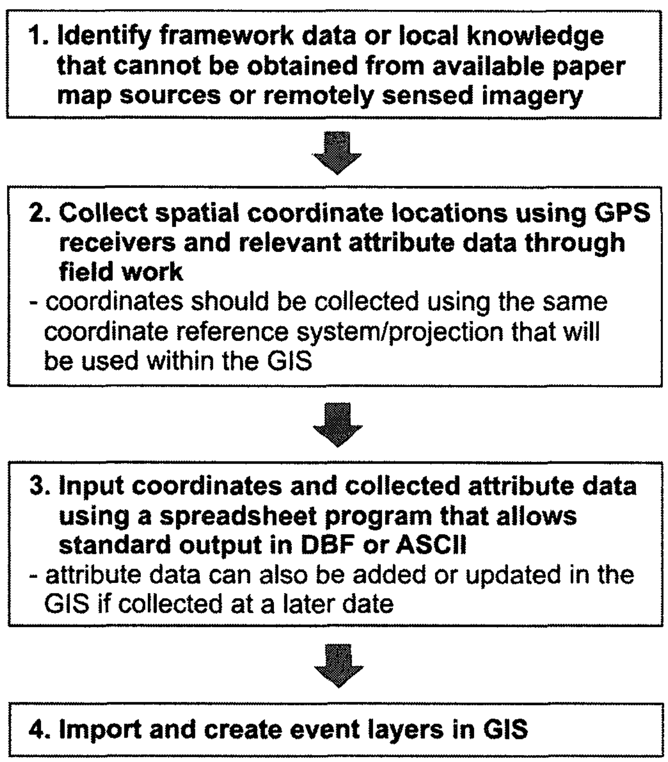


Figure 3.10. Primary steps required for creating framework data using GPS coordinates.

For this data creation method we also used, and highly recommend, a spreadsheet program, such as 'Calc', which is part of OpenOffice. GPS coordinates can be input into Calc, along with other attribute data, and saved as a dBASE (.dbf) file or an ASCII comma separated values (.csv) file. These are the two file types supported by gvSIG's 'add event layer' function which can be used to create spatial data layers from GPS coordinates. Figure 3.11 shows screen shots illustrating the main steps that were taken to create a spatial data point layer of schools and associated attributes. Although this is a hypothetical example, as the location of the schools were arbitrarily selected and the attribute data is fictional, it clearly demonstrates that gvSIG contains the required functionality to create GIS point layers of framework datasets based on manually entered (GPS or otherwise) coordinates and attributes.

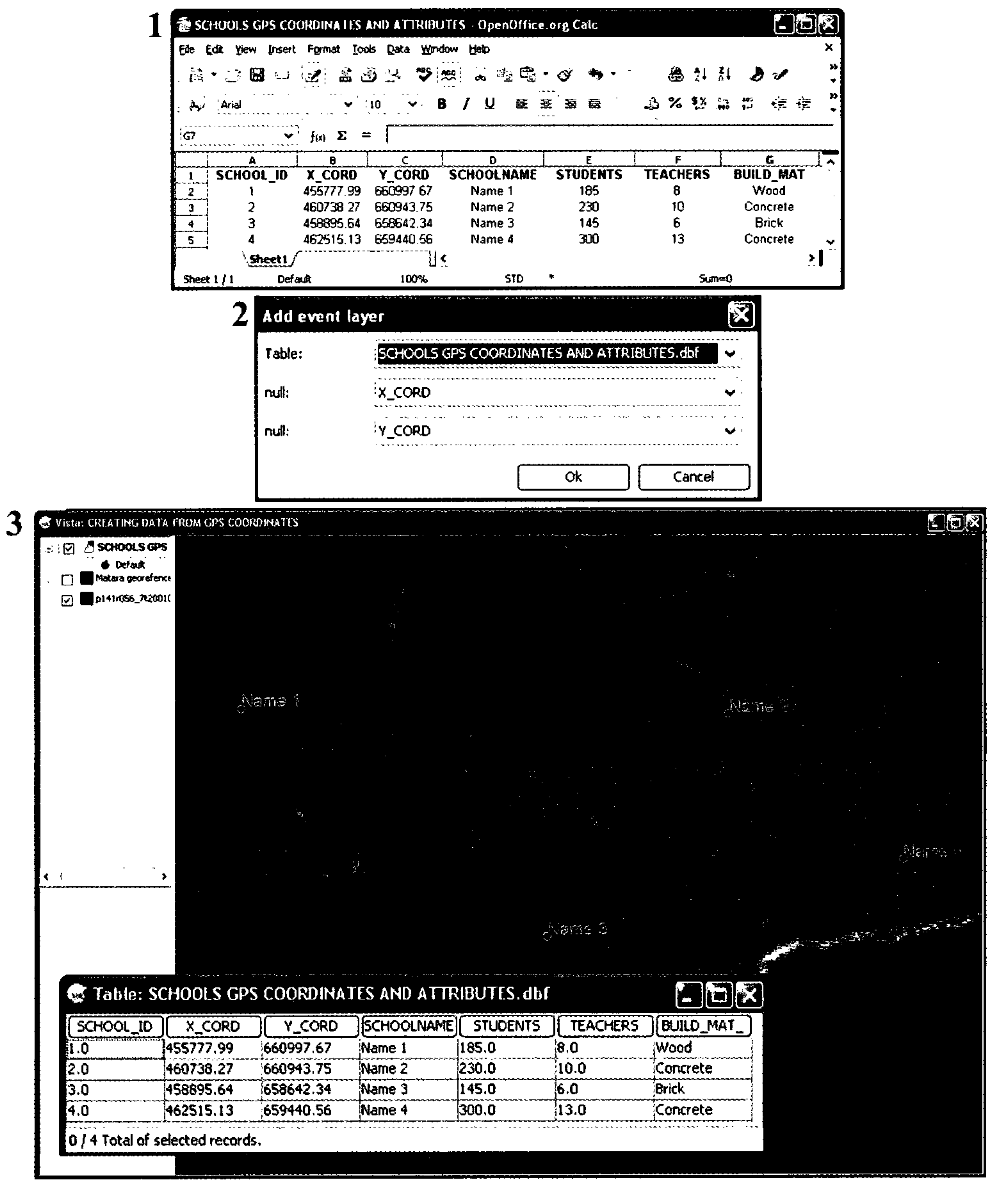


Figure 3.11. Screen shots of the main steps taken to create a schools spatial data layer and associated attribute data. The first screen shot is of the 'Calc' program, which is part of the OpenOffice suite, and the others are from gvSIG.

3.4.4 Image/pixel classification

Leveraging earth observation (EO) data in all phases of the disaster management cycle is well established (Groten, 1993; Wood, 2001; Inglada and Giros, 2004; Ito and Martinez, 2005; Zhou and Baysal, 2005). In the pre-disaster stages, a provision of thematic data describing landuse/landcover can be essential in targeting field collection endeavors. EO datasets can be quickly utilized to provide a means by which a local disaster manager can assess their region for likely populated areas and areas of potential critical infrastructure. The EO approach is particularly relevant when vector data is not available at the required scale and moreover, together with vector based layers (Harris and Ventura, 1995), candidate sites derived from EO can be prioritized for field collection ventures. The potential of EO data for detecting critical aspects of the human use system, including critical infrastructure, date back to pioneering work done in the 1960's (Wellar, 1968a; Wellar, 1968b; Wellar and Moore, 1968; Wellar, 1969a; Wellar, 1969b; Wellar and Moore, 1969).

Since the mid-20th century a number of air and space-borne imaging sensors have been made available for public consumption. Chief among these in terms of total applications are multispectral (MSS) datasets derived from decades of Landsat sensor missions (Engel and Weinstein, 1982; Mika, 1997; Williams *et al.*, 1998; Williams *et al.*, 2006). Up-to-date and archived imagery at 30 m resolution from Landsat MSS missions (Landsat 5 and 7) have been made freely available as of September 2008 (http://landsat.gsfc.nasa.gov/). The availability of both the archived imagery and newly acquired imagery has clear advantages for developing nations, overcoming many of the data dissemination issues associated with acquiring contemporary EO imagery (Aten, 1999) including end-user costs and opening the way for advanced applications by the disaster manager such as change detection (Mas, 1999). The only disadvantage to the user is the fact that imagery available from the Landsat 7 mission is not scan-line corrected (SLC) from 2003 onwards (SLC-off), leaving images with striped gaps of data that increase towards the edges, and NASA no longer offers an SLC service. However, because NASA offers full methodologies on corrections, the user can undertake custom fixes. While it is not our intention to do so here, the reader may benefit from knowing that basic and advanced scan-line correction algorithms can be easily implemented in a FOS GIS platform like gvSIG, at the source-code level and the more basic corrections can be undertaken using the 'Map Calculator' or 'Modeler' functions.

From the disaster management perspective, the creation of framework datasets requires the identification of populated and/or human use regions that can be potentially impacted. The classification of Landsat imagery provides a rapid means of assessment of local environments and their level of exploitation (Kirchhof *et* al., 1980; Iisaka and Hegedus, 1982; Haack *et al.*, 1987; Martin *et al.*, 1988; Vogelmann *et al.*, 1998; Sunar Erbek *et al.*, 2004). By way of illustration, Rüdenauer and Schmitz (2005) used supervised classification techniques and found that Landsat 7 ETM+ data (30 m resolution) could be used to identify and separate out settlements, but that the detection of linear features such as roads, railways and waterways was unsatisfying. Integrating the panchromatic band (15m resolution) into the analysis failed to significantly improve results. Thus, while Landsat imagery can be used to identify settlements it cannot be used as a source to accurately derive other spatial features on the ground.

To illustrate the potential of FOS GIS for image analysis we utilized a Landsat scene covering the Matara district of Sri Lanka (p141r56). The scene is an L1T product that is corrected for atmospheric, terrain and other pre-processing requirements and downloaded from the NASA website. Most of the Landsat mission offerings are L1G or L1T corrected, making them ideal for input directly into analysis procedures within GIS. The images are disseminated in a common tagged image file format (TIFF) making them directly compatible with most GIS software, including gvSIG. The general steps required for image classification of an EO image are provided in Figure 3.12.

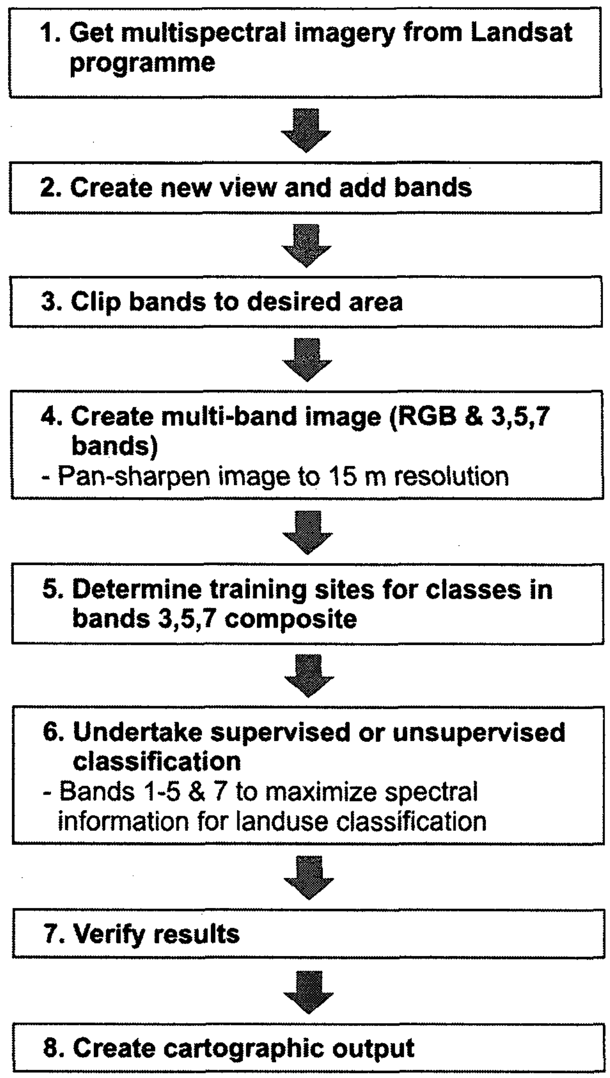


Figure 3.12. Primary steps required in the image classification process.

Beginning the fourth step in Figure 3.12, Figure 3.13 shows the creation of the color composite image using the raster properties, bands tab in gvSIG, where multiband display images are created. A second composite image (false-color) using bands 3,5,7 was also created (Figure 3.14). The 3,5,7 composite allows for better differentiation between water-land (green vs. black) and dense vegetation – less dense vegetation (dark green vs. lighter green) as well as various levels of human induced landuse in the brightest greens. For the purposes of undertaking a supervised classification of the region, the 3,5,7 image can be used to develop spectral signatures for different land cover types. Moreover, using the raster calculator of gvSIG, various band rationing could be undertaken to differentiate specific land covers.

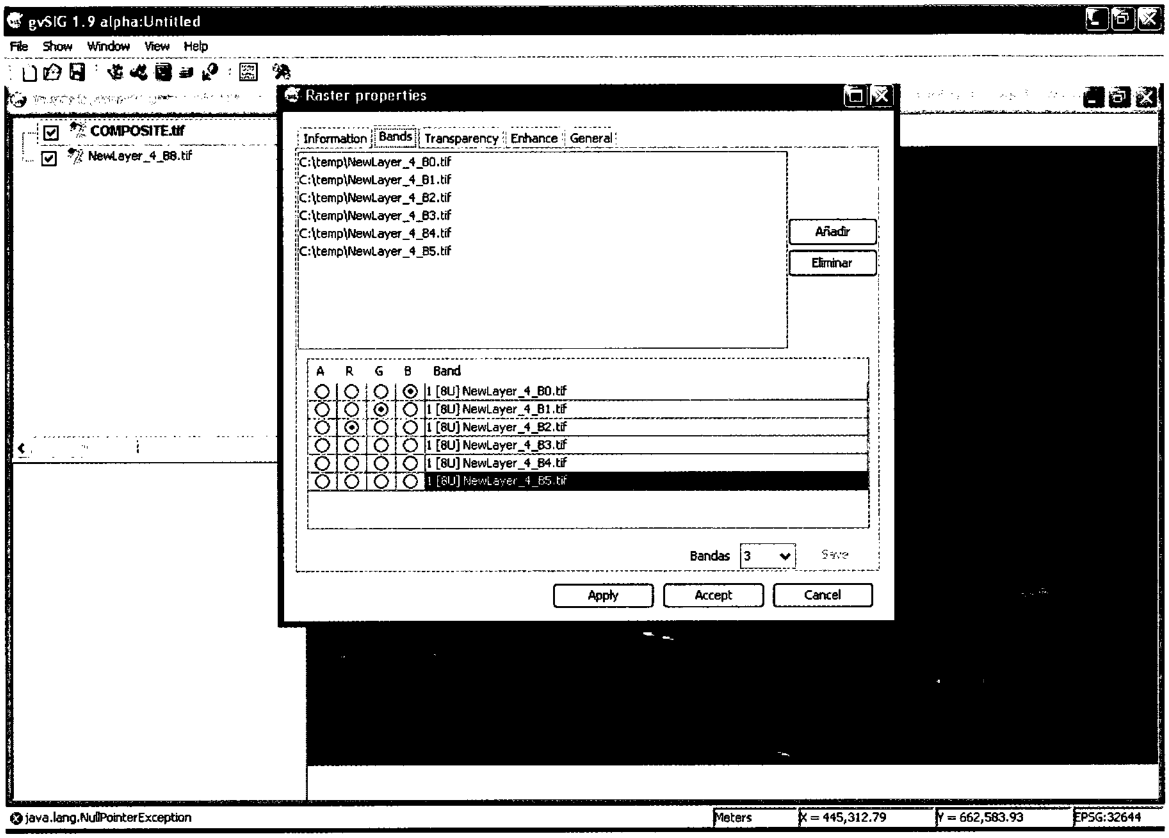


Figure 3.13. Screen shot of RGB color-composite creation in gvSIG using raster layer properties.

Figure 3.14. False color composite using Landsat Bands 3,5,7.

To undertake an image classification in gvSIG, there are three ways and these include the command line, the GUI and model builder (Figure 3.15 and 3.16). The choice of which to use largely depends on the level of knowledge of the user and on the number of times the process must be undertaken.

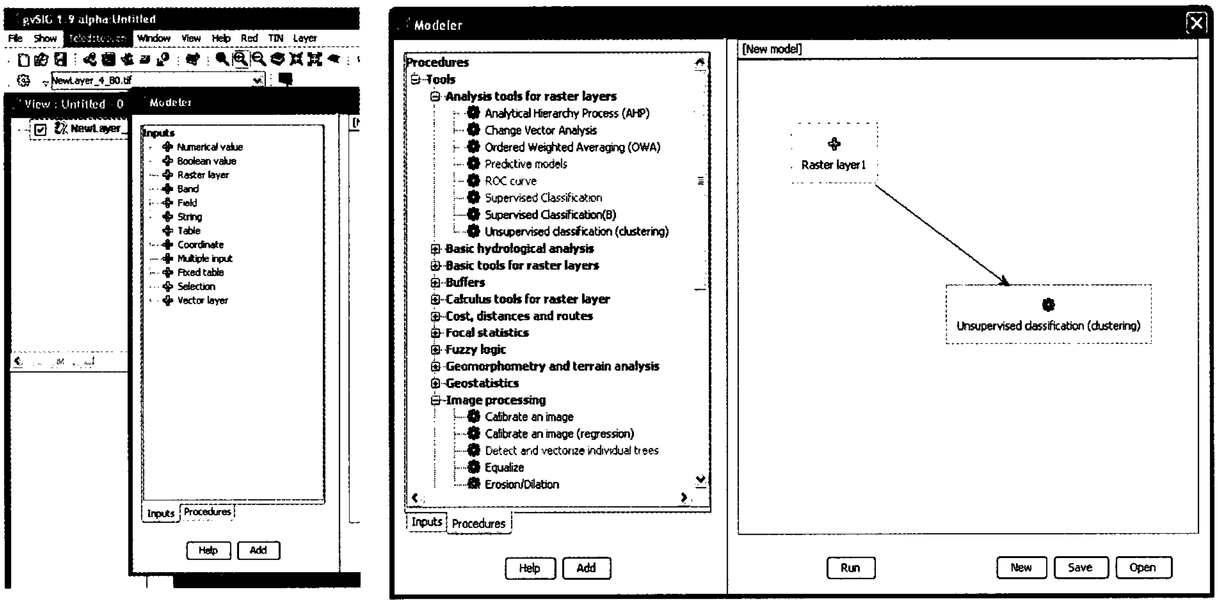


Figure 3.15. Utilizing unsupervised classification in gvSIG Model Builder. Here the user simply adds inputs to the visual model and functions along with setting parameters such as the layer name input, number of classes for the classification etc. Also of note are the many functions and functional categories offered for analysis of raster and image data in gvSIG.

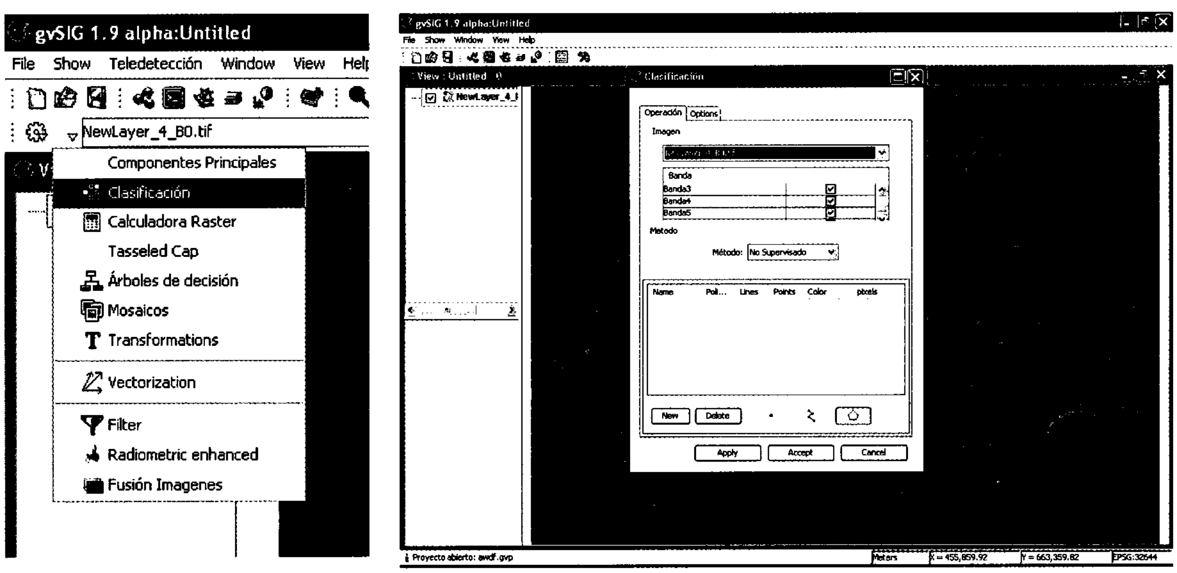


Figure 3.16. Screen shots of image composite undergoing unsupervised classification.

GvSIG software offers both supervised and unsupervised classification techniques and for illustration purposes we utilized an unsupervised classification using a clustering method of the region using bands 1 through 5 and band 7. These bands all have the same spatial resolution and include visible and infrared data which will maximize the information content for the classifier for this sensor. The result of this exercise is a classified image of the Matara district prepared in the 'Map' view of gvSIG (Figure 3.17). The classified image is effective at showing dense human use but this classification was not effective at showing the differences between dense urban area in the City of Matara and land harvested in the north (Figure 3.17).

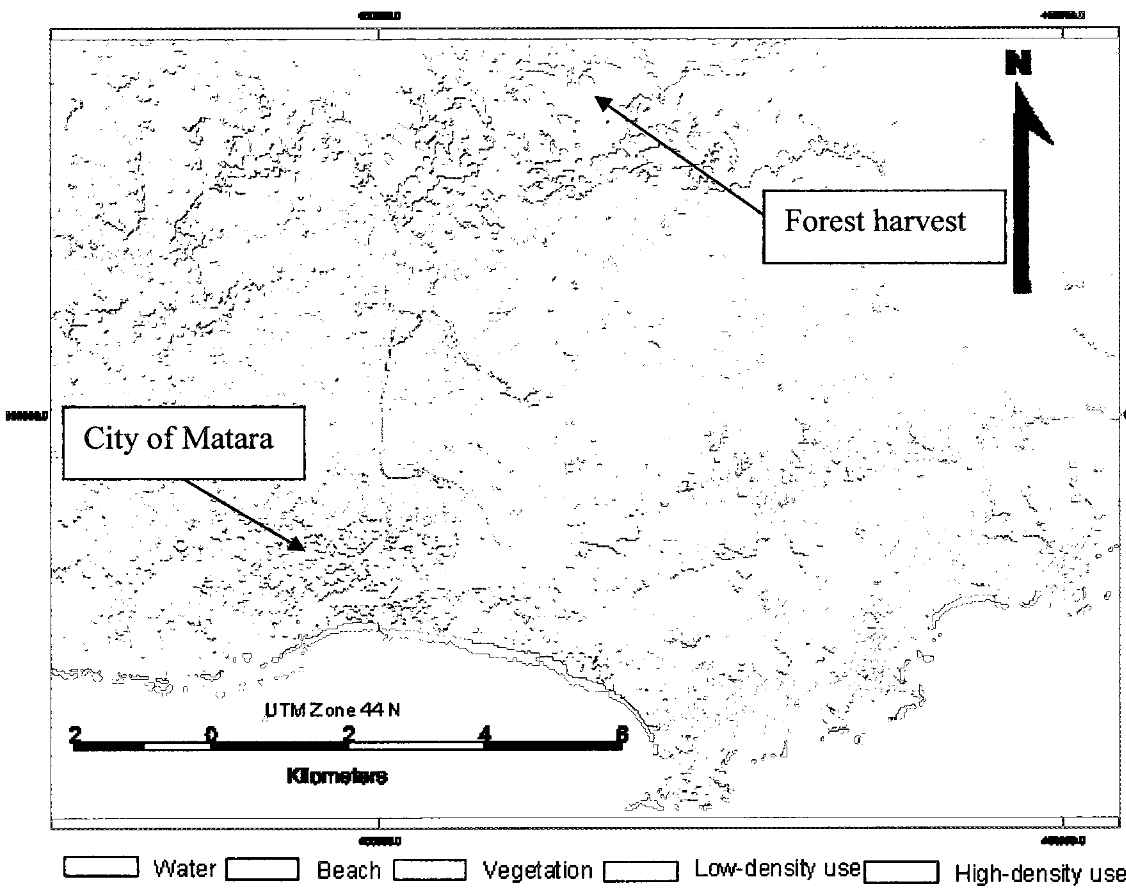


Figure 3.17. Result created in Map View of gvSIG. These classes are named here based on inspection of the original imagery and comparison with higher resolution Digital Globe imagery.

3.5. DISCUSSION

Among the broad set of Millennium Development Goals that the United Nations established in 2000, one stands out: "Make available the benefits of new technologies – especially information and communications technologies[12]." Free and open source geospatial information technology (FOS GIT) fall into this category and their current functionality can provide many benefits to the natural disaster management process in developing countries. As Caldeweyher *et al.* (2006) point out, with the recent advancement of FOS GIS, GIS technology should not be considered elitist, and there are feasible low-lost ways of empowering local communities with access to information which in the past they have been denied due to the technical complexity and high cost of GIS.

The framework datasets described and creation methodologies presented herein may have the drawback of being less sophisticated or accurate than those taken by GIT experts in developed countries, but have the advantage of (1) being financially feasible, and (2) being easily learned, fully comprehendible and achievable by local level GIT practitioners who may lack advanced GIT knowledge/skills. Moreover, the gvSIG main user manual is over 400 pages in length and provides detailed step by step explanations, including abundant screen shot examples, of the different functionality. The user manual dramatically reduced the time required to effectively learn about the different software capabilities related to the development of spatial data, and was instrumental in their implementation.

While it remains a desirable goal to use FOS GIS to produce specific map products that support decision-making and planning processes that can improve the success of disaster management, such a task is beyond the scope of this paper. Our goal was only to demonstrate that currently available FOS GIS, such as gvSIG, contain the required functionality for the development of framework data needed to support and improve natural disaster management at the local level in developing countries. However, we do

[12] See www.un.org/millenniumgoals

note that gvSIG has more than the required functionality for advanced analysis. That aside, improving disaster management in developing countries can only be achieved by taking into account the well-established GIT implementation barriers which include a lack of financial resources and large-scale spatial data. The FOSS-based GIS approach that we have taken, and the examples provided, have regard for both of these barriers and are thus considered feasible for local level GIT practitioners in developing countries.

It is important to emphasize that for the examples demonstrated in this article, no software or data was purchased, aside from the Windows operating system, and therefore the methods presented represent a very cost effective approach for creating the framework datasets. Of course, sufficient computer hardware and a handheld GPS receiver are required, yet these are the only necessary components of this approach that may have to be purchased. In addition, gvSIG now offers a mobile version which is of interest to those with GPS enabled handheld devices. The cost of hardware sufficient for FOS GIT implementation is a very minor expense compared to the cost of acquiring proprietary GIT software or high resolution satellite imagery. In fact, Laben (2002) proposes that an effective hardware platform for implementing GIS, including a colour scanner/printer, can be purchased for under $1,000.00 US, and today in 2009, few would argue that this cost would be around $500 US if not less. Additional costs of GIT implementation relate to work force training, and the cost of required human labour associated with data collection, maintenance and analysis. However, by implementing GIT in the pre-disaster phases, more time may be available and this can reduce the costs of labour in the short-term.

One problem encountered during the use of gvSIG for our examples was that even though the English version was selected during the installations options, there were still some dialog boxes and menu operations that were in Spanish, the native language used for application development. This could potentially be an obstacle to effective use because of terminology differences relating to GIT and we are unaware of the extent of this problem as it relates to other language options available for gvSIG. As expert users, we quickly adapted to the language issues but this may not be so easy for novices. As well, the main user manual has not been created in all languages as of yet, and is only available in Spanish or English. Similarly, and although the gvSIG extensions were not used in the examples presented herein, user documentation pertaining to the extensions are primarily only available in Spanish. Thus, in some cases the international user community may have to wait until user documentation is created in their native language in order to make use of gvSIG's extended functionality.

Finally, as local framework datasets are developed, and to the extent possible, they should be copied and transferred to disaster management authorities operating at higher administrative levels. This serves two essential purposes. First, it fulfills the need to back-up the data in the event that a disaster impacts the local facility or building in which the data is stored. Second, it provides higher administrative levels with important data that can be used in their own disaster management process. Therefore, locally produced spatial databases should feed into district databases, which would feed into state/provincial database and then into national databases (Rego, 2001). The software gvSIG v. 2.0 will support a variety of publication methods for datasets including standards such as the Web Map Services (WMS) and Web Feature Services (WFS) of the Open Geospatial Consortium (OGC).

3.6. CONCLUSION

Although natural disasters are a global phenomenon, developing countries are disproportionately affected. In such countries disasters can have a devastating affect on social, economic, cultural and environmental systems, and cause setbacks that can last for years, or even decades. With this in mind, there is an immediate need to identify ways to improve disaster management capacity in these countries and reduce overall natural hazard vulnerability.

Disasters are inherently spatial (Coppock, 1995), and as a result, disaster management authorities in developed countries rely heavily on geospatial information technology (GIT) during all phases of the management cycle. For example, GIT provide the basis for determining the best evacuation routes, identifying the most hazardous areas, assessing disaster impacts, or planning rebuilding projects that will reduce hazard vulnerability. However, the use of GIT for disaster management in developing countries is limited due to a number of implementation barriers, including a lack of financial resources and spatial data, and a lack of technical skills required for effective GIT use. Thus, there exists a need to identify and develop solutions that can overcome these barriers, and allow GIT to be implemented in developing countries to improve natural disaster management capacity.

In accord with this need, we have described what we refer to as 'framework datasets' required for the successful application of geospatial information technology to assist and enhance the disaster management process in developing countries. We have presented example workflows and discussed relevant considerations regarding the most feasible spatial data creation methods that can be implemented at the local level, and that take into account existing GIT implementation barriers. These methods include on-screen digitizing, modifying/editing existing spatial data, the use of handheld GPS receivers for spatial coordinate collection, and image/pixel classification. The examples provided demonstrate that FOS GIS, and in particular gvSIG, contains the required functionality to develop a spatial database of the many of the proposed framework datasets. Moreover, this can be accomplished using well-established methods and techniques that are relatively simple to implement compared to more advanced GIS capabilities. As such, we have demonstrated a feasible local level approach to improving disaster management capacity in developing countries, one that we hope will ultimately reduce natural disaster impacts in some of the most vulnerable regions of the world.

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CHAPTER IV

Conclusion and Recommendations

4. CONCLUSION AND RECOMMENDATIONS

As the human population continues to grow, and considering recent evidence of climate change that might exacerbate meteorological related natural hazards in particular, there is reason for concern that natural disasters might occur in the future with increasing frequency and consequence. Although all countries are at risk from natural hazards, developing countries are especially vulnerable for different reasons that involve economic, social, political and cultural factors. As a result, disaster impacts in developing countries can be severe and devastating, and often involve high casualty rates compared to developed nations, where economic and property loss are more common.

While disasters cannot entirely be prevented, losses and impacts can be reduced with effective disaster management – the process of mitigation, preparation, response and recovery. Given that natural hazards and disasters have numerous spatial components, such as location, extent, impact, pattern, scale, relation, and coincidence among others, geospatial information technology (GIT) can and should play a large role in disaster management. GITs, including geographic information systems (GIS), remote sensing (RS), global positioning systems (GPS) and Internet GIS (IGIS) can be applied in numerous ways to support all phases of the disaster management cycle, as was demonstrated in Chapter II. GITs are routinely used by disaster management authorities and related organizations in developed countries, and in some cases at the national level in developing countries, however, this is not the case within lower administrative levels. For example, disaster managers operating at the national scale may have access to data and resources (financial and human) that are not available at the regional or local level, even though disaster management duties and responsibilities are often decentralized to local governments.

Generally speaking, the use of GIT for disaster management in developing countries is limited for a number of well documented reasons, including a lack of financial resources, a lack of skilled/knowledgeable GIT practitioners, a lack of fundamental spatial data, and institutional and political instability. To improve the capacity for GIT use that can help reduce natural hazard vulnerability and potential disaster impacts in developing countries requires overcoming these implementation barriers. Such barriers are especially strong at the local level, where a strong disaster management effort must be focussed to reduce overall hazard vulnerability. Given that the theoretical foundation for studying and assessing natural hazard vulnerability and disasters is not set in stone, there is substantial room to derive new methods and techniques, ones that are feasible at the local level in developing countries and that have regard for existing GIT implementation barriers.

The use of free and open source (FOS) software (FOSS) offers a particular opportunity for developing countries in general and in the field of natural disaster management. Recent developments in the FOS GIT software domain in particular now provide opportunities that only a few years ago did not exist. As such, disaster management practitioners in developing countries should harness this potential in an attempt to reduce hazard vulnerability and improve disaster management capacity. Moreover, FOS GIT significantly reduces software costs and can help build local level GIT knowledge/technical skills, which are currently significant GIT implementation barriers in developing countries.

This thesis has demonstrates one way in which currently available FOS GIT can be used by the local level disaster management practitioner community. That is, the capabilities and functionality of FOS GIS allow for the development of spatial data infrastructure (SDI) that can significantly improve disaster management capacity at the local level. Moreover, the methods and skill sets required for the development of these datasets are not that complex, especially when compared to advanced GIS use (e.g. spatial analysis and modelling) which requires abundant GIT knowledge and/or training. Local level practitioners in developing countries are unable to take advantage of advanced capabilities at the current time, and as such, maximum utility will be in the more fundamental approaches to the construction of local SDI. This is a key point, as technological developments intended for use in developing countries must be kept simple, considering the skills and financial resources available at the local level. Developing countries lag behind in terms of technology use, and highly technical solutions are not practical to acquire, use and maintain.

The development of a core set of framework SDI required to improve disaster management capacity though the use of GIT and demonstrating how they can be feasibly created using FOS GIT, is one outcome of this thesis. The framework datasets provide a set of guidelines as to the types of spatial data that are required to improve overall natural hazard and disaster related decision making at the local level. Other types of information that are deemed locally relevant for disaster management, and that can be represented spatially, should also be sought. This includes information based on traditional environmental knowledge (TEK), which is derived from and embedded in the close relationship of local populations with their land and natural resources.

The SDI creation methods that are feasible, and appropriate, at the local level are on-screen digitization, editing/modifying existing spatial data, the use of handheld GPS receivers for coordinate collection, and image/pixel classification. These methods are supported by currently available FOS GIT software, including gvSIG, which is the FOS GIS that was selected to demonstrate framework dataset development in Chapter III. Without adequate and relevant spatial data, GIS themselves are essentially useless. Hence, the first step in building capacity for successful GIS use in any application area must be the development of SDI. Moreover, in the development of framework spatial data, local practitioners will also be gaining valuable knowledge and technical skills that are required to subsequently apply GIT to produce information products that can assist and guide disaster management decision making. As FOS GIT, and FOS GIS in particular, continue to evolve it is anticipated that new functionality will emerge that will require significant spatial data inputs and a strong GIT knowledge/skill base. Beginning to develop that knowledge/skill base now will enable more advanced GIT usage in the future, use that can make a significant contribution to reducing natural hazard vulnerability and potential disaster impacts.

The objectives of this thesis were to (1) determine and (2) demonstrate how currently available free and open source geospatial information technology software can be implemented at the local level in developing countries to improve natural disaster management capacity. In meeting these objectives, this research has determined that improving local level capacity for GIT use to support natural disaster management will first require the development of large-scale spatial data, the type of which have been described in Chapter II and termed 'framework spatial datasets'. The second objective was demonstrated by way of currently available FOS GIS, specifically gvSIG, that contains the required functionality to create many of these framework spatial datasets that are essential to improving disaster management capacity. The GIT knowledge and technical skills required for framework dataset development are considered feasible for local level disaster management practitioners to implement or learn, and the software and hardware requirements take into consideration the well acknowledged GIT implementation barriers. Thus, this thesis has met the objectives that were establish in Chapter I and has answered the central research question.

We recognize that the provision and creation of appropriate large-scale spatial datasets are the equivalent to the provision of fully functional and free GIT software. While the latter is clearly at a level that is mature and ready for use at the local level in developing countries, the former is a bottleneck that can be overcome to a large extent by diligent work on the side of the practitioner community in developing a spatial data infrastructure (SDI). However, the degree and amount of work required can be lessened by reliance on the increasing amount of free datasets available from websites around the world. At the same time, a research priority should be to assess these free datasets for their potential to support SDI development at the local level in developing countries. There is a large gap in the literature in that regard as mentioned by Engler and Hall (2007). With that being said, the development of an SDI for local level DM is a fundamental step towards the production of DM scenarios.

The developed world has made significant strides in spatial data standards and specifications through bodies like the Open Geospatial Consortium (OGC) (http://www.opengeospatial.org/). It is fundamental to recognize these standards but at the same time trying to apply these standards at a local level in developing countries will be challenging for the practitioner community. These standards and specifications will best serve as a guide for developing best practices by the practitioner community and so need to be translated and adapted to be applicable to the practitioner communities who are just beginning to implement GIT solutions for DM.

Finally, with respect to FOS GIT, standards and geospatial data, language and so conceptual barriers exist for the practitioner community in developing countries. The majority of free geospatial data, standards and software are available only in English. As such, conceptual ontological meanings and the semantics of GIT will need to be considered for extension of our approach to developing regions that do not speak English and may initially have a low degree of spatial awareness.

This thesis concludes with a set of recommendations for future research that are based on the finding obtained in Chapters II and III.

1. Although there are many benefits to the use of GIT in natural disaster management, there is a considerable disconnect between the disaster and emergency management research/academic community and the practitioner community, a point also echoed by Cutter (2003). The technological infrastructure (e.g. hardware, software, internet connectivity, power sources, etc.), for example, are all different, and thus what is feasible for academics may not be for local practitioners. If the research/academic community does not fully understand the limitations and constraints faced by the disaster management practitioner community, there is some pessimism as to the extent to which their GIT science and application development can actually benefit the practitioner community. Thus, there exists a need for the research/academic community to better examine the fundamental challenges faced by the practitioner community in order to make GIT more usable. GIT use can benefit the natural disaster management practitioner community, but it must be made compellingly evident and be feasible for institutions, local governments and related decision makers.

2. While this thesis has demonstrated how currently available FOS GIT support the development of framework datasets required for disaster management at the local level, additional research is required that specifically demonstrates

how these datasets can then be combined, analyzed and successfully utilized to generate specific map and other information products that can assist disaster management related decision making. Therefore, one recommendation is that future research should explore FOS GIT analytical functionality as it specifically relates to natural disaster management in developing countries. Such research will become increasingly possible as FOS GIT continue to develop and mature, and in general, as FOS GIT are adopted by a broadening user community.

3. This thesis has specifically explored some of the functionality of gvSIG, and numerous other capable FOS GIT software are currently available. As such, these other software coud be explored from a disaster management and developing country perspective.

4. We suggest that international development agencies, humanitarian/aid agencies and related organizations that are attempting to build local capacity in developing countries to reduce natural hazard vulnerability should make it a priority to utilize FOSS-based approaches. This is especially true in the case of GIT, given the high cost of proprietary GIT and the overall difficulty of maintaining them.

5. To bring spatial awareness to the local-level will require ontological and semantic matching of geospatial concepts and capabilities for any particular non-English world. This task may be suitable for specific projects in small regions but translation should be a priority for NGO organizations and other development agencies who have partnerships and staff versed in cultures where development is critical.

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APPENDIX I

Integrating Geographic Information Systems, Spatial Databases and the Internet: A Framework for Disaster Management

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ABSTRACT

At the global scale, high magnitude – low frequency natural disasters are a damaging phenomenon. There is growing recognition that successful disaster response strategies depend upon access to real-time spatial data/information that can be effectively utilized by not only relief agencies but also by local decision makers. Currently, many local and regional authorities are developing geographic information system (GIS) - based spatial decision support systems (SDSS) in order to improve local disaster response and management capacity. Although such systems are useful, the evidence is that they tend to lack interoperability, and they require substantial GIS/technical knowledge through each of the design, development and implementation stages. Moreover, their creation and maintenance requires significant human and financial resources, and frequently access to information derived from such systems is very limited during the disaster response phase.

Due to the different characteristics of disasters, and variations in appropriate response mechanisms and initiatives, increasing attention is being given to open source, Internet-based SDSS capabilities that can be made accessible by Internet connections of modest bandwidth. This concept of an intuitive, user-friendly, online GIS-based SDSS, which has powerful implications for disaster response (for the operations, planning and management functions), is yet to be fully explored.

Experience to date indicates, however, that Internet-based GIS could play a key role in the collection and dissemination of pertinent information in a fast, relatively inexpensive and straightforward manner during various stages of a disaster life cycle. That is, by integrating datasets from various online spatial data networks into one consistent Web-enabled GIS interface, using open source MapServer technology and Open Geospatial Consortium (OGC) standards, vital spatial information is readily available to numerous users without requiring high-level technical skills on the hardware, software, data collection, data fusion, and data transformation side. In this paper we outline a framework for establishing an online GIS-based SDSS for natural disaster management on a global scale that integrates what we term "spatial reporting."

Key words: Disaster Management, GIS, Internet, SDSS, Open-Source

1. INTRODUCTION

The field of disaster management has greatly benefited from recent advancements in computers and related technology. In particular, GIS, remote sensing, and the Internet have had a significant impact, and are currently being used in a variety of ways during all phases of disaster management. Integrating these technologies to create a spatial decision support system (SDSS) offers new possibilities for disaster management, particularly during the initial response phase, when the change detection capability is most urgently required (Wellar, 1998). During this phase, access to pertinent spatial information/data is among the most essential requirements (Jayaraman *et al.*, 1997). However, a primary challenge for disaster managers is how to distribute appropriate, accurate information in a timely manner to the necessary parties involved (Radke *et al.*, 2000). Furthermore, to use the aforementioned information technologies effectively often requires considerable technical skills and/or training time, which, in the hours and days immediately following a high magnitude disaster, are typically in short supply. Creating a way for non-experts (e.g. local decision makers, aid workers and the public) to quickly utilize mapping technology would increase their capacity to make informed and effective decisions based on the most up-to-date data and information.

In this paper we emphasize the need, and discuss the basic framework, for developing a user-friendly, online GIS-based SDSS specifically designed for non-experts. It is the intention that the system be used during the response phase following high magnitude-low frequency natural disasters, which often require international assistance. Our proposed system is designed for use particularly in developing countries which are most vulnerable to large-scale high magnitude natural disasters for reasons ranging from population distribution, socioeconomic characteristics, and resource bases to planning and building codes. The introductory sections of this paper provide a brief overview of natural disasters and how information technology is an integral component of disaster management. Subsequent sections explain our proposed system design and its architecture and present concluding considerations.

1.1 Natural disasters: an overview

The December 26th, 2004, tsunami in the Bay of Bengal resulted in a large-scale natural disaster, and provides recent evidence of the severe devastation and disruption that natural hazards can cause (see Figure 1). Each year, some 210 million people are affected by natural disasters (IFRCRCS, 2001). Although disasters are so complex that they defy easy classification, Smith (2004) describes them as: "an event, concentrated in time and space, in which a community experiences severe danger and disruption of its essential functions, accompanied by widespread human, material or environmental losses, which often exceed the ability of the community to cope without external assistance." Natural hazards can be understood as unpredictable acts of nature, characterized by extremes in physical processes (Zerger and Smith, 2003).

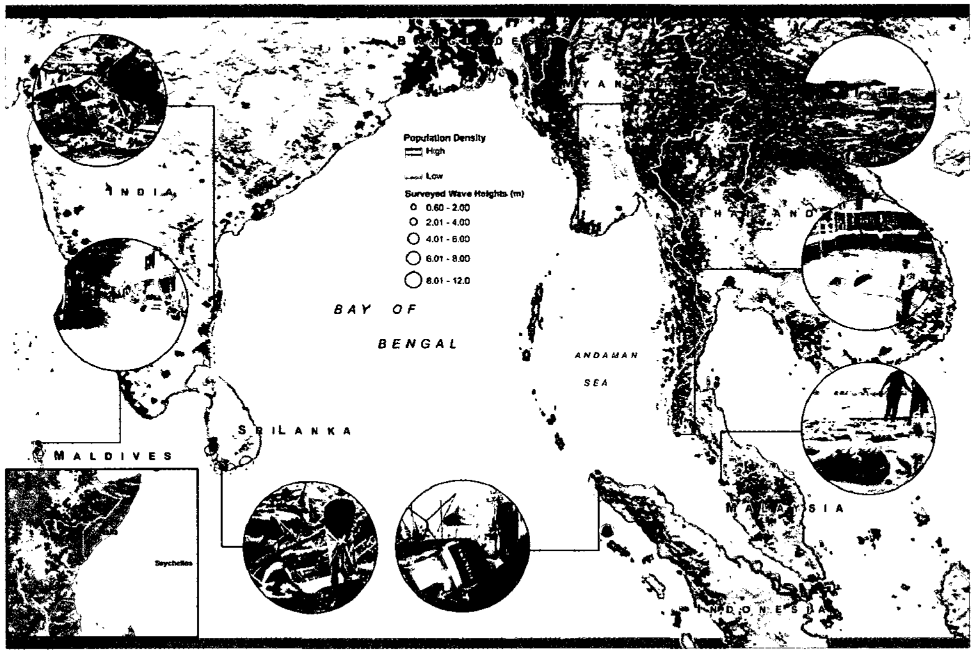

Figure 1: Geography of December 26th, 2004, tsunami affected region

Although natural disasters occur globally, their impact is more severe on the population and economy of developing countries, which lack the capability to deal with such events for many reasons, including poverty, illiteracy and the inability to undertake mitigation and preparedness initiatives. About 90% of impacts from natural disasters are felt by developing countries, and loss of GNP due to disasters is 20 times that of the developed nations (Alexander, 1995). To exacerbate the situation, there is mounting evidence that climate change could increase the frequency of such atmospheric hazards as major storms and floods (Smith, 2004). This vulnerability, coupled with an increased potential for natural hazards, provides reason for concern. The designation by the United Nations of the 1990's as the International Decade for Natural Disaster Reduction (IDNDR) recognizes the impact of past disasters and the impending consequences of future natural hazards.

1.2 Disaster management from an information technology perspective

Although natural disasters are increasing in frequency as global population rises, so are the ways in which we manage the disaster process and consequences. Disaster management can be understood as a cycle (Figure 2) which includes an effort to mitigate against, prepare for, respond to, and recover from a disaster (Montoya, 2002). Effective disaster management requires assimilation and dissemination of real-time information/data to various decision makers. This requirement can be considerably assisted with the use of GIS and remote sensing technology. Many studies (Rivereau, 1995; Simonovic, 2002; Mansor *et al.*, 2004; Becking, 2004) highlight the intelligence gathering potential of satellites (e.g. SPOT, IKONOS, RADARSAT) to dramatically assist all phases of disaster management by providing critical earth observation information. Similarly, GIS are useful tools in the disaster management process for displaying, modeling and/or integrating data and information derived from satellites, and other spatial data sources (Kumar *et al.*, 1999; Gunes and Kovel, 2000).

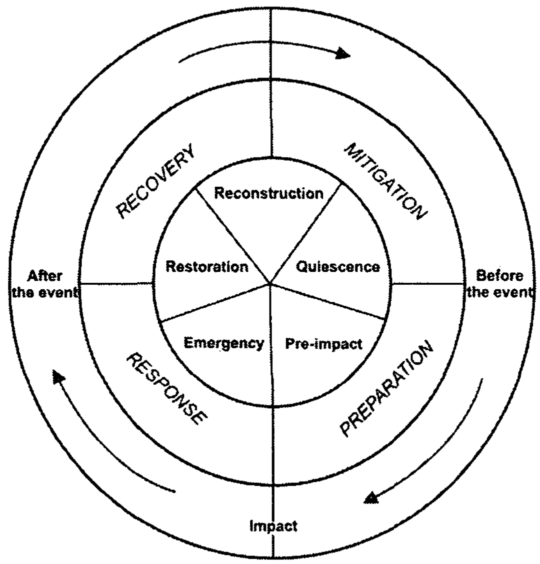

Figure 2. Disaster management cycle (from Alexander, 2000)

Recently, the Internet is gaining popularity as a mechanism that can facilitate the exchange of information/data (spatial and non-spatial) relevant to a disaster. Initiatives such as the Global Disaster Information Network (GDIN) provide evidence of the importance and the value of disaster-related information, as well as the need to be able to obtain and share it effectively. The aim of GDIN is to "provide the right information, in the right format, to the right person, in time to make the right decision" (GDIN, 2005). However, to make a decision implies that there are choices. Spatial decision support systems, commonly considered as application-specific software solutions (Rinner, 2003), are used in solving complex spatial problems where alternative decisions require consideration. Wellar (1990) and Crossland *et al.* (1995) showed that the use of GIS as a type of SDSS reduced the decision time and increased the accuracy of individual decision-makers, while Peng and Tsou (2003) emphasize that the Internet provides an ideal platform for non-experts to realize the power and benefits of GIS. Integrating these technologies in an on-line GIS-based SDSS has the potential to increase the use and accessibility of spatial data, as well as the accuracy and efficiency of decision making, thereby improving the effectiveness of disaster response.

However, developing countries lag behind in terms of their technological use, and highly technological solutions are too expensive to acquire and maintain in most cases (Alexander, 1991). Harnessing the Internet to create a simple, user-friendly, map-based system would allow local decision makers in developing countries to utilize beneficial data and technology they otherwise would not have the access to, nor the expertise to implement. Accessibility is a prerequisite to use and so accessibility to mapping technologies will increase the local capacity for disaster management, and reduce reliance on international aid. To date, the authors are unaware of any similar system created and maintained by the international community that is designed specifically for use in developing countries following high magnitude – low frequency natural disasters.

2. SYSTEM DESIGN

Our system falls under the broad category of 'Internet GIS', or IGIS which, since its infancy in the early 1990s, has greatly evolved to comprise a wide range of services and applications. Peng and Tsou (2003) define IGIS as network-based geographic information services that can utilize wired or wireless internet to access geographic information, spatial analysis tools and GIS Web services. While there are many GIS software vendors that offer packages designed for IGIS, there is increasing awareness of the many benefits of the open source software movement. A main advantage of open source software, aside from being free, is that it can easily be customized to meet a wide variety of end-user requirements.

Our current prototype utilises MapServer, an open source development environment for constructing spatially enabled Internet applications (University of Minnesota, 2003). MapServer supports several scripting languages, including PHP, Perl and Python, and its notable features include the following:

- fully customizable with template driven output
- feature selection by item/value, point, area or another feature (basic spatial query)
- supports tiled raster and vector data
- map element automation (scalebar, reference map, and legend)
- scale dependent feature drawing and application execution
- on-the-fly projection

MapServer also supports several Open Geospatial Consortium (OGC) Web specifications. OGC is an international industry consortium of 278 companies, government agencies and universities participating in a consensus process to develop publicly-available interface specifications (OGC, 2005). OGC specifications support interoperable solutions that 'geo-enable' Web, wireless and location-based services. These specifications empower technology developers to make complex spatial information and services accessible and useful with a variety of applications. A limitation of many present GIS-based Web services it that they lack interoperability and do not comply with Web mapping specifications.

Our system also utilizes another open source Web mapping program called Chameleon (*v*.2.0). Chameleon is a distributed, highly configurable environment for developing Web mapping applications (DM Solutions Group, 2003). It is built on MapServer as the core mapping engine, and works with all MapServer supported data formats. An advantage of Chameleon is that it incorporates the ability to quickly set up new applications using a common set of core functions called 'widgets.' Widgets are defined through special Chameleon Web Mapping Components (CWC) tags in standard HTML Web pages.

Since Chameleon was designed and developed to support evolving OGC standards, it can be used to incorporate any remote data sources that publish data consistent with these standards. Another benefit of this type of application is that is utilizes a thin client/thick server model, where data and software are concentrated on a single machine (the server). This type of architecture is generally cheaper, easier to update, and uses computer power more efficiently (Plewe, 1997). GIS and mapping are computationally-intensive tasks, and by using a powerful server less load is put on the user's computer which may be performing a variety of functions, particularly in the developing world. In addition, and perhaps the largest advantage of our system, is the ability to provide mapping capability to anyone who can run a Web-browser, even in low-bandwidth conditions. Gigabytes of spatial data can be manipulated on the server-side and only small compressed images (usually < 100 Kb) are sent to the client. This is in stark contrast to scalable vector graphics (SVG) Web-based mapping which must send large text files containing data across the internet for maximum detail. The Internet bandwidth required to achieve transfers between the server and client is an especially important feature, given that most regions in developing countries lack wide-scale accessibility to high-speed Internet connections.

2.1 Spatial reporting

An important feature of our system is the implementation of a "spatial reporting" component. This allows the creation of spatial features (points, lines and polygons) on the map, and the association of particular attributes with these features, updating the server-side database. For example, a user could input an area recently established as a distribution center for critical supplies, such as food and water; or input a point with a note attached detailing how particular infrastructure, such as a bridge, has been affected by the disaster. Providing functionality for users to dynamically update maps with new data/information dramatically increases the ability to provide key spatial information in a useable form to those who need it most.

2.2 Interface design

Since our system is intended for use by people in developing countries, many of whom may be unfamiliar with GIS technology, important consideration must be given to the system functionality and interface design. It is important that the interface be designed in an intuitive and user-friendly fashion, and that the functionality does not exceed what users can comprehend (Wellar, 1995). An example of a Web-browser based mapping application can be seen in Figure 3. Attractive button graphics enhance the recognition of the various user tools and increase the overall aesthetics of the application interface, thereby making it more user-friendly.

Figure 4, another screen shot, shows an example of how the spatial reporting feature can increase the information content of the map. In this example the point location of the CIG conference (The Westin Hotel, Ottawa, Ontario) was added to the map, along with a label. The development of this addressed-based geocoding functionality was done at LAGGISS to test the effectiveness of spatial reporting within the context of another Web-based mapping project for the Ontario Early Years Centers in Ontario.

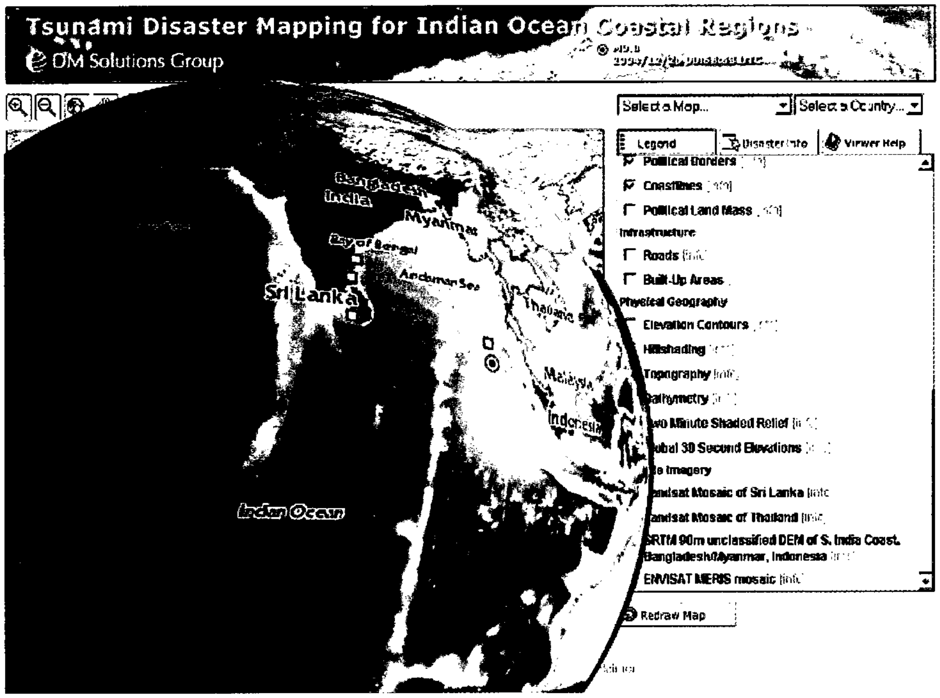

Figure 3. Example of a Chameleon-based Web application interface for the disaster Web-mapping portal (DMapP- http://mapsherpa.com/tsunami/) that was developed for the tsunami devastated regions in December 2004 by DM Solutions Group in conjunction with the Laboratory for Applied Geomatics and GIS Science (LAGGISS).

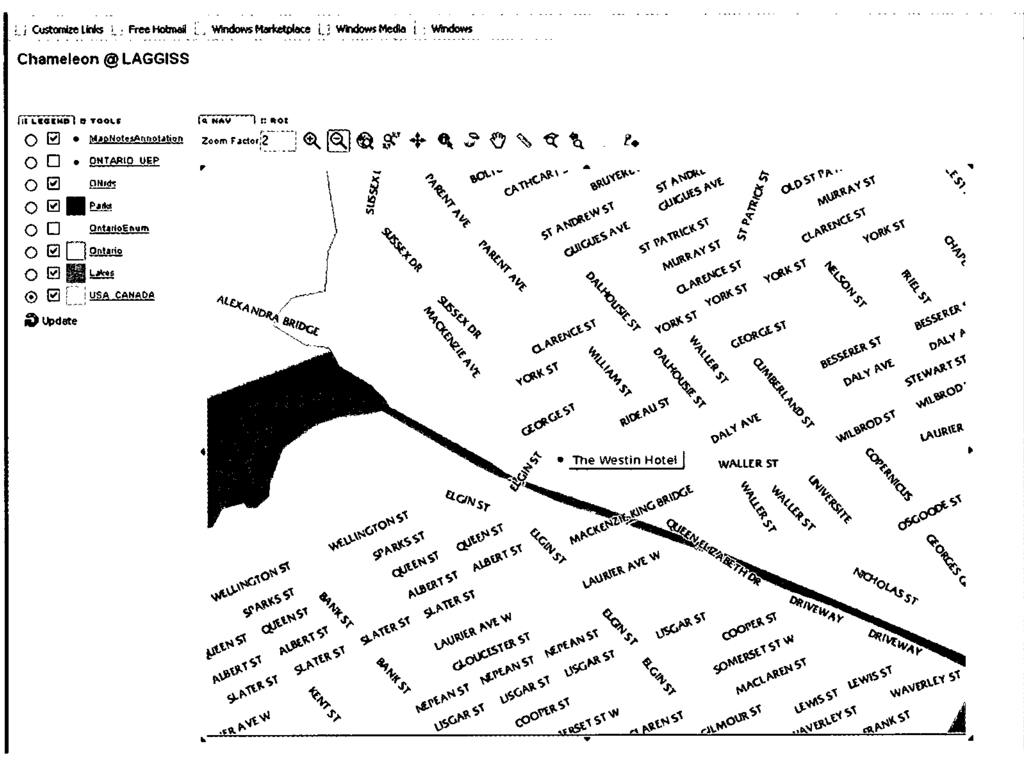

Figure 4. Spatial reporting feature (addressed based geocoding functionality added to MapServer at LAGGISS)

3. CONCLUSION

Disaster management in developing countries exists within a complex political, social and economic environment, where a coherent and coordinated approach can be difficult to implement. As such, large-scale high magnitude – low frequency disasters will continue to overwhelm local disaster managers, prohibiting effective management, particularly during the response phase. Although most natural disasters cannot be prevented, disaster losses can be minimized when appropriate actions are taken which utilize the latest technology and best available spatial data/information. Through appropriate applications of GIS and remote sensing we can move a significant way toward making data/information available, and answering questions concerning the spatial and temporal dimensions of disaster management.

Our system integrates GIS, satellite imagery and spatial data networks to form a Web-based SDSS. Maps are the primary output of this system which, when displayed on computer screens, are more dynamic and versatile than hard copy versions (Alexander, 1991). This type of system complies with Coppock (1995) who points out that technological developments intended for use in developing countries must be kept simple, considering the skills (both technical and bureaucratic) and resources available.

Realizing that in many developing countries spatial data may be difficult to obtain, and that spatial data is a prerequisite for the effective use of the proposed system, it is hoped that future improvements in satellite sensor technology accompanied by the willingness of various agencies to share and create necessary spatial data will help the system realize its full potential.

Finally, computer-based disaster management systems reduce some of the pressure of having to organize information and data directly after a disaster and in the midst of a time of crisis. They provide decision makers with the information that they require to develop and maintain their understanding of the spatial characteristics of a natural disaster, and its impacts over a range of time. As a result, they will improve the capacity of developing countries to provide more effective disaster response, and thus reduce their overall vulnerability to the apparently increasing number of natural hazards.

Acknowledgments
This paper is based on a M. Sc. research project that is being carried out at the Laboratory for Applied Geomatics and GIS Science (LAGGISS), Geography Department, University of Ottawa. A beta-version of the proposed system will be implemented over the next year. The addressed based geocoding and spatial reporting functionality added to MapServer at LAGGISS was supported by the University of Ottawa Interfaculty Research Grants programme. We thank Dr. Jason Morrison, Dr. Michelle Driedger and Mr. Poopalasingham Elenkesewaran who are working with us on the IMAP technology development. This research is supported by an NSERC, CFI and OIT grant to Dr. M. Sawada. We also acknowledge the outstanding humanitarian contributions of DM

Solutions Group Inc. who have dedicated considerable resources to this project over the past year.

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