GEOGRAPHICAL INFORMATION SYSTEMS AND NATURAL RESOURCE MANAGEMENT IN ZAMBIA

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GEOGRAPHICAL INFORMATION SYSTEMS AND NATURAL RESOURCE MANAGEMENT IN ZAMBIA

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DEDICATION

To my mother ***Mary Tembo***

To the memory of my father ***Robin M. Mwape***

ABSTRACT

Natural resources play a critical role in the welfare of developing countries. In Zambia, even though its vast natural resources have been important to its economy as well as its people, their exploitation has resulted in severe land and environmental degradation in most parts of the country. Reliable information as to the exact extent and degree of natural resources problems is critically lacking. For effective control and management of these natural resources problems, timely, up-to-date, accurate and complete spatial data are needed.

The integrated application of Geographical Information Systems (GIS) and remote sensing to model natural resources management data, especially at regional level, is presented in this dissertation. Three case studies in Zambia are presented and free, internet-based, datasets are used to demonstrate the application of GIS to support natural resource management decisions in Zambia.

The results of the case studies show that while data-gathering obstacles remain in the use of GIS in Zambia, the systems can be used successfully to fill gaps in decision-making in natural resources management. The results of the case studies have been used to make recommendations as a way forward for the use of GIS and remote sensing data in natural resource management in Zambia. Finally, selected technical issues associated with data access, data incompatibility and data accuracy are identified as important areas of future research.

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CHAPTER ONE

INTRODUCTION

This objective of this chapter is to introduce the study. The first section presents a brief background to the research problem. The second elaborates the research problem. The third introduces the research aim and outlines the corresponding research objectives. The fourth and the fifth sections provide the research value and the research approach respectively. Finally, the last section provides the structure of the dissertation.

1.1 Background

Natural resources play a critical role in the welfare of developing countries (Huizing et al., 2002). For many developing countries, natural resources are the base upon which all life depends. However, many developing countries have experienced, and continue to experience, severe degradation of their natural resources. Expansions in technology, population and economic activities have led to accelerated and unsustainable exploitation and depletion of natural resources (Satapathy et al., 2008). This degradation, especially of forest cover, has led to diminishing soil fertility, soil erosion, increased severity of the impact of drought, and a further reduction in the ability to produce food and other biological resources demanded by the human and animal populations (*Ibid*).

Zambia is not an exception with reference to these problems. It is currently facing serious land and environmental degradation due to increasing anthropogenic pressure on its natural resources (Ministry of Tourism, Environment and Natural Resources, 2002). The vast natural resources found in Zambia have been important to its economy and its people. However, their exploitation has resulted in severe land and environmental degradation in many parts of the country. To address these problems, the Zambian Government, through the Ministry of Tourism, Environment and Natural Resources adopted a National Conservation Strategy in 1985 and the National Environmental Action Plan (NEAP) in 1994. The main aims of the NEAP are to identify environmental problems and issues, to analyse their causes and to recommend appropriate action for their resolution. Currently, this plan forms the policy framework for environmental intervention and management. The NEAP recognizes five priority environmental problems (Ministry of Tourism, Environment and Natural Resources, 1994). These include soil degradation, deforestation, water pollution, air pollution in the copper mining towns and wildlife depletion (fish and game). However, in all cases, reliable information about the extent and degree of environmental problems is critically lacking (*Ibid*). While it has been recognised that natural resources have been on the decline, estimates of the size of decline and remaining stocks are based on assessments carried out in the early 1960s. These estimates are outdated and unreliable. For example, based on the 1960s inventories, the nationwide average rate of deforestation is estimated at 250,000 to 300,000 hectares per year with an average annual forest decrease factor of 0.5% (Ministry of Tourism, Environment and Natural Resources, 2002). However, more recent studies (Chipungu and Kunda, 1994; Chidumayo, 1996) have estimated higher rates ranging from 850,000 to 900,000 hectares per year.

Because of the lack of comprehensive and reliable data, the management of Zambia’s natural resources is neither accurate nor efficient (Ministry of Tourism, Environment and Natural Resources, 2002). Use of traditional methods for mapping and estimating the extent of decline of the remaining stocks and the degree of environmental problems is relatively costly and time consuming, and is subject to a variety of errors of different types and sources (Ononiwu, 2002). Therefore, there is an urgent need for alternative technologies to collect relevant, reliable and accurate spatial natural resource data and to build integrated spatial databases that could provide a basis for the analysis of diverse environmental problems.

In this dissertation, the application of geographical information systems (GIS) and remote sensing data is suggested as a potential means of dealing with this complexity. Several researchers, for example, Goodchild (1993), Yilma (2004), Satapathy et al. (2008)

and Johnson, et al. (2008) have endorsed the potential significance of GIS and remote sensing technology in natural resource management and planning. According to Johnson, et al. (2008), GIS and remote sensing also offer the potential to solve many natural resource problems by providing a means of generating information, regular monitoring and analysis to predict and visualize future scenarios and helping managers in making informed decisions.

Possible contributions of GIS to a more effective use of natural resource information include, a better visualization of the spatial diversity of resources (Huizing et al., 2002), improved possibilities to analyze and integrate data from different sources and the possibility to assess impacts of alternative interventions (Cowen, 1988). GIS, with their capabilities for spatial analysis and modelling of diverse data, can enhance the ability to address several natural resource and environmental issues that have a spatial component (Nijkamp & Scholten, 1993). GIS can facilitate the organization, manipulation and analysis of diverse data often associated with these issues, and the data structures, and analytical techniques of GIS can be incorporated into a wide range of management and decision-making operations that pertain specifically to natural resources.

1.2 Problem Statement

Many developing countries have experienced severe environmental degradation and ecological deterioration in the past century, with little or no real solutions to alleviate many of these problems. Information on the variability and distribution of natural resources and natural resource problems is needed to enhance decision-making in natural resource management. Use of traditional methods for mapping and estimating potential risk areas is relatively costly and time consuming and is subject to a variety of errors. Recently, however, advances in computing power and the increasing availability of remote sensing data have renewed interest in using GIS to address a wide range of environmental issues and questions. The main challenge in developing countries is how to make the best use of the sparse data available from different sources when addressing urgent environmental problems.

1.3 Aim and Objectives

The aim of this study is to demonstrate how GIS and remote sensing can provide quantitative information for enhancing decision-making in natural resource management in Zambia.

To achieve this aim, the following objectives were set:

- To determine what spatial data are available and suitable for GIS-based analysis in Zambia.
- To develop spatial databases to study specific environmental problems (deforestation, water pollution and soil degradation) using selected regions in Zambia as case studies.
- To analyse the spatial data for the purpose of providing accurate quantitative descriptions of the selected environmental issues.

1.4 Research Value

This study demonstrates how GIS and remote sensing can provide accurate quantitative data and descriptions of environmental issues. The quantitative information generated could be used for enhancing decision-making and policy formulation. This study is significant, particularly to natural resource management, in several ways: 1) it demonstrates the value of using remote sensing data and GIS in a data poor environment; 2) it shows how to bridge the data gaps between remote sensing technology and information requirements for natural resource management and; 3) it paves the way for more studies aimed at using remote sensing derived data, further enriching the limited knowledge on data-to-information conversion involving remote sensing and GIS technologies.

1.5 Research Approach and Structure

The approach adopted in this study is divided into three categories: (i) collection of suitable spatial data, (ii) development of case studies based on the available data and (iii) analysis of data using GIS-based techniques.

Including this introductory chapter, this dissertation is comprised of eight chapters (Figure 1.1). The outline of these chapters is presented below.

- Chapter 2: The literature review outlines information relevant for the purpose of this dissertation. The review covers natural resource management, the basic concepts and principles of GIS and the major application areas of GIS in natural resource management. Finally, the challenges to GIS users in developing countries, with particular emphasis to Zambia, are explored.

- Chapter 3: The general approaches and methods employed in this study are detailed in this chapter. The chapter also provides brief descriptions of the approach used to collect data, the criteria for selection of suitable data, the development of case studies, data analysis and the GIS software used in this study.

- Chapter 4: In this chapter the results of the first case study are presented. In this case study, the application of GIS and remote sensing to provide data for enhancing decision-making in NRM are demonstrated by assessing forest loss and generating a deforestation risk map for an area in the Luangwa Valley in Eastern Province, Zambia

- Chapter 5: In this chapter the results of the second case study are presented. In this case study, GIS is used to map and quantify soil erosion intensity in the Lusitu River catchment using information from remotely sensed data, digital elevation data, soil data and other relevant data.

- Chapter 6: In this chapter the results of the third case study are presented. In this case study, illustration of the functionality of GIS in water pollution management is provided through its application to a reach of the Kafue River in the Congo-Zambezi catchment in the Copperbelt Province, Zambia.

- Chapter 7: In this chapter the results of this study are discussed in relation to other studies and the current literature as well as in relation to the study objectives.

- Chapter 8: The main conclusions drawn from the study are stated and seven recommendations are presented.

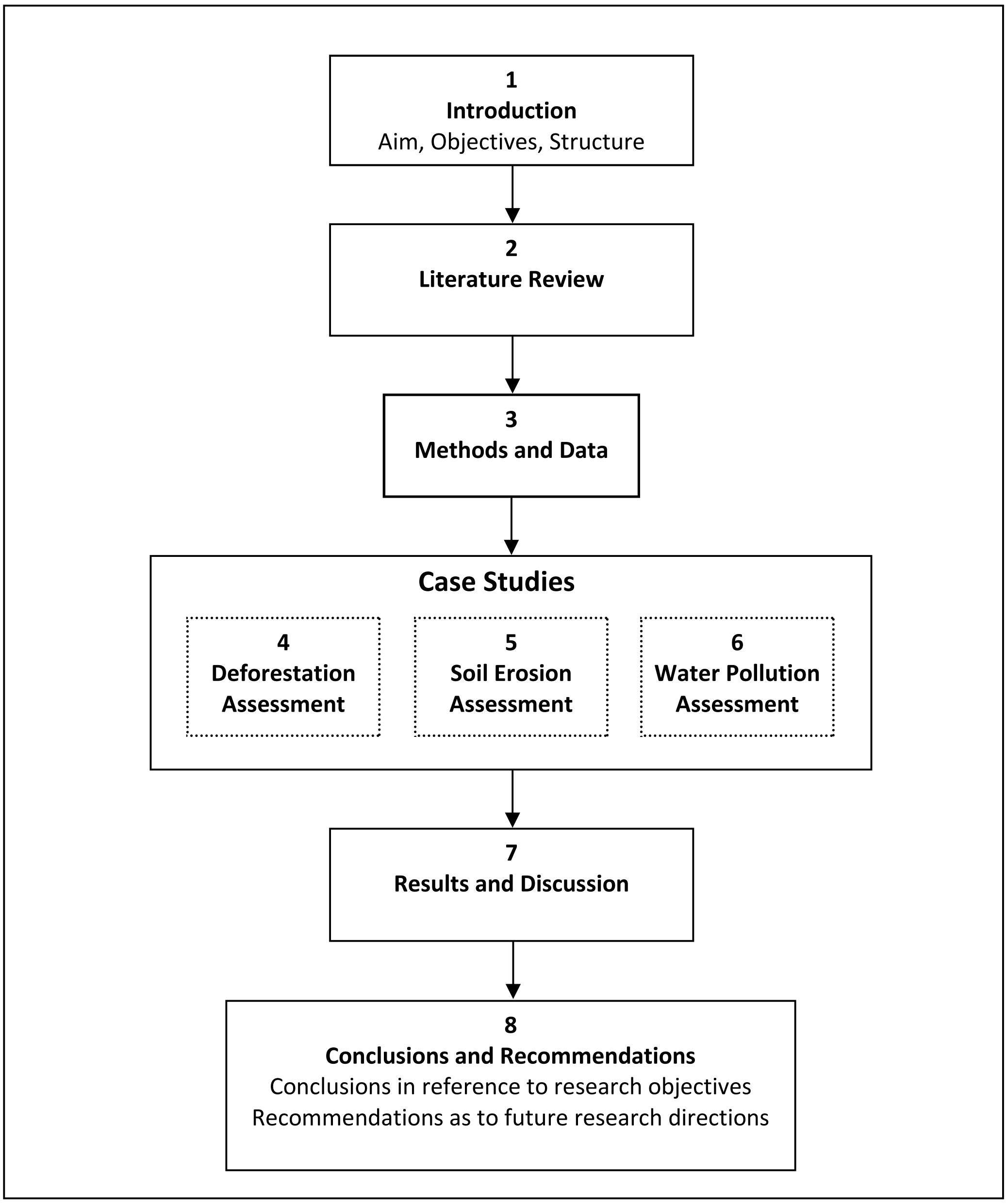


Figure 1.1 Structure of dissertation

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of literature which is relevant to the various sections of this dissertation. The chapter begins with a brief description of natural resources management. It follows with some basic concepts and principles of GIS then a general review of the major application areas of GIS in natural resource management. It finishes with a review on the challenges of GIS application in developing countries with particular emphasis on Zambia.

2.1 Natural Resource Management

Natural resources management (NRM) is a discipline in the management of natural resources with a particular focus on how management affects the quality of life for both present and future generations (Wikipedia, 2009). It involves the manipulation of the resource to preserve or supply products on a sustained basis (Knight and Bates, 1995). The aim of NRM is to manage natural resources so as to achieve a balance between their functions for the quality of the environment and their functions for the quality of human life (Schmidt-Vogt & Shrestha, 2006). To achieve this aim, NRM revolves around, but is not limited to, manipulation and analysis of information from various sciences and disciplines.

According to Kliskey (1995), natural resource management provides structured processes in which decision-making and problem-solving occur. Seasons (1989) characterised the strategic planning process as a suitable framework for dealing with natural resource issues. Strategic planning is a disciplined effort to produce fundamental decisions shaping the nature and direction of an issue (Bryson & Roering, 1987). It is primarily concerned with problem-solving, the linkages with an organisation’s operating environment, and information needs. While the scope of the management process is wider than this, the focus on the strategic planning process provides a useful structure within which to consider information and decision-support in natural resource management (Kliskey, 1995).

The components of the strategic planning process, such as problem identification, goal articulation, identification and evaluation of plan alternatives and their implementation, point to the importance of information in planning and problem-solving. There is little doubt that the successful outcome of decision-making and problem-solving within the planning process is dependent on the input of information and its subsequent manipulation and handling (Kliskey, 1995). In this context, generating reliable information for input in the planning process is vital.

In the context of natural resource management, reliable, geographically specific information from a variety of sources is required. Traditional methods of generating this information are relatively costly and time-consuming as they require extensive mapping and monitoring programmes (Ononiwu, 2002). As a result, in many developing countries, with neither the capacities nor the resources to undertake extensive mapping and monitoring programmes, existing geospatial information is often either incomplete or out-dated and thus not compatible with modern management requirements (Kalensky, 1996). Consequently, there are often severe limitations on the ability of decision-makers in developing countries to obtain the required information to fill the existing geospatial information gaps in their natural resource management planning. Alternative technologies such as GIS and remote sensing may provide a sensible platform for generating suitable information for input in the planning process. Using GIS, along with remote sensing, has a distinct advantage over traditional methods of mapping and monitoring natural resources (Joshi et al., 2006).

2.2 Geographical Information Systems

A GIS is a computerized data management system which has the ability to capture, store, manage, retrieve, analyze and display very large databases of spatially referenced information (Clarke, 1999). The Environmental System Research Institute (ESRI) (1990) defined a GIS as a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially referenced data for solving complex planning and management operations.

Scholten and Stillwell (1990) have stated that a GIS has three main tasks. Firstly, there is the storage, management and integration of large amounts on spatially referenced data where the spatial databases contain two types of information, locational and attribute data. The second task is to carry out analyses related to the geographical component of the data. The third task involves the organisation and management of large quantities of data in such a way that it can easily be accessible to all users. This description also indicates that a GIS has some functions that are similar to several other data display and output systems such as Computer Aided Design (CAD), Computer Aided Mapping (CAM) and Database Management Systems (DBMS). However, a GIS is distinguished from other related computer software packages by its ability to link tabular data with spatial location to perform analysis (Cowen, 1988). The analytical capabilities of a GIS and its ability to generate new information from the combination and manipulation of existing data make it a powerful tool compared with other related systems (DeMers, 2000). A GIS has the capability to integrate disparate sources of spatial information and condense them into a form that helps decision-makers reach conclusions (Nijkamp & Scholten, 1993). In this context, a GIS has been more accurately defined as a decision support system involving the integration of spatially referenced data in a problem solving environment (Cowen, 1988).

In natural resource management, the role of GIS is related to its functions (Densham, 1991). Since a GIS can collate, store, manage, retrieve, analyze and display disparate spatially referenced information (Nijkamp & Scholten, 1993), it is able to support various aspects of natural resource management. According to Densham (1991), GIS functionalities, especially the manipulative and analytical capabilities, enhance the problem-solving environment in two ways. First, the problem can be examined to increase the level of understanding and to refine the definition. Secondly, the generation and evaluation of alternative solutions to the problem enables the identification of potential conflicts and trade-offs and the unanticipated impacts resulting from proposed solutions. In these roles, GIS provides functionality for analysis, modelling and evaluation and therefore becomes a linking mechanism between identifying a problem, evaluating alternatives and decision-making. Furthermore, GIS provides a more integrated approach to problem-solving and an interdisciplinary understanding of the decision context (Kliskey, 1995).

2.3 Major GIS Applications in Natural Resource Management

One of the strongest and most successful applications for GIS has been in addressing environmental problems (Goodchild, 1993). GIS have been used in the development of spatial databases, assessment of status and trends of resource utilization and to support and assess various natural resource management decisions (Clark, 1990). Some major areas of application of GIS within the broad area of natural resource management are highlighted in below.

2.3.1 Natural Resource Inventory

Natural resource inventory (NRI) is the recording and assessment of the availability and condition of natural resources. A NRI provides relevant information that is used to formulate effective environmental policies and legislation, implement resource conservation programs, and enhance the public’s understanding of natural resources and environmental conditions (Brown et al., 1998). GIS can be used to store and analyse inventory data and estimate rates of resource change in response to management. Once the inventory data are entered in GIS, maps can be generated to show the location and extent of existing resources.

2.3.2 Hazard and Risk Assessment

Natural hazards such as floods, droughts, cyclones, earthquakes, landslides and forest fires are unavoidable. However, it is possible to minimise the potential risk posed by such hazards by developing early warning strategies, preparing and implementing developmental plans to provide resilience to such hazards and to help in rehabilitation and post disaster reduction (Samir, 2002). GIS and remote sensing have been used in the analysis, monitoring and mitigation of a wide variety of natural disasters. According to Samir (2002), GIS provides the data base from which the evidence left behind by disasters that have occurred in the past can be interpreted, and combined with the other information to arrive at hazard maps, indicating which areas are potentially dangerous. For example, landslide hazards have been estimated and mapped of using GIS-based statistical models (Reis et al., 2009). Floods have been predicted, warned against and mapped by combining morphological information derived from digital terrain models with hydrological models (Consuegra et al., 1995; Sanyal & Lu, 2003; Uamkasem & Simking, 2008). Lava flow pathways have been simulated and volcanic hazard maps have been developed using GIS techniques (Carrara et al., 1999). In most of these studies, GIS and remote sensing have been used to develop suitable disaster management strategies and occupational frameworks for their monitoring, assessment and mitigation.

2.3.3 Change Detection

Information about change is necessary for updating land cover maps and the management of natural resources. Change detection by GIS is a process that measures how the attributes of a particular area have changed between two or more time periods. Change detection often involves comparing aerial photographs or satellite imagery of the area taken at different times (Yang, 1999). It is useful in many applications such as land-use changes, habitat fragmentation, deforestation assessment, coastal change and urban sprawl. For example, Ochego (2003) used GIS to map forest loss and identify key factors involved in the deforestation process. Laurance et al. (2001) also used GIS to predict regional-scale changes in the Brazilian Amazon. Prenzel & Treitz (2004) applied change detection techniques in watershed studies to enhance the capacity of local governments to implement sound environmental management. Mitra (1999) and Dahdouh-Guebas (2002) analysed coastal environmental changes through qualitative evaluation techniques.

Furthermore, Barnes et al. (2001) used GIS-based techniques to derive a change map by vegetation index differencing, image rationing, image differencing and image regression. Epstein et al. (2002) also used GIS-based change detection techniques in infrastructure planning in urban areas, and for studying regional growth and Sudhira et al. (2003) detected, mapped and analyzed the physical pattern of sprawl on landscapes using GIS. In all these studies, the basic principle of the change detection techniques was that the digital number of one date is different from the digital number of another date.

2.3.4 Suitability Analysis

Suitability analysis is a process of determining the fitness of a specific landscape condition to support a well-defined activity or land use (Steiner, 1991). The basic premise of suitability analysis is that each aspect of the landscape has intrinsic characteristics that are to some degree either suitable or unsuitable for the activities being planned, and that these relationships can be revealed through detailed evaluation and assessment (Marsh, 1998). Suitability analysis involves the process of finding the best location to support some desired activity while minimising negative impacts on the environment (Church, 2000). GIS-based suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability and habitat for animal and plant species (Store & Kanga, 2001; Dwivedi et al., 2006), suitability of land for agricultural activities (Bandyopadhyay et al., 2009), landscape evaluation and planning (Miller et al., 1998 as cited by Malczewski, 2004), selecting optimal sites for public and private sector facilities (Church, 2002) and regional planning (Jolly et al., 2001).

2.3.5 Environmental Monitoring

Monitoring is the process of observing and determining qualitative and quantitative transformations that may be occurring and to predict their future trends. GIS presents the opportunity of undertaking effective graphical and numerical monitoring of environmental and natural resource issues. Globally, GIS has been heavily depended upon for environmental monitoring (Tsou, 2004) e.g. pollution monitoring (Briggs et al., 2000) and monitoring land degradation and soil loss (Manoj, 2000). The ability of a GIS to seamlessly integrate data of varying structures (i.e. vector, raster, tabular) and of varying scales makes it key to the success of integrated natural resource monitoring efforts.

2.3.6 Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a decision process which aims both to identify and anticipate the impacts on the natural environment, human health and quality of life, and to interpret and communicate the information about those impacts. Given the spatial nature of many environmental impacts, GIS have been successfully applied in all EIA stages, i.e. from the acquisition, storage and display of thematic information relative to the vulnerability of the affected resources, to impact prediction and quantification, evaluation and presentation for decision support (Antunes et al., 1996).

Crucial and mandatory components of EIA are the prediction of the magnitude of environmental impacts, the design of appropriate preventive or mitigation measures for negative impacts and the enhancement of measures for positive measures (Satapathy et al., 2008). GIS have been used to develop simulation models for predicting the magnitude of environmental impacts (Fedra, 1993). The model results obtained, often in the form of maps showing the spatial distribution of values of a given environmental descriptor, have been used to estimate the extent of environmental impacts. Simple GIS techniques such as overlay, classification, buffering, interpolation, etc have also been used to generate additional information to support impact prediction (Antunes et al., 2001).

More complex uses of GIS for EIA have also been reported. Schaller (1992) used GIS in complex modelling representation techniques. He produced a visual representation, which he called “annoyance mountain,” by combining population data with the noise levels expected from the installation of a new airport in Munich. Johnston et al. (1988) explored the potential of GIS as a repository of data and cumulative impact assessment.

Sankoh (1996) also used GIS to generate space resistance maps and identify route alternatives that presented minimum conflict with the environment.

GIS have also been used for economic valuation of the environment through the preparation of economic value maps (Eade & Moran, 1996). This area of application has increased the practical application of cost-benefit-analysis and consequently enhanced the role of economic valuation on EIA. In all these respective case studies, GIS technology has demonstrated great potential to address natural resource management issues.

2.4 GIS in Developing Countries

The growth of GIS in developing countries has occurred primarily over the past decade. According to Hastings and Clark (1991), much of the initiative of GIS resulted from the desire to apply computer technology to cartography, remote sensing, data management and environmental assessment. In Africa, for example, GIS installations are said to have started in the late 1970s (*Ibid*) with their transfer by international agencies (Yapa, 1991). This transfer encompassed the acquisition of computer software, hardware and the development of human capacity to apply the technology. A few successful GIS installations were also reported in Latin America in the early 1990s (Smith, 1992). According to Sheng et al. (1997), the growth of the use of GIS has been facilitated by a significant decrease in the cost of hardware and modest reduction in the cost of software, along with the wider availability of digital spatial data. Currently, GIS is being used to address a range of spatial problems in the developing world. Common applications include land resource appraisal, urban and regional planning, population policy formulation, national agricultural development, natural resource management and disaster preparedness (Bishop et al., 2000).

In spite of the perceived advantages and extensive applications of GIS, their deployment in developing countries has not been without problems. Various researchers have identified a variety of problems ranging from institutional barriers to technical constraints as well as limited human resources capacities. The difficulties and challenges of implementing GIS in developing countries include the susceptibility of GIS to the changing expectations and/or limited life spans of externally funded development projects, periodic licensing of software, financial constraints, poor vendor support, cumbersome bureaucratic procedures for the approval and procurement of technology, and failure of politicians to support GIS projects. They also include lack of trained personnel, unreliable communication networks and power supply, lack of organisational support to maintain GIS installations, inadequate support of GIS research and poor cooperation among government, academic and private organisations (Sahay & Walsham, 1996; Ramasubramanian, 1999; Bishop et al., 2000; Burrough, 1991; Cartwright, 1992; Hall, 1999; Perera & Tateishi, 1995; Smith, 1992; Sombroek & Antoine, 1994; Taylor, 1991; Yapa, 1991; Yeh, 1991).

In addition to the difficulties and challenges mentioned above, lack of suitable GIS datasets has been mentioned as a major constraint in the implementation of GIS in developing countries (ESRI, 2003). In such cases, the potential of GIS to address spatial problems is severely curtailed since the power of GIS application relies on the scope and quality of the data used. Although readily available in industrialised countries, spatial data in developing countries are often nonexistent or of poor quality. Kalensky (1996) asserts that the existing geospatial information in developing countries are often either incomplete or obsolete and thus not compatible with modern management requirements. Bishop et al. (2000) lend credence to this view and state that where spatial data exist, they are often outdated or lamentably fragmented among and within various institutions and therefore unavailable for widespread use.

Existing data are also difficult to find due to a poor data sharing culture and a lack of institutional commitment to provide data. According to Fox-Clinch (1991), the main reason for this is the bureaucratic apathy towards such requests displayed by the holding institutions that restrict access to maps. This is often legitimised by national security and defence concerns (*Ibid*). Consequently, agencies outside government institutions that need such data have the least chance of obtaining them as they are largely confined to selected scientific departments. Sahay and Walsham (1996) have argued that the problems associated with data sharing are sufficiently severe, in both technical and organisational terms, that it is common in practice for the data in GIS applications to be developed from scratch, even when they already exist.

Furthermore, digital representation of spatial data is rare in developing countries. According to Bishop et al. (2000), generating spatial databases is expensive, time consuming and technically and administratively complex. They further state that most developing countries have neither the capacities nor the resources to undertake the extensive mapping and monitoring programmes required to fill the geospatial information gaps in their environmental management.

In the recent past, however, proprietary data and public domain databases (such as the US census Bureau's TIGER files and Digital Chart of the World satellite imagery) have reduced the drudgery of converting, compiling and formatting data required for GIS projects. Thus, there has been substantial progress in terms of digital data production in many developing countries. The Inter-American bank (1998) points out that spatial data sets in the developing world are becoming increasingly accessible because national mapping agencies are converting hard-copy maps to digital formats. However, experiences in many developing countries indicate that, even when information is accessible, it is often not used to support decisions on nature resource use and management (Dalal-Clayton & Dent, 1993). A survey in eleven countries in Sub-Saharan Africa, by Linden (1992), led to the conclusion that the majority of existing GIS installations are hardly used or do not meet the initial expectations in dealing with urgent problems such as the rapid depletion of natural resources together with environmental degradation.

Levinsohn (1989) asserts that institutional issues such as project planning and management, attention to changes in the institutional culture, and coordination and cooperation between organizations are the major causes of many GIS implementation failures, rather than technical issues. He argues that the scope of GIS implementation is governed by the institutional setting into which the system is to be implemented and advises that greater emphasis must be placed on dealing with institutional concerns if GIS is to achieve the potential that has been ascribed to it. Huizing et al. (2002) lend credence to these views put forward by Levinson. They analysed the factors hindering the implementation of GIS for natural resources management and planning in Zimbabwe and observed that even where technical barriers of GIS implementation were overcome through the acceptance of lower data quality, the provision of minimum hardware and software, a short training course and demonstration of the developed applications, the response among key decision-makers still remained low. Thus, the application of GIS, in a developing country context, requires a context-sensitive approach and involves a variety of modifications to suit local needs in a manner that is compatible with the interaction between the technology and the specific social or institutional setting (Levinsohn, 1989).

2.5 GIS in Zambia

In Zambia, like many other developing countries, the use of GIS is still in its infancy (Moyo & Bwalya, 2001). According to the Ministry of Health (2006), technical barriers exist to adoption, implementation and management, due in part to the lack of trained personnel and awareness of GIS technology and functional capabilities. GIS implementation is also hampered by limitations in data availability and accuracy. Where they exist, they are often fragmented among and within various organisations and only reflect the individual projects that each organisation is responsible for completing (*Ibid*).

Despite these issues, several government and private organisations in Zambia are using GIS to address domain specific applications. These include the Environmental Council of Zambia; the Wildlife Conservation Society; the Forestry Department of the Ministry of

Tourism; Environment and Natural Resources; the Electoral Commission of Zambia; the Survey Department; the Central Statistic Office; the Ministry of Health; and the University of Zambia (Ministry of Health, 2006). These organisations use GIS to plan new projects, analyze current infrastructure, perform environmental monitoring and create customized maps. Some international donor-supported resource management projects using GIS and related technologies are also present in Zambia. For example, the Integrated Water Resource Management for Zambia (IWAREMA), an initiative of the European Space Agency's TIGER, analyses water-related problems and uses satellite data to close the information gap on water availability (Science and Development Network, 2007). According to Moyo and Bwalya (2001), the Survey Department of the Ministry of Lands, the official mapping agency in the country, is currently leading various stakeholders within the National Environmental Information Network and Monitoring System (EINMS) to develop digital topographic database standards and base maps to be utilised for various environmental and natural resource management applications.

A few GIS-based studies, undertaken in Zambia, have been reported in recent academic literature. Munyati (2000) investigated wetland change on a section of the Kafue Flats floodplain wetland area in southern Zambia. He classified four Landsat images obtained in different years and analysed them for change in each land cover category by overlaying them in a GIS framework. Yang and Prince (2000) used GIS to assess the effectiveness of the historical Landsat MSS archive and remote sensing techniques to estimate savannah vegetation structure change in eastern Zambia. They mapped the major land cover types in the study area and the changes that had occurred between 1972 and 1989 using Landsat Multi Spectral Scanner (MSS) data. MSS estimates of canopy cover and canopy cover change were then compared with canopy cover values measured from multispectral aerial photographs. The spatial patterns of land cover change were also explored in relation to possible causative factors. In another study, Limpitlaw (2003) applied GIS and remote sensing to map mine wastes in the Copperbelt province to determine environmental changes over time. He conducted change detection analysis using a combination of data sets including panchromatic aerial photographs (for 1968, 1984 and 1990), a Landsat MSS image (for 1972), Landsat Thematic Mapper (TM) images (for 1984 and 1998) and a Landsat Enhanced Thematic Mapper (ETM) image (for 2000). This allowed the identification and delineation of changes in the area occupied by various types of mine infrastructure. Finally, in a recent study conducted in the Eastern Province of Zambia, Symeonakis et al. (2007) used GIS to develop a method that combined a tree-based decision-support approach with Multiple-Criteria Evaluation techniques to target areas for tsetse fly control. In all these case studies, GIS and remote sensing demonstrated great potential to address the various natural resource management issues.

2.6 Natural Resource Issues in Zambia

Like many other developing countries, Zambia is faced with several environmental problems that are an immediate concern in relation to the sustainable management of natural resources (MENR, 1994). These include deforestation, soil degradation, water pollution, air pollution in the copper mining towns and wildlife depletion (fish and game).

2.6.1 Deforestation

In Zambia, forests are being destroyed without a clear knowledge of all the consequences and without a commitment to sustainable use (Mbindo, 2003). Deforestation is being caused by a combination of practices such as shifting cultivation, felling of trees for timber, wood-fuel or charcoal and uncontrolled bush fires (Chidumayo, 1996). One form of shifting cultivation, referred to as the *chitemene* system, is particularly an important cause of deforestation. It involves cutting down of trees and burning trees and grass as a way of fertilizing the soil (World Rainforest Movement, 2001). This system leaves the soil bare of trees or grass or any other vegetation and renders it susceptible to erosion especially when heavy rains fall.

Large dependence on charcoal for energy is another major cause of deforestation (World Rainforest Movement, 2001), particularly around urban areas such as the

Copperbelt and Lusaka Provinces. Forests are cleared to supply charcoal to meet household energy needs in poor rural and urban households. This has been worsened by the high electricity tariffs and the unreliability of supply (Chipungu & Kunda, 1994; World Rainforest Movement, 2001).

Another cause of deforestation, particularly in Zambia's Western, Eastern and Southern provinces, is the uncontrolled or poorly controlled commercial exploitation of timber (World Rainforest Movement, 2001).

The nationwide average rate of deforestation in Zambia is estimated at 250,000 – 300,000 hectares per year with an average annual forest decrease factor of 0.5% (MTENR, 2002). However, these figures are conservative, as they are based on the 1960s inventories. More recent studies (Chipungu and Kunda, 1994; Chidumayo, 1996) have estimated higher rates ranging from 850,000 to 900,000 hectares per year. According to the Food and Agriculture Organisation (2001), forest cover in Zambia reduced from 39,755,000 hectares to 31,340,000 hectares from 1990 to 2000. Presently, it is a great concern that forest in many parts of the country are disappearing (Shakacite, 2000).

2.6.2 Soil Degradation

Soil degradation (the decline in soil quality caused by human misuse) is one of the most important environmental challenges facing mankind (Oldeman, 1988). It affects soil quality for agriculture and has implications for urban environment, pollution and flooding. The soil becomes less able to support plant and animal growth as there is a decline in levels of available moisture, and nutrients and reduced biological activity. Acidification, salinity, organic depletion, compaction, nutrient depletion, chemical contamination, and erosion are all forms of soil degradation that can be brought about by inappropriate land use practices.

Soil erosion, caused by water in particular, is the most important cause of soil degradation in Zambia (Moyo et al., 1993). The Government of Zambia subscribes to this view and notes that soil erosion has become common place in Zambia (Ministry of Tourism, Environment and Natural Resources, 2002). The problem of soil erosion has been reported to be serious in Central, Eastern Southern and Lusaka Provinces (CSPR, 2002). However, the wide extent of its impacts has not yet been quantified (*Ibid*). According to the Commonwealth Forestry Association (2009), Zambian soils are generally susceptible to erosion due to the geomorphological processes that have taken place over geological time scale. As a result, most of Zambia's plateau and some hilly areas are degraded. Moyo et al. (1993) assert that felling of trees, shifting cultivation and burning of forests are often the causal factors of soil erosion in Zambia. Another major factor that contributes to soil erosion is overgrazing (Osei-Hwedie, 1996). Overgrazing bares landscapes devoid of trees and grass especially in cattle-keeping areas of Southern, Central and Eastern Provinces.

2.6.3 Water and Air Pollution

Water pollution in Zambia is caused mainly by waste waters from industrial activities, effluent from sewage treatment plants and nutrient-rich runoff from agricultural lands (Environmental Council of Zambia, 2000). The mining and manufacturing sectors are the most important polluters of the atmosphere and water in Zambia (Chipungu & Kunda, 1994). According to Dymond et al. (2007), the process of separating copper ore leaves behind an acidic liquid which contains small particles of unused rock that is disposed off into rivers. Water pollution also arises as a result of runoff from mining dumps, seepage from tailing dams and accidental discharges of untreated wastewater. For example, in 2006, Zambia's biggest mining company, Konkola Copper Mine (KCM), caused widespread water pollution when its acidic effluent entered the Kafue River, the main source of water for about two million people in the area. Newspaper reports at the time indicated that the liquid contained 1,000 times more copper, 77 times more manganese and 10,000 times more cobalt than the recommended levels (Dymond et al., 2007). In addition to water pollution, the copper production process also causes air pollution.

Large amounts of sulphur dioxide are released into the atmosphere which is hazardous to people's health and damages the ecosystem, vegetation and infrastructure. According to Dymond et al. (2007), sulphur dioxide, when mixed with water, produces acid rain which leads to changes in the soil chemistry and reduces the photosynthesis process in plants. This in turn causes problems for the local communities – both in terms of growing food and securing a livelihood. For example, Chipungu and Kunda (1994, p. 52) cite Konkola township in Mufulira as the hardest hit by sulphur dioxide emissions, where residents are reported to suffer from respiratory diseases, are unable to grow vegetables in their backyards, and have paint peeling off from their houses.

2.6.4 Wildlife Depletion (Game and Fish)

Zambia's wildlife suffers depletion from small-scale hunting for food by local people and large scale commercial poaching (Holmes & Wong, 2009). Although game management areas have been created and modern laws that restrict access to wildlife have been imposed, Zambia's wildlife population has still continued to decline. For example, elephants which in 1980 were estimated at 100,000, were less than 22,000 in 1993. The population of rhino has declined from 15,000 in 1980 to less than 100 by 1993 (Ministry of Tourism, Environment and Natural Resource, 2007). The fisheries resource base has also be depleted due to over-fishing and pollution of the fish habitat with fertiliser and discharge of industrial effluent. A number of factors contribute to this situation. These include excess hunting licenses, inadequate law enforcement, corruption, high trophy prices, poaching and lack of involvement of local communities in wildlife management and benefit sharing (Mupimpila et al., 1995 as cited by Civil Society for Poverty Reduction, 2002). According to the Civil Society for Poverty Reduction (2002) conflicts over land use for wildlife management between the central government and traditional authorities is a major cause of this decline. Furthermore, the economic benefits of wildlife, although evident at central government level, are not made available to local communities. Consequently, local communities commonly regard wildlife as agricultural pests and a treat to human life (*Ibid*).

CHAPTER 3

METHODS AND DATA

This chapter describes the general approaches and methods employed to demonstrate how GIS and remote sensing can provide quantitative information for enhancing decision-making in natural resource management in Zambia. It begins by describing the approach used to collect data. It then describes the criteria for data selection, the development of case studies and the process of data analysis. The chapter concludes with a description of the software used in the study.

3.1 Data Collection

Collecting spatial data, preparing the data for GIS use, and documenting those processes are usually the most expensive and time-consuming aspects of any GIS project (Lo & Yeung, 2002). To minimise the cost, in this study, efforts were made to obtain and use GIS databases that already existed. Available data were collected from different organisations within and outside Zambia. A systematic approach was followed to collect the data. This included (i) identifying the type of data needed to assess natural resources in general, (ii) identifying the main organisations involved in the collection of socio-economic and natural resource data, (iii) searching databases (and in some cases contacting the respective organisations) and (iv) downloading available data.

Priority was given to data produced within the country, to which other sources available on the internet were added. Initially, free data sources were chosen, to keep the data search as simple as possible, to keep costs down and to test the availability of Zambian datasets on the internet. Access to databases available within different organisations in Zambia, the United States National Aeronautical and Space Agency (NASA), the University of Maryland free online data services and many other public domain databases helped facilitate the search process.

3.2 Assessment of Data Availability

In Zambia, like many other developing countries, the available data were scarce, sparse and unreliable. Even so, several organisations involved in the collection of socio-economic and environmental data were identified. These included; the Ministry of Lands, Survey Department, the Ministry of Agriculture and Co-operatives, the Ministry of Local Government and Housing, the Ministry of Tourism, Environment and Natural Resource, the Central Statistical Office, the Wildlife Conservation Society, the Electoral Commission of Zambia, the Environmental Council of Zambia and the University of Zambia, Department of Geography. These organisations use GIS to plan new projects, analyze current infrastructure, perform environmental monitoring and create customized maps. Hence, subsets of GIS data that reflect the individual projects that each organisation is responsible for completing were available and could thus be used to form the skeleton of a GIS database.

Table 3.1 shows the available data layers and their sources within Zambia.

Table 3.1 Available GIS data layers and sources in Zambia

Core Dataset Entity	Source(s)	Date	Feature Description
Administrative Boundaries a) International Boundary b) Provincial Boundary c) District Boundary	Survey Department, Ministry of Lands Central Statistical Office /CSO http://www.zamstats.gov.zm	1996	ARC/INFO polygon coverage containing the first, second & third level boundary data at a 1:1,000,000 scale.
Infrastructure a) Road network b) Railway c) Airport locations	Survey Department, Ministry of Lands	undated	ARC/INFO line and point files at a 1:1,000,000 scale.
Hydrology a) River network b) Inland water bodies	Survey Department, Ministry of Lands	undated	ARC/INFO line & polygon coverage at a 1:1,000,000 scale.
Soil Units	Survey Department, Ministry of Lands	1974	ARC/INFO polygon coverage at a 1:500,000 scale.
Agro-climatic Zones	Disaster Management & Mitigation Unit http://www.dmmu-ovp.gov.zm/	undated	ARC/INFO polygon coverage at a 1:1,000,000 scale.
Lithology Units	Survey Department, Ministry of Lands	undated	
Population	Central Statistical Office /CSO http://www.zamstats.gov.zm	2000	2000 census data

Because of the problem of not being able to access some data from sources within Zambia and in required quality, it was inevitable that it would be necessary to extend the search to sources outside Zambia. For example, data layers, such as topographical data, land cover data and satellite data were only accessible from sources outside the country.

Satellite images covering Zambia were accessible from public domain databases such as NASA's Warehouse Inventory Search Tool (WIST) and Earth Explorer. There are several satellite systems in operation that collect satellite images. Each type of sensor offers specific characteristics that make it more or less appropriate for a particular application.

In general, there are two characteristics that may serve as a guide for the choice of satellite data: *spatial resolution* and *spectral resolution*.

- Spatial resolution refers to the fineness of detail visible in an image (Verbla, 1995). In other words, it is the size of the area on the ground that is summarised by one data value in the imagery.
- Spectral resolution refers to the width across the electromagnetic spectrum that the remote sensing instrument is detecting (*Ibid*).

The major satellite systems used in natural resources management include Landsat, SPOT (Le System Pour l' Observation de la Terre) and the Advanced Very High Resolution Radiometer (AVHRR).

A summary of the data available outside Zambia and their sources are shown in Table 3.2.

Table 3.2 Available data layers and sources from outside Zambia

Core Dataset Entity	Source(s)	Date	Feature Description
Land Cover	Global Mapping http://www.iscgm.org/cgi-bin/fswiki/wiki.cgi	2003	A GLCNMO is the data of 1km grid with 20 land cover items. The data were created by using MODIS data observed in 2003. A 16 days composite of 2003 is used for land cover classification. The classification is based on LCCS developed by FAO.
Land Cover (2)	Globcover http://wwww.esa.int/due/ionia/globcover	2004 to 2006	300 m resolution regional land cover map derived by an automatic & regionally-tuned classification of a MERIS full resolution time series. The classification is based on LCCS developed by UN.
Digital Elevation Models	USGS EROS Centre http://eros.usgs.gov/ Digital Chart of the World http://www.maproom.psu.edu/dcw/		GTOPO 30 (1 kilometre resolution) SRTM 90 (90 metres resolution) ASTER (15 and 30 metres resolution)
Crop Use Intensity Level	Global Mapping http://www.iscgm.org/cgi-bin/fswiki/wiki.cgi	1986 to 1988	This coverage was created to allow for the accumulation and graphic presentation of data linked to cropped lands in Zambia from 20 map sheets derived from Landsat MSS at a scale of 1:200,000. The agricultural overlay was prepared through interpretation of Landsat 5 Mulitspectral Scanner (MSS). The MSS Imagery was from 1986-1988.
Satellite Imagery	NASA – Warehouse Inventory Search Tool (WIST) https://wist.echo.nasa.gov/~wist/api/imswelcome/index.html Digital Globe (Quickbird & image finder) http://www.digitalglobe.com Earth Explorer http://edcsns17.cr.usgs.gov/EarthExplorer/ USGS Global Visualisation Viewer http://glovis.usgs.gov/ImgViewer/Java2ImgViewer.html Google (for visual interpretation)		Landsat, TM, ASTER

3.3 Criteria for the Selection of Data

In order to use data from different sources and produce reliable results in a GIS environment, it is essential that data are selected and used based on how well they match information needs within the decision process. The different data layers must be compatible in terms of projection, scale, level of accuracy and completeness. Issues of projection can easily be solved in a GIS environment. Therefore, it was the scale, level of accuracy and completeness that mainly determined the suitability of data. These are important for effective use in the planning and decision-making process.

In terms of scale, some data can be used at broad scale while other data can be used at a finer scale in detailed analyses. According to Ononiwu (2002), environmental monitoring can be executed at 1:1,000,000 – 1:1,500,000 scales for global applications and 1:100,000 – 1: 250,000 scale for regional applications. Geospatial information at these scales is only suitable for reconnaissance. At the control level 1:50,000 – 1:100,000 are suitable for pre-feasibility, 1:5,000 – 1:50,000 for feasibility and 1:1,000 – 1:5,000 for detailed survey.

With regard to the level of accuracy and credibility of the data, access to good documentation about the different data layers and reliable ground reference are required. Therefore, in this study, available data were considered suitable if they were at scales that could be used effectively for regional applications and were accompanied by good documentation (Meta data).

Based on these criteria, suitable remote sensing data (ASTER imageries), digital elevation models, soil data, road network and river network datasets were selected for the GIS analyses undertaken in this study. In order to produce reliable results, every effort was made to ensure that the different data layers were compatible in terms of projection, scale, level of accuracy and completeness. All the data layers were projected to the UTM coordinates zone 35 south. The spheroid and datum were also referenced to WGS 84.

The ASTER imageries acquired from EROS Data Centre were used in this study. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an advanced multispectral imager on board the Terra satellite which was launched in December 1999 (Earth Remote Sensing Data Analysis Centre, 2004). The ASTER orthorectified images were mapped in Universal Transverse Mercator (UTM) coordinate system and were in GeoTIFF file format. These images were mainly used to generate land cover maps of the study areas.

As with the remote sensing data, 30m x 30m digital elevation models (DEMs) were also acquired from the EROS Data Centre. Initially, these DEMs were developed from ASTER satellite data. Topographical factors such as slope and slope length were derived from these DEMs.

3.4 Development of Case Studies

Three example case studies were developed to demonstrate a variety of ways in which GIS and remote sensing data can be used, not only for visualizing environmental themes but also for providing pertinent environmental data for decision-making based on the selected suitable data. The case studies were developed around key natural resource issues in Zambia.

According to Yin (2002), the development of case studies is appropriate when a researcher seeks to address “how or why” research questions and where the research focus is on contemporary events within a real-life context. Therefore, since contemporary events are the focus of this study, the case study strategy was applied.

3.5 Data analysis

GIS applications are used in response to spatial questions (Falbo et al., 2002). The ensuing operations, such as data collection, database development, data analysis and output, are undertaken in response to those questions. Figure 3.1 shows the logical structure of GIS operations undertaken in this study to assess the various natural resource issues.

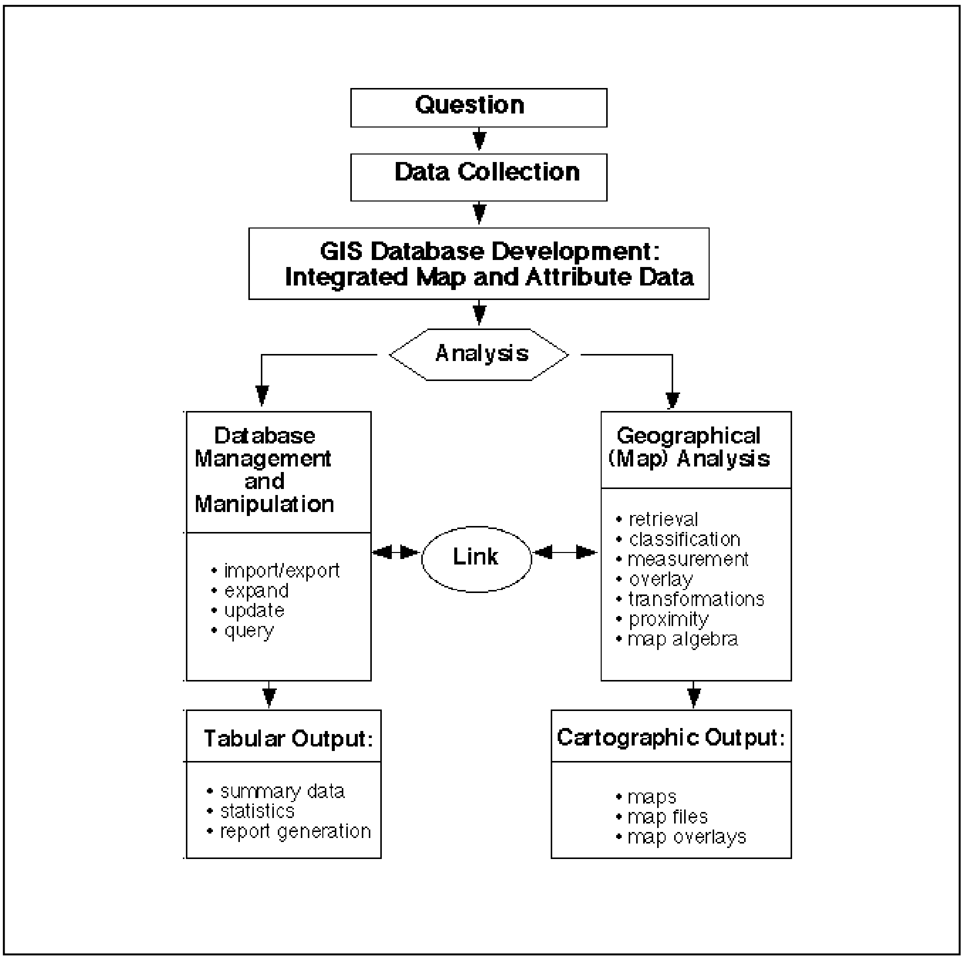


Figure 3.1 Logical flow chart of analytical operations within a GIS framework
(Adopted from Falbo et al., 2002)

3.6 GIS Software

In this study, the GIS software IDRISI and ArcMap (version 9.3) were used for all spatial data manipulation, analysis and presentation.

IDRISI is a geographic information and image processing software system developed at Clark University. It is designed to provide professional-level geographic research tools on a low-cost non-profit basis. Introduced in 1987, IDRISI has become the most widely used raster-based microcomputer GIS and image processing software because it covers a full range of GIS and remote sensing needs.

ArcMap is the central applications in ESRI’s ArcGIS software use primarily to view, edit, create and analyse geospatial data.

These GIS software were used in this study for the following reasons:

- Ease of operation,
- Familiarity with the software,
- Availability at Massey University, Manawatu Campus
- Applicability to several situation in natural resource management

CHAPTER 4

CASE STUDY 1: DEFORESTATION ASSESSMENT

4.1 Introduction

Deforestation of tropical lands has become an issue of worldwide significance (Apan & Peterson, 1998, pp. 137). Combating deforestation requires action at a range of political and social levels. The first step however, is the production of factual information on the rate, extent and location of deforestation (Ochego, 2003). GIS and remote sensing are powerful tools in the provision of such information. By using GIS and remote sensing data it is possible to map deforestation, determine the causal factors and use the resultant models to produce habitat risk maps (Mertens & Lambin, 1997). Such information is vital both at local and national levels to provide guidance or regulation against inappropriate use of forest resources (Apan & Peterson, 1998).

This chapter presents the first case study. The main aim of this case study was to demonstrate the application of GIS techniques and remote sensing data by assessing forest loss and generating a deforestation risk map. Inherent in this case study were the interpretation of remote sensing data, evaluation of the quality of the resulting change information and application of remote sensing and other ancillary data as input in GIS to analyse the deforestation process.

4.2 Case Study Area

This case study was implemented in the Luangwa Valley in Eastern Province, Zambia (Figure 4.1). This area chosen is particularly significant due to the presence of great variations in form and composition of the savannah vegetation (Cole, 1986) and because vegetation change or habitat alteration has been a major concern for conservation management in the Luangwa catchment (Abel & Blaikie, 1986). Vegetation in the study area includes miombo woodland on the plateaus and low hills in the valley, Colophospermum mopane (mopane) woodland in distributary alluvial areas, miombo shrub land in dissected terrain, thickets on freely draining alluvium and grassland on alluvial clay plains and the riverine strip (Astle, 1988).

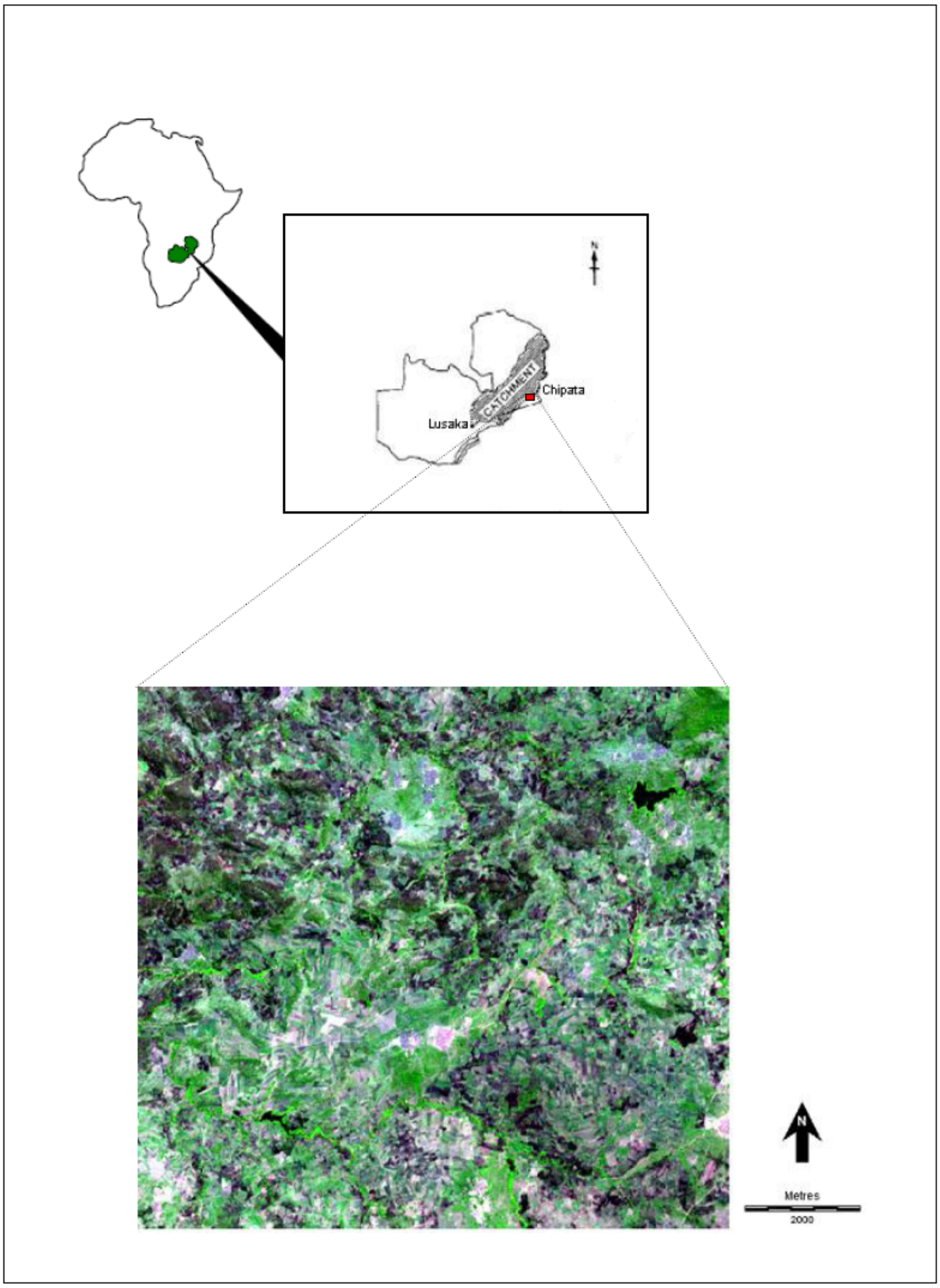


Figure 4.1 Subset of an ASTER image of the study area and its location in the Luangwa Valley catchment in Eastern Province, Zambia

4.3 Methodology

The basic method used in this case study constituted of two major steps:

(i) Generation of a land cover change map and

(ii) Analysis of the deforestation process.

The overall outline of the study flow is shown in Figure 4.2.

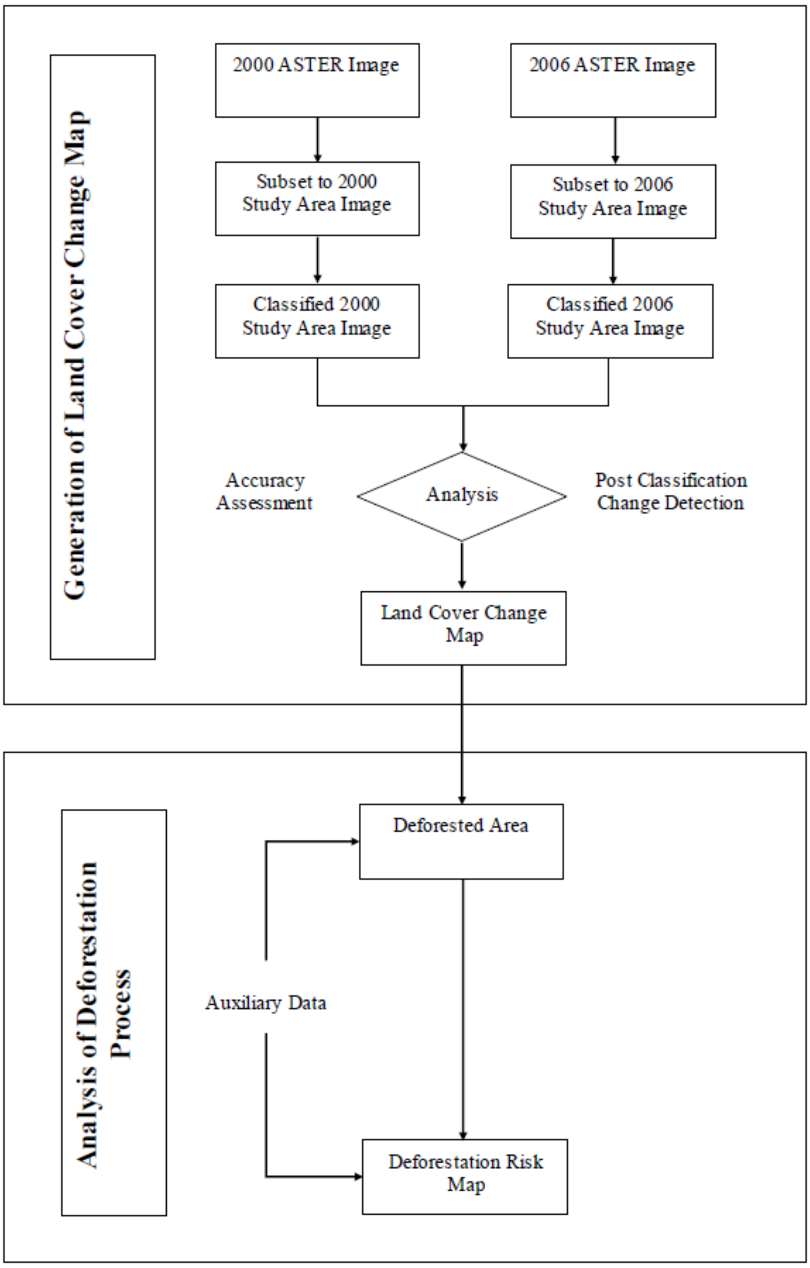


Figure 4.2 Overall case study flow

4.4 Data

Two ASTER VNIR images, with a spatial resolution of 15 m, were used to produce forest cover maps for the years 2000 and 2006. The forest cover map for 2000 was derived from a 1455 x 1304 pixel subset from ASTER orthorectified digital data, taken on 28 July 2000 while the 2006 forest cover map came from a similar digital data set acquired on 22 July 2006. Both images were already orthorectified and geo-coded (Universal Transverse Mercator) by their providers.

A digital elevation model (DEM) of the study area with 30 m resolution was also used. This DEM was acquired from the USGS EROS Data Centre. Slope and elevation were derived from this DEM.

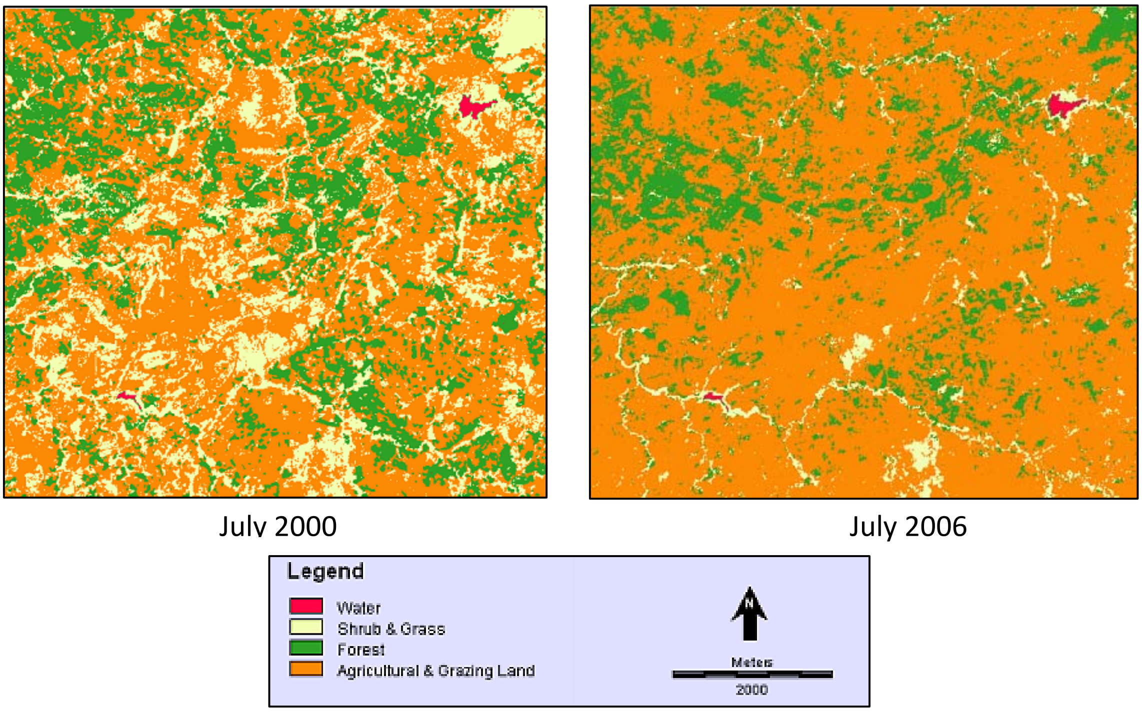
A road network layer was also used to support the satellite data. This layer was digitised on-screen as a vector file using as a background a composite image created from the ASTER images. This file was converted to raster for further manipulation and analysis.

The software package IDRISI Taiga was used in this case study for all image processing tasks.

4.4.1 Image Classification

Image classification is the extraction of differentiated classes from raw remotely sensed data. Supervised classification was performed because it showed better extraction of information than unsupervised classification. This involved exploring the image and computing clusters that represented groups of pixels with similar spectral properties. Eight classes were created based on spectral differences in the classified image, topographic features, previous knowledge and visual interpretation of high resolution data from Google Earth. The eight classes were then reclassified into four land cover classes using the Edit/ASSIGN module in IDRISI. The final output of the classified images were then filtered using 3 x 3 mode filter to produce a smooth view and avoid having isolated individual pixels. As a result, four land cover classes were discriminated namely;

water, shrub land, forest and agriculture/grazing land. The classified images of the study area for 2000 and 2006 are shown in Figure 4.3.


July 2000

July 2006

Figure 4.3 Land cover classes in the study area for 2000 and 2006

4.4.2 Image Enhancement

Image enhancement techniques, performed on the satellite data included, composite generation and digital filtering. To generate composite images for visual analysis, several band combinations were tested. False colour composite images of spectral bands 2-3-1 provided the best band combination for both temporal scenes. They clearly distinguished between forest cover and other types of land cover. Several filters (3x3) were also tested and then used. The 3 x3 mode filter was used because it gave clear and smooth results. False colour composite images for both temporal scenes are shown in Figure A.1 and A.2 of Appendix A.

4.5 Selection of Factors

Factors influencing the rate of deforestation were selected using criteria based on related previous studies (Table 4.1). The selection of the factors also depended on the availability of data and the possibility of expressing the factor as a map layer.

Table 4.1 Selection of input factors for the deforestation assessment

Factor Selected	Reasons for selecting the factor in this study	References that have used the factor
Elevation	Elevation is an important factor. It is generally hypothesized that high-lying areas tend to limit the rate of deforestation.	Dirzo & Garcia (1992); Holmes (2001); Ludeke et al. (1990).
Slope	Slope factor is important because steep slopes limit deforestation due to the difficulties of transport and land preparation.	Ludeke et al. (1990); Rudel (1993); Sader & Joyce (1988)
Proximity to roads	Proximity to roads is important because roads provide access for loggers, cultivators and encroachers who can cause deforestation (Grainger, 1993).	Chomitz & Gray (1995); Deininger & Minten (1997); Grainger (1993); Liu et al. (1993); Ludeke et al. (1990); Mamingi et al. (1996); Mertens & Lambin (1997); Nelson & Hellerstein (1997); Sader & Joyce (1988)

4.6 Creation of Input Factors

The GIS raster layers representing slope and elevation were derived from the DEM of the study area while the other layer representing proximity to roads was produced using simple GIS distance analysis of its raster layer.

- Slope Gradient and Elevation Factors: Slope and elevation maps, derived from the DEM of the study area, were used to represent these factors. Slope gradient in the study area ranged from 1 to 27^0 while elevation ranged from 850 to 1320 m above sea level.

- Proximity to Roads: Proximity to roads was represented by an image of simple linear distance from all roads in the study area. To create this image, the roads vector file was converted to grid and the module DISTANCE in IDRISI was used to produce a continuous surface of Euclidean distance values from the roads.

4.7 Results

The following are the results of the classification and analysis:

4.7.1 Computation of Area

After classification, the AREA module in IDRISI was used to compute the areas of the land cover classes that resulted from the classification. A comparison of the area results for the two images is presented in Figure 4.4 and Table 4.2.

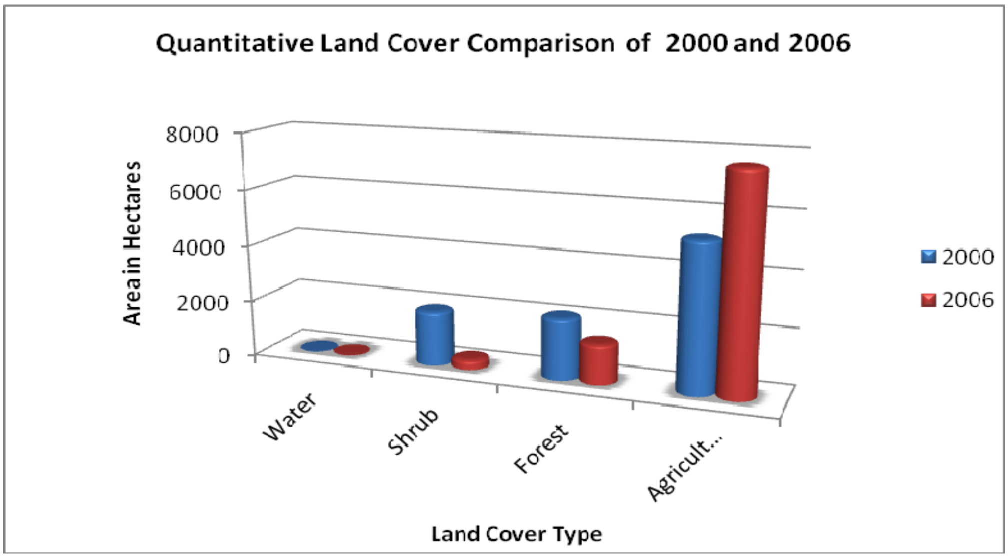


Figure 4.4 Land cover area comparison of 2000 and 2006

Table 4.2 Land cover area comparison between 2000 and 2006

CATEGORY	2000	2006
Water	17 ha	16 ha
Shrub	1951 ha	339 ha
Forest	2172 ha	1413 ha
Agriculture/Grazing land	5232 ha	7603 ha

Figure 4.4 and Table 4.2 clearly demonstrate the decline in water bodies (5.8%), forest (35%) and shrub land with an overall decrease of 83%. While these were shrinking, agricultural and grazing land increased by 31%.

4.7.2 Land Cover Change Assessment

Change assessment implies analysis of temporal transition. A technique, known as post-classification change detection, was used to form the "from-to" matrix. Table 4.3 shows the resulting change detection matrix. The change detection matrix provided a convenient means of summarising all land cover changes between sensing epoch.

Table 4.3 Land cover change detection matrix from 2000 to 2006

FROM 2000	**TO 2006**				**TOTAL CHANGE (HA)**
	Water	Shrub	Forest	Agriculture	
Water	17	0.34	0.32	0	0.7
Shrub	0.11	274	380	1297	1677.11
Forest	0.02	31	581	1560	1591.02
Agriculture	0	34	451	4746	485

The table clearly shows that most (98%) of the deforestation was caused by change of forest to agriculture. 31 hectares (2%) of forest changed to shrub whilst only 0.02 ha (0.001%) changed to water. The diagonal values (shaded) in the table indicate classes of no change.

The change detection matrix also provided the opportunity to highlight significant categories and to explain their relationship using a map. Figure 4.5 shows the overall land cover change for the 6 years between 2000 and 2006 derived from the change detection matrix. The change categories are as follows:

- Deforested areas (Forest to shrub and agriculture and pasture)

- Change to non forest (Shrub to agriculture and pasture)
- Change to shrub (Agriculture and pasture to shrub)
- Reforested areas (Shrub to forest, agriculture and pasture to forest)

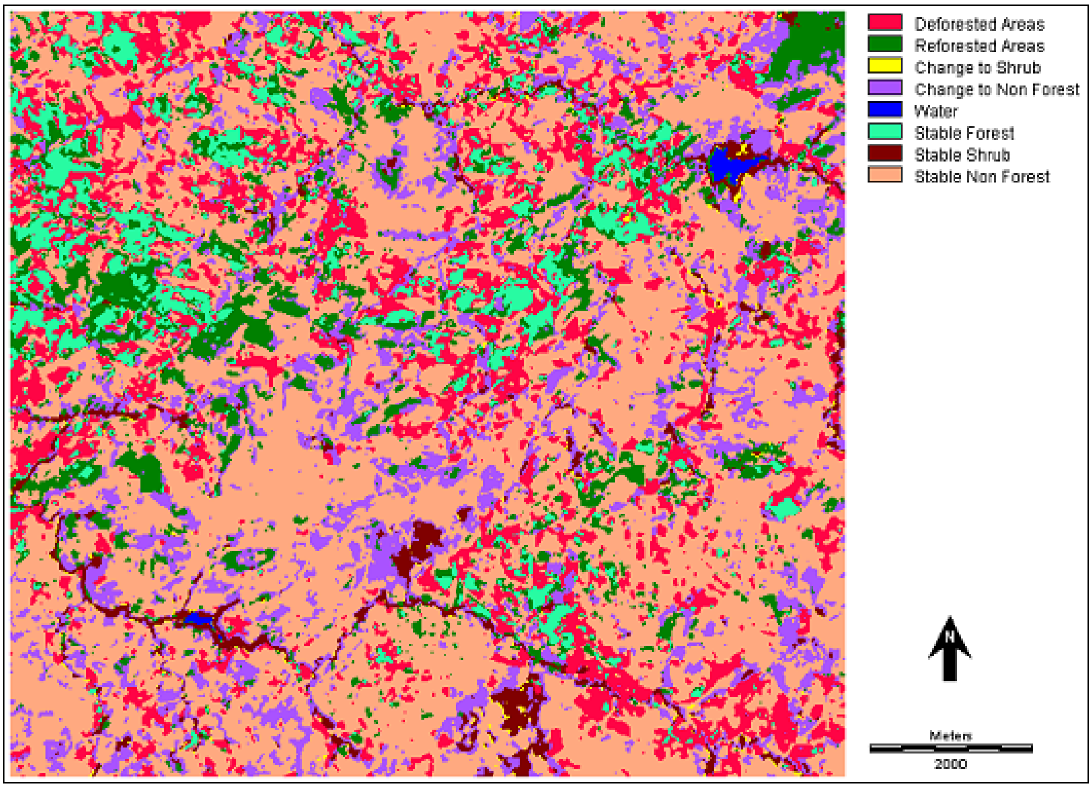


Figure 4.5 Land cover change between 2000 and 2006

The areas and percentages of the land cover change between 2000 and 2006, derived from the change detection matrix, are also shown in Table 4.4.

Table 4.4 land cover change between 2000 and 2006

CATEGORY	AREA (HA)	AREA (%)
Deforested Areas	1591	17
Reforested Areas	832	9
Change to Shrub	35	0.4
Change to Agriculture & Pasture	1298	14
Water	17	0.2
Stable Forest	581	6
Stable Shrub	274	3
Stable Agriculture & Pasture	4746	50.4

4.7.3 Type of Deforestation

The types of deforestation and their respective areas in hectares were also computed as shown in Table 4.5.

Table 4.5 Types of deforestation and their area

TYPE OF DEFORESTATION	AREA (HA)	AREA (%)
Forest to water	0.02	0.05
Forest to Shrub	31	1.95
Forest to Agricultures & Pastures	1560	98

4.7.4 Deforestation vs. Elevation

The deforested area image was combined with a 30m DEM of the study area and the total numbers of deforested pixels were extracted from the DEM dataset. Figure 4.6 shows the relation between deforestation and elevation. Most of the land deforested in the study area was on elevations between 921 and 1040 metres.

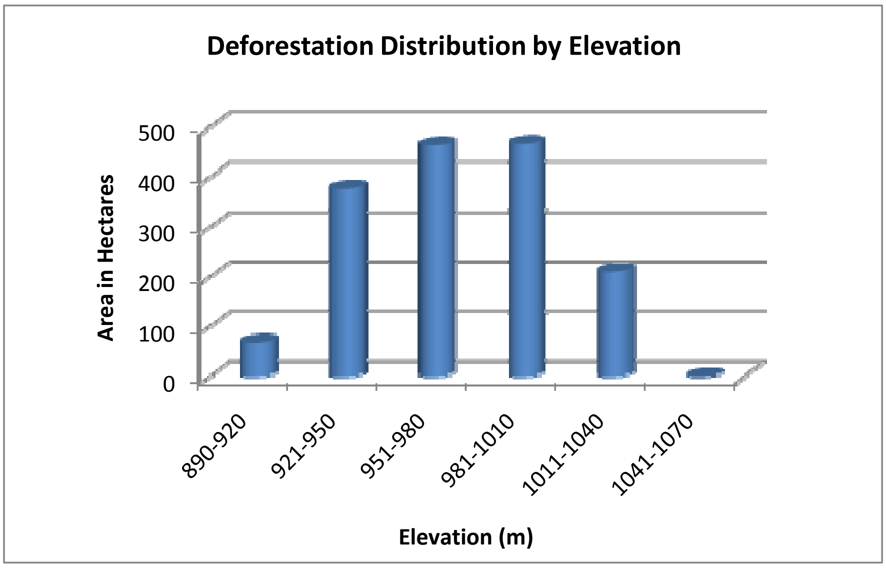


Figure 4.6 Relation between deforestation and elevation

4.7.5 Deforestation vs. Slope

This analysis was made by combining the deforested area image with the slope dataset generated from the DEM. Figure 4.7 shows the relation between deforestation and slope. The total numbers of deforested pixels were extracted from the slope dataset to plot the graph. 95% of the total deforestation occurred within 0 to 6 degrees in slope gradient.

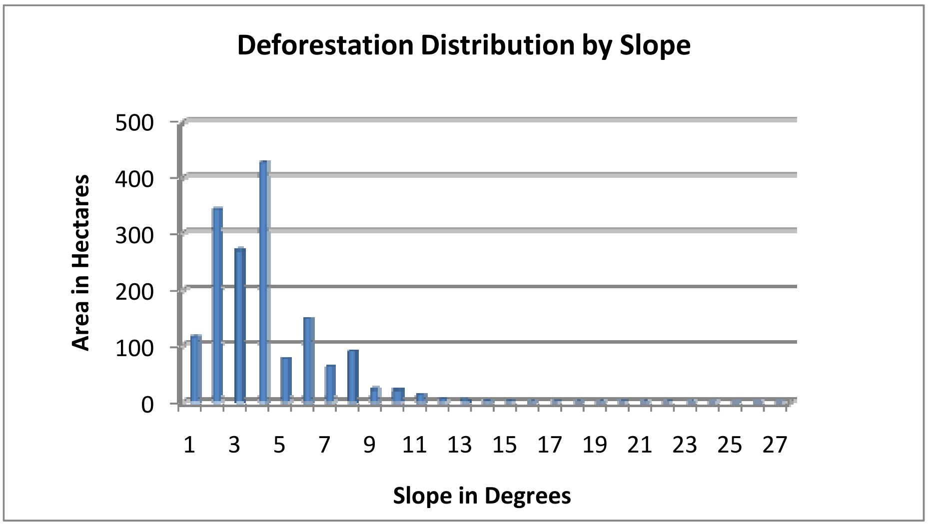


Figure 4.7 Relation between deforestation and slope

4.7.6 Deforestation vs. Proximity to Roads

Proximity to roads was represented by an image of simple linear distance from all roads in the study area. To create this image, the roads vector file was converted to grid and the module DISTANCE in IDRISI was used to produce a continuous surface of Euclidean distance values from the roads. The total numbers of deforested pixels were extracted from this image to plot the graph. Figure 4.8 shows the relationship between deforestation and proximity to roads.

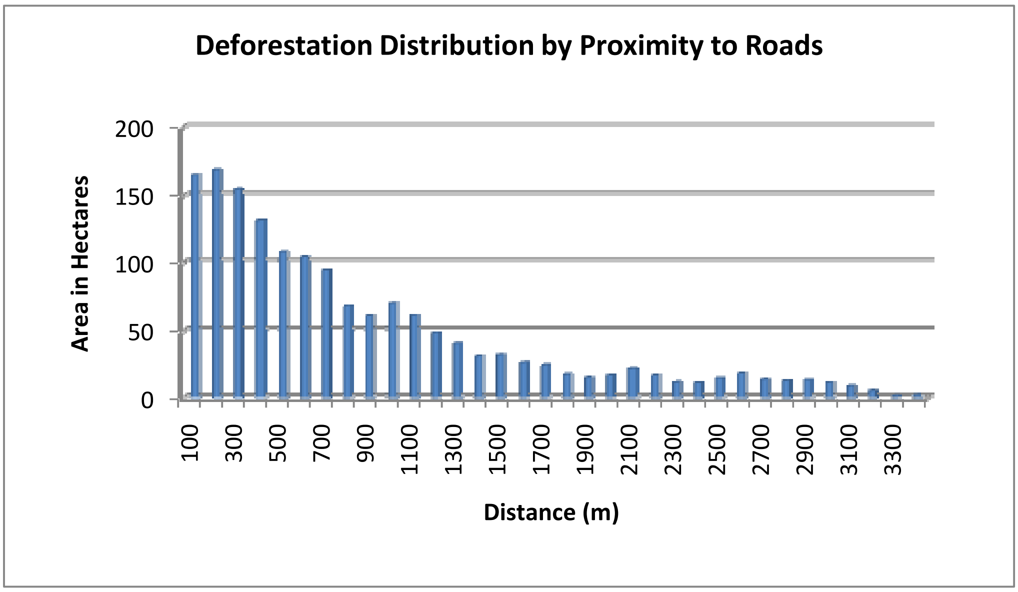


Figure 4.8 Relationship between deforestation and proximity to roads

The figure shows that the deforestation amount decreased as the distance from the road increased. 95% of the deforested areas in the study area were within 2 km of a road.

4.7.7 Deforestation Risk Map

A deforestation risk map for the study area was produced based on 95% deforestation conditions (i.e. elevations between 0 to 1040m, slopes between 0 to 6 degrees and distances within 2 km of a road). A map showing the deforestation risk zones was thus generated based on the three variables by using the RECLASS and OVERLAY functions of IDRISI. Five categories of deforestation risk included: very low, low, medium, high and very high risk zones (Figure 4.9). The resulting map showed that 5% of the study area is designated to be very low risk. Low, medium and high risk zones make up 24%, 37% and 27% respectively. The zone corresponding to very high susceptibility constitutes 7%.

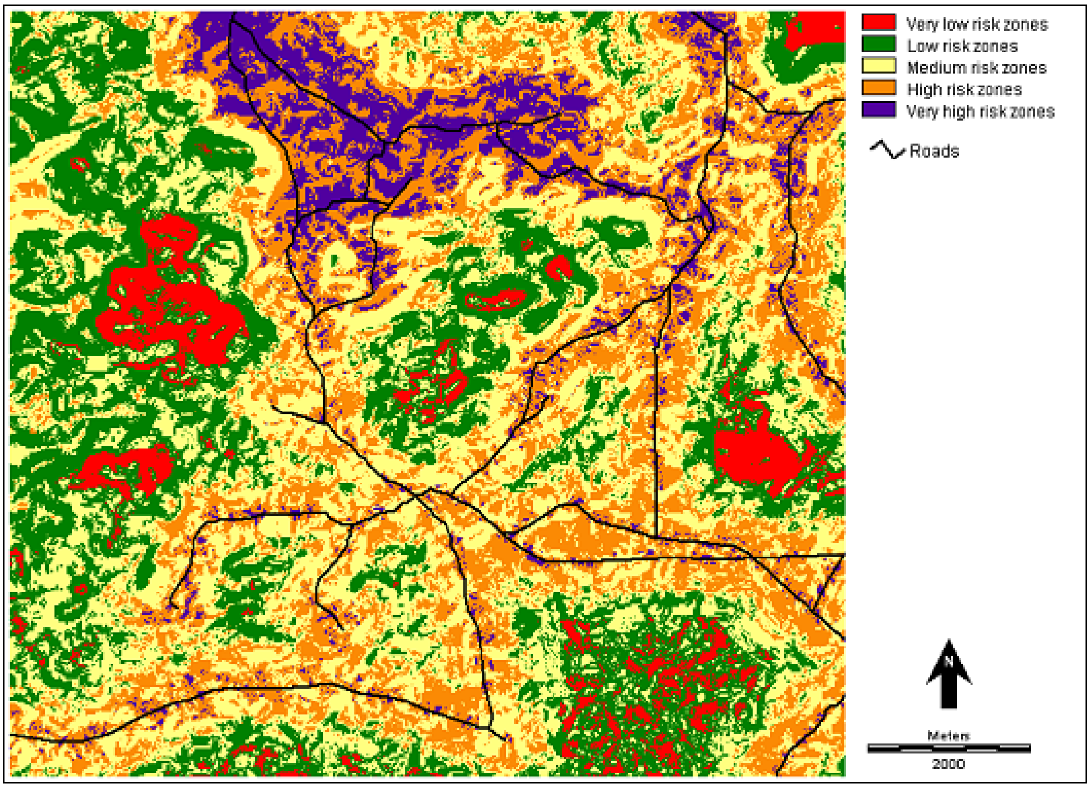


Figure 4.9 Deforestation risk map

4.8 Discussion

This case study has demonstrated how GIS and remote sensing can provide quantitative data for forest resource management. Inherent in the study was the interpretation of remote sensing data, evaluation of the quality of the resulting change information and application of remote sensing and other ancillary data as input in GIS to derive quantitative data and analyse the deforestation process. By using the data manipulation and analysis of GIS, it was possible to obtain quantitative data on the land cover classes, land cover changes, location of deforestation and types of deforestation in the study area. A deforestation risk map was also generated.

This type of information is vital, both at local and national levels, to provide guidance or regulation against inappropriate use of forest resources (Apan & Peterson, 1998). The relationship between the deforestation process and a set of deforestation-influencing factors was also analysed in order to gain insight into the causes of the process in the study area. According to Grainger (1993), the identification of factors contributing to deforestation is a major step in controlling forest loss and is necessary in comprehensive forest management planning. The factors considered in this study included slope, elevation and proximity to roads.

The results show that the slope factor in the study area is a major factor limiting deforestation. This observation has been made by other studies (Grainger, 1993; Ludeke et al., 1990; Rudel, 1993; Sader & Joyce, 1988). In general, steep slopes limit deforestation by logging due to the difficulties of transport and mechanized operations.

With regard to elevation, the results indicate that elevations between 921 to 1040m are more susceptible to deforestation in the study area. Considering the possible causes of deforestation in the study area cited by Moyo et al. (1993), the action of forest fires is the most likely possible cause of deforestation in high-elevation areas as it is the only known cause that could overcome the limitations imposed by slope and elevation.

Pertaining to the proximity variable (i.e. proximity to roads), locations near roads were hypothesized to be highly susceptible to deforestation than those further away. The results show distances within two kilometres of a road to be more susceptible to deforestation. This finding conforms to results indicated by other studies (Grainger, 1993; Mertens & Lambin, 1997; Nelson & Hellerstein, 1997). These studies indicate that deforestation declines rapidly beyond distances of two or three kilometres from a road. However, Liu et al. (1993) and Mamingi et al. (1996) report that deforestation and distance from roads remain strongly correlated at much greater distances.

4.9 Conclusions

This case study has demonstrated the application of GIS techniques and remote sensing data by assessing forest loss and generating a deforestation risk map. By using the data manipulation and analysis of GIS, it has been possible to obtain quantitative data on the land cover classes, land cover changes, location of deforestation and types of deforestation in the study area thereby demonstrating the usefulness of GIS and remote sensing. The results demonstrate a decline in water bodies, shrubs and forest and an increase in agriculture and grazing land.

A deforestation risk map for the study area was also generated using simple GIS operations. This type of information is necessary for comprehensive forest management planning. The case study has successfully demonstrated how GIS and remote sensing data facilitate the extraction of complete and accurate information to analyse the types, location and rates of forest/land cover change.

CHAPTER 5

CASE STUDY 2: SOIL EROSION ASSESSMENT

5.1 Introduction

Soil erosion is a worldwide problem because of its economic and environmental impacts. Development of effective soil erosion control plans requires the identification of areas vulnerable to soil erosion and quantification of the amounts of soil loss from various areas (Lim et al., 2005). GIS and remote sensing data can be used to identify areas that are at potential risk to extensive soil erosion and provide information on the estimated value of soil loss at various locations (Baban & Wan Yusof, 2001). This information is very useful in the decision-making context for planners to take appropriate soil conservation measures.

In this second case study, GIS was used to map and quantify soil erosion potential using information from remotely sensed data, digital elevation data, soil data and other relevant literature. The objectives were to (1) develop a soil erosion potential map of the study area; (2) estimate of annual soil loss from erosion and to thus provide a scientific basis for soil conservation planning.

5.2 Case Study Area

This study was carried out in a sub-catchment of the Lusitu River catchment in the Southern Province, Zambia (Figure 5.1). The sub-catchment covers 5942.7 ha and has altitudes ranging between 370 and 1117m above sea level. The climate is humid subtropical with dry winters and hot summers and an average seasonal rainfall (from October to March) varying between 700 and 800 mm. The vegetation in the study area can be classified into four types - woodland savannah, termitaria glassland, permanent swamps and floodplain glassland. The catchment is underlain by three soil types - Albic Arenosol, Lithosol and Chromic Luvisol (classified according to FAO, 2006), the most abundant being Chromic Luvisol.

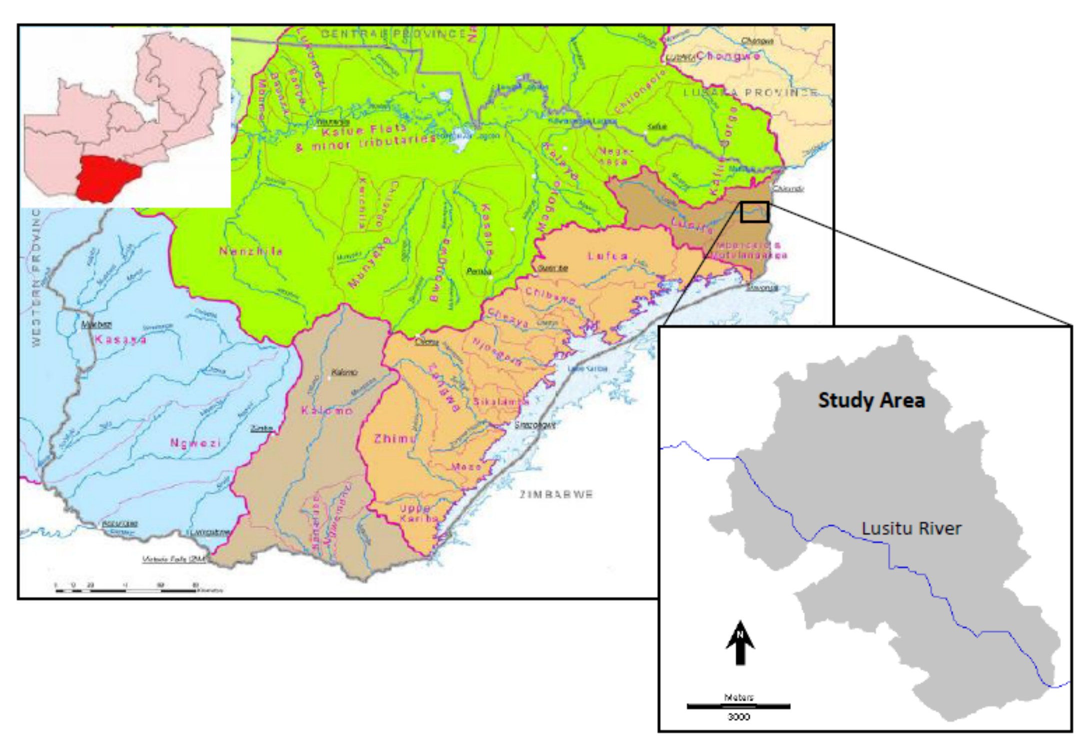


Figure 5.1 Location of study area in the Lusitu River catchment in Southern Province, Zambia

5.3 Methodology

The methodology in this case study involved the integration of the Revised Universal Soil Loss Equation (RUSLE) in a GIS environment. RUSLE (Renard et al., 1997) is an empirical soil erosion model designed on the Universal Soil Loss Equation (Wischmeier & Smith, 1978). It estimates annual soil loss per unit area from rill and inter-rill erosion caused by rainfall splash and overland flow, but excludes gully and channel erosion. Because of its convenient application and its compatibility with GIS software, RUSLE has been the most frequently used empirical soil erosion model globally (Julien & Tanago, 1991).

The RUSLE formula to compute average annual soil loss is:

$$A = R * K * LS * C * P \qquad (1)$$

In this formula:

A = average soil loss (t ha^{-1} $year^{-1}$),

R = rainfall/runoff erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$),

K = soil erodibility factor (t ha h MJ^{-1} h^{-1} mm^{-1}),

L = slope length factor (dimensionless),

S = slope steepness factor (dimensionless),

C = cover and management practice factor (dimensionless), and

P = conservation support practice factor (dimensionless).

This formula is ideally suited for application in a grid-based environment where map algebra can be performed. Therefore, the GIS software IDRISI was used to build and integrate the RUSLE factors, to generate a soil erosion potential map and to calculate soil loss interactively.

5.4 Data

Data to generate the RUSLE factors included an ASTER image (land cover), a DEM, a soil map and the results of other relevant studies.

5.4.1 Land Cover

ASTER satellite imagery, with a spatial resolution of 30m (taken on 06 February 2006), was used to produce the land cover map of the study area. The ASTER imagery was acquired from the Centre for Earth Resources Observation and Science (EROS). A stratified supervised classification using the Maximum Likelihood Method was carried out to generate the land cover map of the study area. The map consists of four dominant land cover classes namely; primary forest, secondary forest, shrub and grass and water (Figure 5.2).

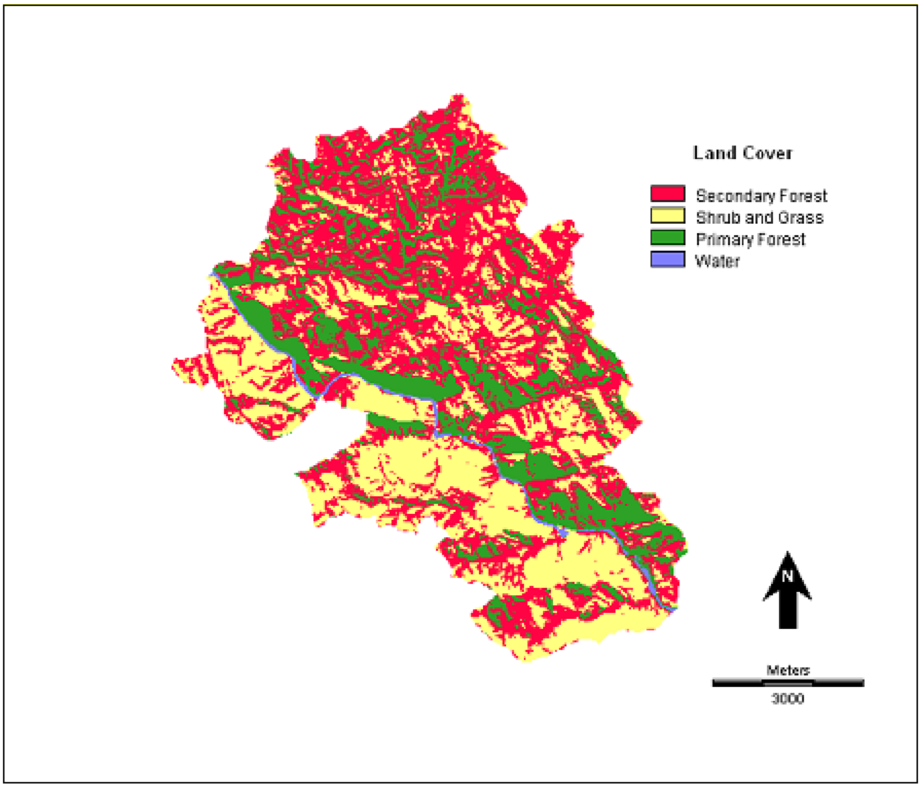


Figure 5.2 Land cover map of the study area

5.4.2 Soil Data

The soil data for this study were acquired from the Food and Agriculture Organisation (FAO). These were initially generated by the Survey Department of the Ministry of Lands, Zambia at a scale 1:500,000.

5.4.3 Topographical Data

A 30 x 30 digital elevation model of the study area was acquired from the USGS Centre for Earth Resources Observation and Science (EROS). This DEM was initially developed from ASTER satellite data by its providers. Slope and slope length were derived from this DEM.

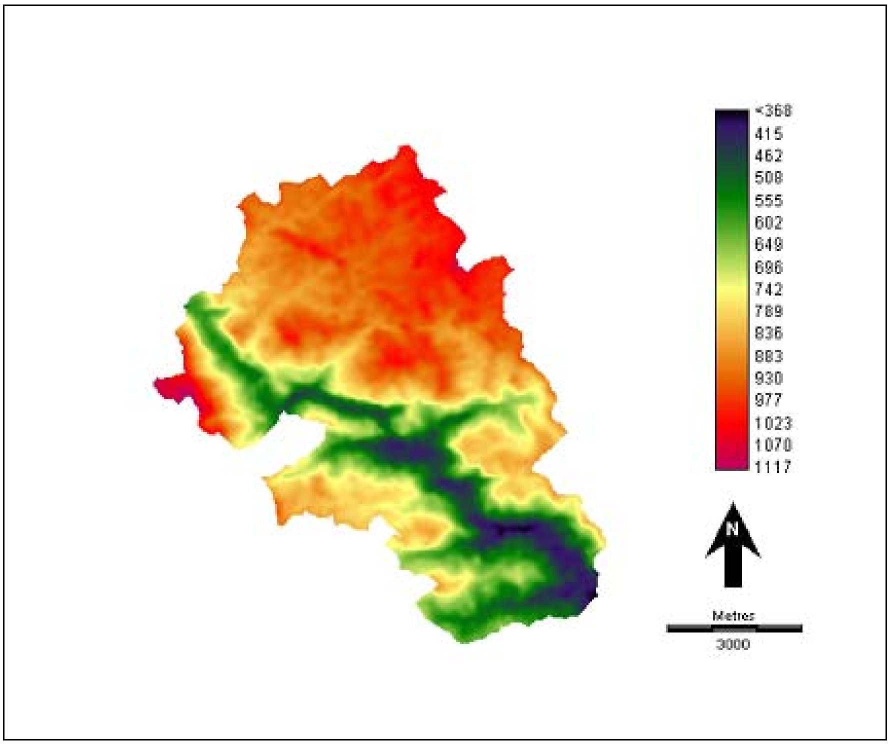


Figure 5.3 DEM of the sub-catchment area

5.5 Determining RUSLE Factors

Determination of the necessary RUSLE factors for this study is described below.

5.5.1 Topographic factors (S and L)

Within the RUSLE, the slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion (Lu et al., 2004). There are many relationships available for estimating the LS factor (e.g. Moore & Burch, 1986; Moore & Wilson, 1992; Renard et al., 1997). Of these, the one proposed by Moore and Burch (1986), for estimating the RUSLE LS factor was applied because of its simplicity and suitability for integration in GIS environment. With this technique, the LS factor is estimated based on flow accumulation and slope steepness and is given as:

$$LS = (\text{Flow Accumulation} * \text{Resolution}/22.13)^{0.4} * (\text{Sin slope}/0.0896)^{1.3} \qquad (2)$$

In this formula, Flow Accumulation is a grid theme of flow accumulation expressed as a number of grid cells and resolution is the length of a cell side. The flow accumulation grid was created from the 30 meter DEM discussed earlier using the watershed delineation tools in ArcMap. The LS factor was then computed using equation 2. The LS factor values in the study area varied from 0 to 2.92 with a mean of 0.4. A map showing the distribution of the LS factor in the study area is shown in Figure B.1 of Appendix B.

5.5.2 Cover and management practice factor (C)

The C-factor is used to reflect the effect of cropping and management practices on soil erosion rates in agricultural lands and the effects of vegetation canopy and ground covers on reducing soil erosion in forested regions (Renard et al., 1997). Based on the classified land cover map prepared from the ASTER images acquired in 2006, the C-factor values corresponding to each vegetation class were estimated from RUSLE guide tables (Wischmeier & Smith, 1978) as shown in Table 5.1. These values were used to reclassify the land cover map to obtain the C-factor map of the study area (Figure B.2 of Appendix B). The C-factor values in the study area varied from 0 to 0.11 with a mean of 0.006.

Table 5.1 C-factor values for different land cover classes

Land Cover Class	C-Factor
Primary forest (canopy cover > 40%)	0.002
Secondary Forest (canopy cover 10 – 40%)	0.006
Shrub and Grass	0.11

Adapted from Wischmeier & Smith, (1978)

5.5.3 Soil erodibility factor (K)

The soil erodibility factor (K) represents the average long-term soil and soil profile response to the erosive power associated with rainfall and runoff. K values are usually estimated using the soil-erodibility nomogragh method (Wischmeier & Smith, 1978). This method involves collapsing many measurable soil properties to five most closely correlated with soil erodibility - percent silt (0.002 – 0.1mm), percent sand (0.1 – 2mm), organic matter, soil structure and permeability. However, in this study experimental results for the K-factor values were adopted from Wischmeier and Smith (1978) a publication of the Zambian Ministry of Energy and Water development (2007) (Table 5.2.).

Table 5.2 K-factor values for different soil types

Soil Type	K Factor
Albic Arenosol	0.2
Lithosol	0.15
Chromic Luvisol	0.37

Adapted from Wischmeier & Smith, (1978) and Ministry of Energy and Water development (2007)

5.5.4 Rainfall erosivity factor (R)

The rainfall factor (R) is a measure of soil loss potential due to climate, such as shower distribution, intensity and the rainfall amount, at a particular location. In this study, the experimental catchment area was small enough (5,943 ha) and was assumed to fall within a single designated region. Therefore, a constant R value of 80 was assumed in all classes of the K-factor image.

5.5.5 Conservation support practice factor (P)

The conservation support practice factor (P) is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage (Renard et al., 1997). In this study, the P-factor was not relevant to the study area and therefore was represented by a constant P value of 1, which did not influence the output of the analysis in any way.

5.6 Results

The following are the results of the analysis:

5.6.1 Estimated Annual Soil Loss

In an attempt to identify which areas were more prone to soil loss, the RUSLE factors LS, C, K, R and P were integrated within IDRISI to generate a composite map of erosion potential. The annual soil loss was estimated on a pixel-by-pixel basis and the spatial distribution of soil erosion potential in the study area was obtained. The quantitative output of predicted soil loss rates were then classified into five ordinal classes: minimal, low, moderate, high and extreme (Figure 5.4). A soil loss value of 10 t ha^{-1} yr^{-1} was accepted as the boundary measure of soil loss for the low and moderate classes. This value was based on the assertion of Morgan (1995) that this is an appropriate boundary measure of soil loss over which decision-makers should be concerned. According to the map, 4703 ha (79%) of the study area is designated to be of minimal soil loss risk. Low, moderate, high and extreme soil loss zones make up 420 ha (7%), 460 ha (8%), 354 ha (5.9%) and 5 ha (0.1%) respectively. In general, the study area was exposed to low risk soil erosion.

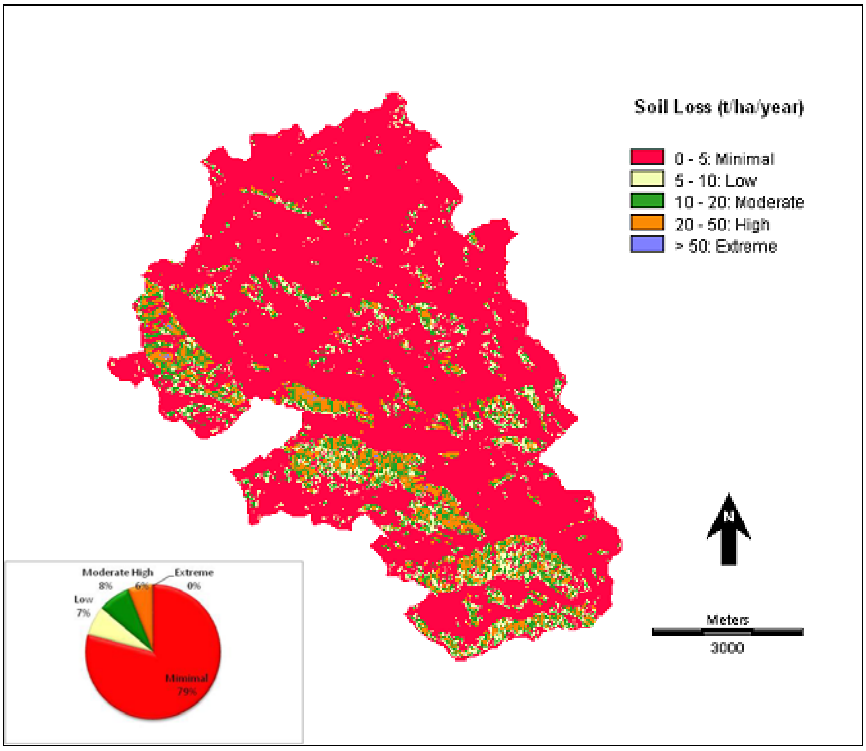


Figure 5.4 Distribution of estimated soil loss in the sub-catchment

The quantitative output of the estimated soil loss in the five ordinal classes is listed in Table 5.3 as well as the corresponding areas and amounts of soil loss in each class. The results show that the estimated mean annual soil loss is between 1 and 70 t ha^{-1} yr^{-1} in most parts of the study area. The actual mean value of the soil loss is 5 t ha^{-1} yr^{-1} and the gross amount of actual soil loss amounts to 28,248 t year^{-1}.

Table 5.3 Soil loss categories, areas and corresponding amounts of soil loss

Soil Erosion Category	Numeric Range (t ha-1 yr-1)	Area (ha)	Area Percent	Soil Loss (t year-1)	Soil Loss Percent (%)
Minimal	<5	4703	79	5714	20
Low	5 – 10	420	7	3454	12
Moderate	10 – 20	460	8	7043	25
High	20 – 50	354	5.9	10413	37
Extreme	>50	5	0.1	1623	6
Total		**5943**	**100**	**28248**	**100**

5.6.2 Distribution of Estimated Soil Loss by Slope and Land Cover Type

IDRISI was also used to identify the spatial distribution of the soil loss in the study area based on slope and land cover type (Figure 5.5). Three slope intervals (0-5^0, 5-10^0, 10-15^0) within each land cover type were considered. The catchment was comprised of 1,192.55 ha (20%) primary forest, 2,755.82 ha (46.37%) secondary forest, 1930.63 ha (32.5%) shrub and grass, and 63.7 ha (11%) water. The distributions of soil loss by slope in each land cover type are shown in Figures 5.5.

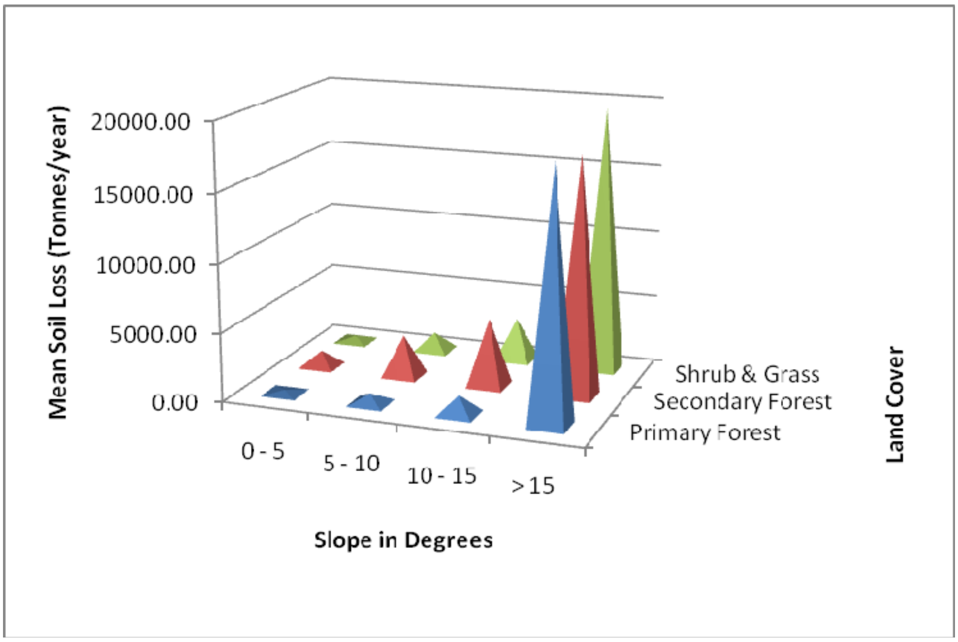


Figure 5.5 Distribution of soil loss by slope and land cover type

The figure demonstrates that soil loss in the study area varied dramatically with slope steepness. It is apparent that slopes greater than 10 degrees were the major contributors to soil loss in all land cover types, where soil loss was more than 80% of the total soil loss. In contrast, areas experiencing low erosion were located on low slopes in all land cover types.

From these results, it can be concluded that slope steepness is an important factor in erosion and consequently soil conservation measures in the study area.

5.6.3 Estimated Potential Annual Soil Loss

To estimate the potential annual soil loss, the worst case scenario (i.e. having bare land with no conservation measures to protect the soil) was assumed. Rain erosivity (R factor), soil erodibility (K factor) and topography (LS factor) were considered as naturally occurring factors determining the soil erosion process. The estimated potential soil loss was obtained by overlaying the three grid surfaces (R factor, K factor and LS factor) of the study area using the multiplication function. The distribution of the five classes of estimated potential annual soil loss in the study area is shown in Figure 5.6.

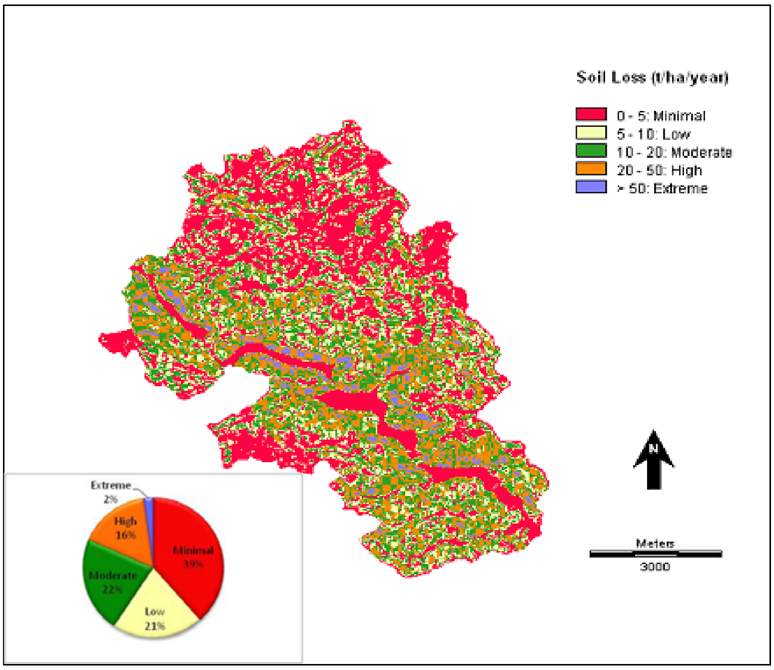


Figure 5.6 Distribution of estimated potential soil loss in the sub-catchment

The results show that 2,318 ha (39%) of the study area is at minimum risk of soil loss. Low, moderate, high and extreme soil loss zones make up 1,248 ha (21%), 1,307 (22%), 950 ha (16%) and 118 ha (2%) respectively.

The estimated potential annual soil loss in the study area is between 1 and 86 t ha^{-1} yr^{-1} with a mean value of 12 t ha^{-1} yr^{-1} and an estimated gross potential soil loss of 71,640 t year^{-1} (Table 5.4).

5.6.4 Capability of Preventing Soil Erosion

The value of the soil conservation due to land cover type was estimated by subtracting the estimated annual soil loss grid from the estimated potential annual soil loss grid in IDRISI using the OVERLAY function. The estimated annual gross amount of soil conservation of the catchment amounts to 45,615 t year^{-1} (Table 5.4). The ratio of the estimated potential annual soil loss and the estimated annual soil loss of different land cover types was considered to be the capability of preventing soil erosion by the land cover type. The results in Table 5.4 show that the capability of soil conservation in the primary forest is the strongest, with a value of 16. The capability of soil conservation in the secondary forest is next strongest with a value of 9. The shrub and glass land cover type has the weakest soil conservation capability with a value of 1. The mean value of soil conservation capability in the catchment is 9.

Table 5.4 Quantities of soil loss and soil conservation capability of the land types

Land Cover	**Total Soil Loss (Tonnes/year)**		**Soil Erosion per Hectare (Tonnes/ha/year)**		**Soil Conservation**		**Soil Conservation Capability**
	Potential	Actual	Potential	Actual	Total Soil Loss (Tonnes/year)	Soil Conservation per Hectare (Tonnes/ha/year)	
Primary Forest	20670	1316	17	1	19354	16	16
Secondary Forest	26729.55	3044	10	1	23686	9	9
Shrub & Grass	24240	21665	13	11	2575	1	1
TOTAL	71640	26025	40	13	45615	26	26
AVERAGE	23880	8675	13	4	15205	9	9

5.7 Conclusion

This case study has demonstrated the application of GIS techniques and remote sensing data by assessing soil loss. The method used is fairly simple to manipulate once all the necessary layers were acquired. The greatest obstacle however, is the accuracy of the estimated RUSLE factor values. Processing data into RUSLE requires the use of several algorithms, each of which enhance the existing errors in data. Overall, the case study has demonstrated the effectiveness of remote sensing and GIS in generating essential quantitative information on soil erosion. This type of results provide useful quantitative information and maps which could serve as valuable resources for decision-makers to develop effective erosion control/soil conservation plans.

CHAPTER 6

CASE STUDY 3: WATER POLLUTION ASSESSMENT

6.1 Introduction

A third illustration of the usefulness of GIS is in water pollution management. In this example GIS is applied to a reach of the Kafue River in the Congo-Zambezi catchment in the Copperbelt province, Zambia. The Kafue River provides a good illustration because of its susceptibility to pollution. The river constitutes an important water reservoir and is used for many purposes, including drinking water, irrigation systems and production of hydroelectric power (Norrgren et al., 2000).

The Kafue River drains a basin of 155,000 km² and covers a total distance of about 2000 km. Through the Copperbelt province, the Kafue River flows close to the copper mining towns of Chililabombwe, Chingola and Mufulira and through the outskirts of Nchanga and Kitwe. In this region, the Kafue River is at great risk of pollution from urban waste and copper mine tailings (Visit Zambia, 2005). Water pollution arises from runoff from mining dumps, seepage from tailing dams and accidental discharges of untreated wastewater. As an example, in 2006, Zambia's biggest mining company, Konkola Copper Mine (KCM), caused widespread water pollution when its acidic effluent entered the Kafue River. A similar incident occurred at Mopani Copper Mine, the country's second largest copper producer, after a pump malfunction allowed untreated water to be released into the reticulated water system of a private water utility company (Dymond et al., 2007).

When pollution incidents occur, it is imperative to quickly identify sensitive downstream environments that may be adversely affected by the exposure to toxic substances and to prioritize the various components of the response (Tamagawa et al., 1999). Determining the downstream movement of a pollutant within a river network is also an important component of water resource management. Quantitative information e.g. an accurate measurement of the distance from a pollution source upstream to a drinking-water intake downstream and associated flow data would assist combat agencies to provide better protective measures and to manage consequences of emergency incidents more effectively.

The GIS network capabilities have the potential to model and simulate such a network system (Yang & Zhou, 1998). In this study, a hypothetical pollution incident from a mine location on the Kafue River has been modelled using GIS network capabilities. The goal is to accurately predict the downwards movement of pollution resulting from the incident and to estimate the concentration changes for the purpose of warning water users along the river network.

6.2 Case Study Area

The case study area is shown in Figure 6.1. This area is particularly significant due to the presence of copper mining industries. The Copperbelt province has a total land area of 31 014 km^2. Mining activities in the Copperbelt province provide almost 80 percent of Zambia's exports, but also produce vast amounts of tailings (material discarded after minerals have been extracted) that pollute the Kafue River and its tributaries.

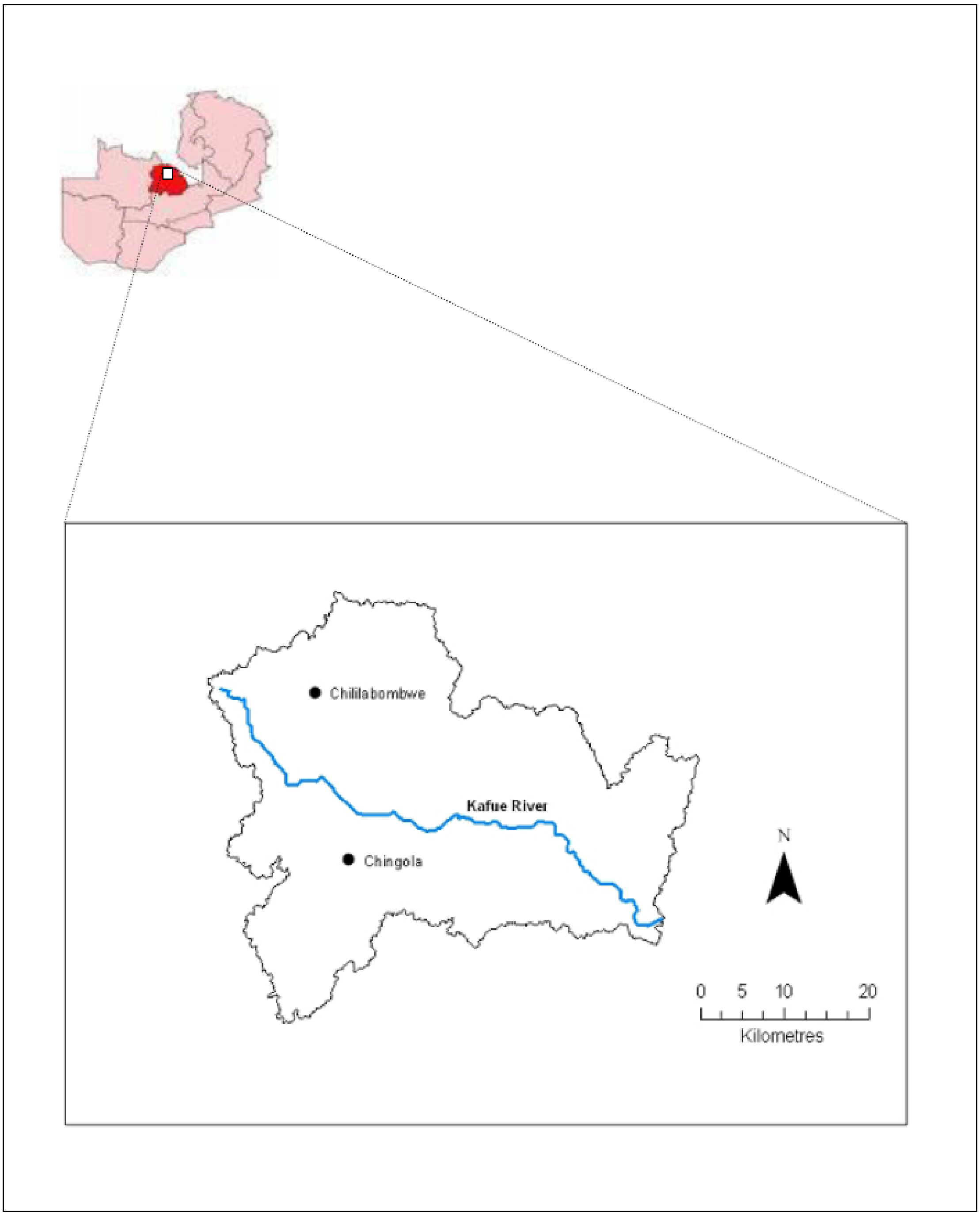


Figure 6.1 Location of the study area in the Congo-Zambezi catchment in the Copperbelt Province, Zambia

6.3 Methodology

The basic methodology of this case study included the following steps:

- (i) Delineation of the sub-catchment area,
- (ii) Creation of a geometric network,
- (iii) Estimation of discharge from the sub-catchment,
- (iv) Estimation of stream flow and pollution concentration.

6.3.1 Delineating the Catchment

Delineating of the catchment was achieved using the WATERSHED module in ArcMap. This process involved computing the flow direction and identifying the pour points (i.e. catchment outlet) prior to determining the catchment boundary. The computed flow direction grid was used as input into the WATERSHED function of ArcMap to delineate the catchment boundary. The delineated catchment boundary was used to clip all input data sets including the DEM and river network of the study area (Figure 6.2).

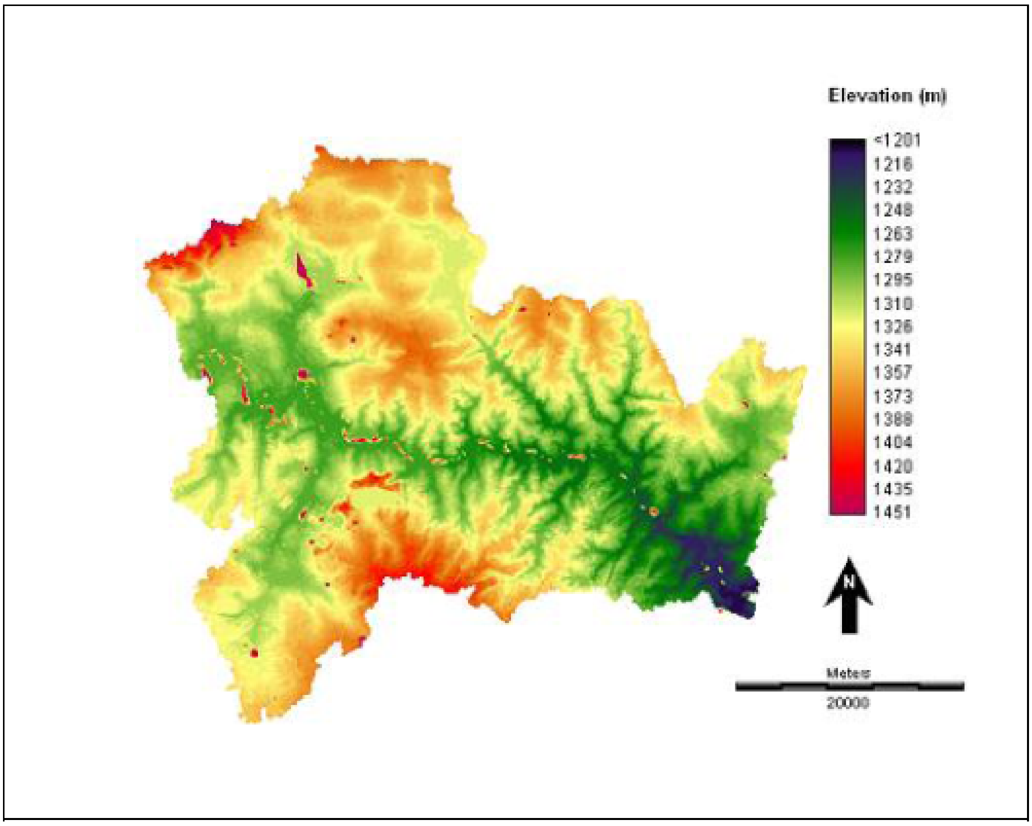


Figure 6.2 Delineated catchment depicting the DEM of the study area

6.3.2 Creating a Geometric Network

The geometric network was created using ArcMap's ArcCatalog. First, a new personal geodatabase was created with a feature dataset of the river network. One shape file (pollution source) was added to the geodatabase using the Import/Shapefile command. Second, an outlet feature class was created to act as a sink in the network (A sink is a junction where all flow terminates or drains out of a network). Finally, the geometric network was created from the river network feature dataset using the geometric network wizard.

The river network, the positions of the pollution source (mine) and the flow path from the mine to the catchment outlet are shown in Figure 6.3.

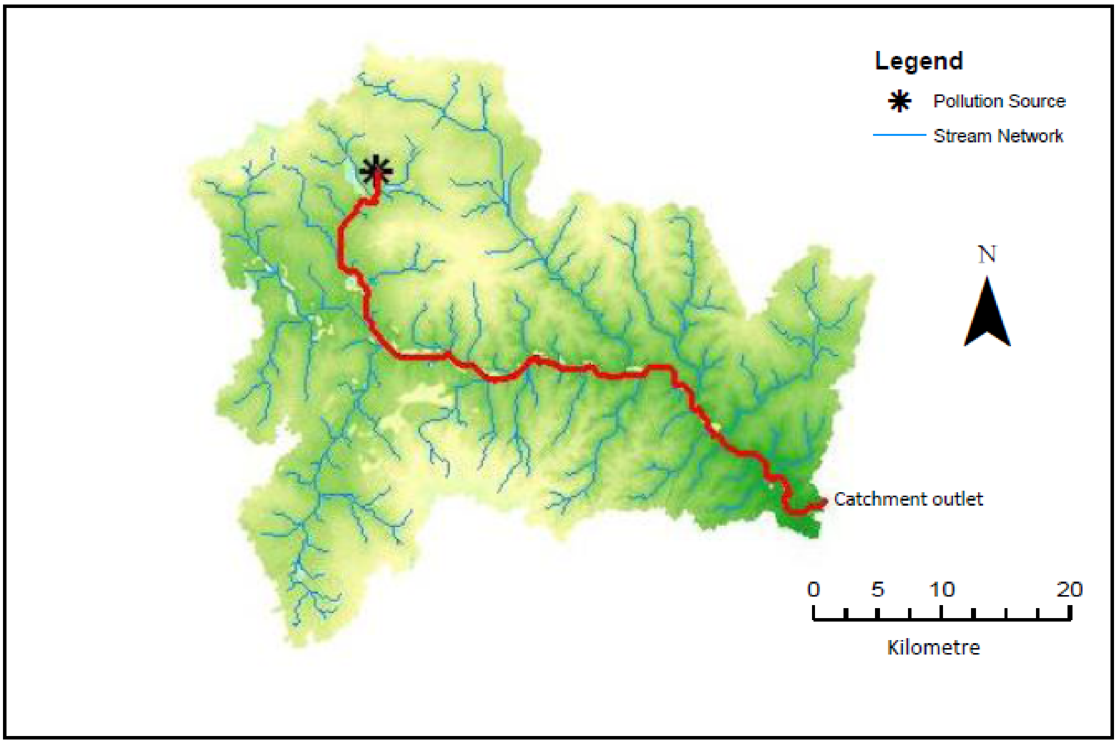


Figure 6.3 River network, position of pollution source and flow path

6.3.3 Estimating Discharge

The discharge of rivers or streams plays a significant role in determining the effects of pollution on them. Discharge is defined as the volume of water flowing over a point per unit time interval. In this study, the goal was to estimate the discharge in the river associated with a given rainfall event. The discharge was estimated based on the amount of runoff produced from the catchment. The Rational Method (Chow et al., 1988) was used to estimate the flow:

$$Q = 0.0028CiA \qquad (1)$$

Where: Q = Discharge (m^3/s)

i = Rainfall intensity (mm/hr)

A = Drainage Area (ha)

C = Runoff coefficient (dimensionless)

This equation states that if it rains long enough (in excess of the time of concentration of the catchment), the peak discharge from the drainage basin will be the average rate of rainfall times the drainage basin area, reduced by a factor to account for infiltration.

6.3.4 Estimating Pollutant Concentration

The pollutant concentration was estimated with respect to volume at various points along the stream length. The pollutant was classified as conservative (In a conservative pollutant the unit mass remains the same over the time period the pollutant is transported from upstream to downstream). In the absence of data quantifying the amount of the identified pollutant, a concentration of 10 mg/l was assumed at the source.

6.3.5 Other Assumptions

For this case study, the following assumptions were made:

(i) The river was of uniform cross section throughout its length,

(ii) The pollutant was evenly dispersed within the river at all times.

6.4 Data

The following data layers were used to perform GIS network analysis:

- River network layer
- Pollution source point layer
- DEM

The river network layer was the main layer used for the network analysis. It contained the segment of the river system in the study area and the associated attribute table containing the network cost fields. The stream network was delineated from a DEM using the output from the Flow Accumulation function in ArcMap.

The pollution source point layer was digitised on-screen as a vector file using as a background a composite image of the study area.

In this case study, the GIS software ArcMap (version 9.3) was used for all spatial data manipulation, analysis and presentation.

6.5 Results

The following are the results of the analysis.

6.5.1 Estimated Flow Information

To estimate the volume of water flowing over a point per unit time interval, the catchment was disaggregated into smaller sub-catchments and the runoff volume from each sub-catchment was estimated based on the area of the sub-catchment, runoff coefficient and an assumed rainfall event. The aim of this catchment-disaggregation was to enable the computation of the volume of flow generated from the tributaries in each sub-catchment. Figure 6.4 shows the disaggregated sub-catchments in the study area and Table 6.1 shows the area and potential volume generated from each sub-catchment after application of simulated rainfall of 50mm/hr lasting 15 minutes.

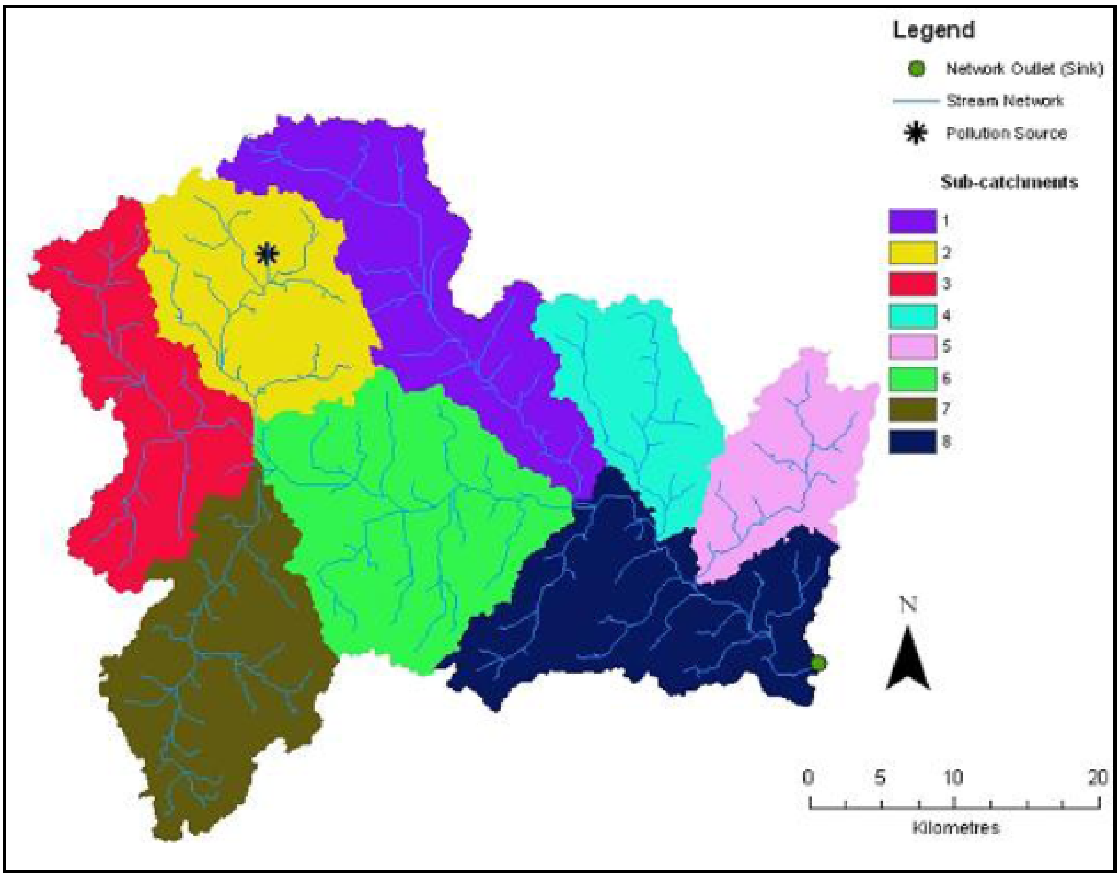


Figure 6.4 Sub-catchments within the study area

Table 6.1 Area and volume generated from each sub-catchment

Sub-catchment	Area (ha)	Volume (m^3)
1	195.65	489121
2	242.15	605388
3	126.88	317191
4	116.99	292485
5	197.79	494475
6	283.10	707758
7	245.02	612552
8	241.52	603813

Often in water quality modelling, extreme and average conditions are investigated to enhance decision-making and policy implementation. Therefore, to access the extreme as well as the average stream flow conditions, three rainfall intensities (low, medium and high) were used. In this example, the following rainfall intensities were assumed based on the rainfall conditions in the study area,:

- Low = 10 mm/hr
- Medium flow = 30 mm/hr
- High Flow = 50 mm/hr

The discharges produced for the different rainfall intensities were estimated based on the relationship between the volume produced in each sub-catchment using Equation 1. Table 6.2 is a summary of the computed cumulative stream flows and pollutant concentrations at 30 points/locations along the flow path for the different rainfall events.

On the basis of these results, simulated flow volumes in the length-section of the river were plotted (Figure 6.5). Similarly, pollutant-concentrations, with respect to distance at various points along the river, were plotted (Figure 6.6).

Table 6.2 Estimated cumulative stream flow and pollutant concentration along the flow path

Point Along Flow Path	Distance From Pollution Source (km)	Cumulative Stream Flow (m^3/s)			Pollutant Concentration (mg/l)		
		10mm/hr	30mm/hr	50mm/hr	10mm/hr	30mm/hr	50mm/hr
1	-0.77	2	5	8	0	0	0
2 (Source)	0	35	105	174	49.71	16.57	10
3	2	38	113	189	45.79	15.40	9.23
4	4	48	143	239	36.25	12.17	7.31
5	10	51	152	254	34.11	11.45	6.87
6	12	78	233	389	22.31	7.47	4.49
7	16	80	239	399	21.75	7.28	4.37
8	18	105	314	523	16.57	5.54	3.34
9	20	108	323	538	16.11	5.39	3.24
10	24	110	329	548	15.82	5.29	3.18
11	26	1365	1636	1907	1.27	1.06	0.91
12	28	1379	1676	1973	1.26	1.04	0.88
13	30	1420	1800	2180	1.23	0.97	0.80
14	32	1427	1821	2215	1.22	0.96	0.79
15	34	1468	1944	2420	1.19	0.89	0.72
16	36	1474	1963	2452	1.18	0.89	0.71
17	38	1478	1974	2571	1.18	0.88	0.70
18	40	1490	2011	2531	1.17	0.87	0.69
19	42	1492	2016	2540	1.17	0.86	0.69
20	44	1498	2034	2571	1.16	0.86	0.68
21	46	2211	2816	3421	0.79	0.62	0.51
22	48	2221	2847	3473	0.78	0.61	0.50
23	50	2223	2853	3483	0.78	0.61	0.50
24	52	2584	3227	3869	0.67	0.54	0.45
25	54	2606	3292	3977	0.67	0.53	0.44
26	56	2616	3322	4028	0.67	0.52	0.43
27	58	2954	3679	4404	0.59	0.47	0.40
28	60	2962	3705	4447	0.59	0.47	0.39
29	62	2991	3792	4593	0.58	0.46	0.38
30	64	2996	3807	4618	0.58	0.46	0.38

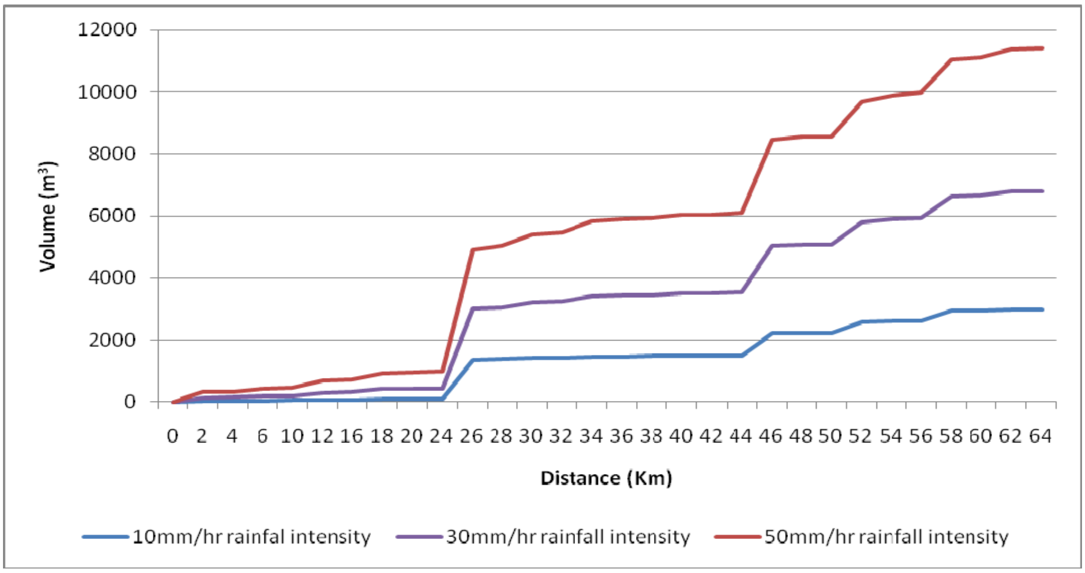


Figure 6.5 Simulated flow volumes as distance increases downstream at different rainfall conditions

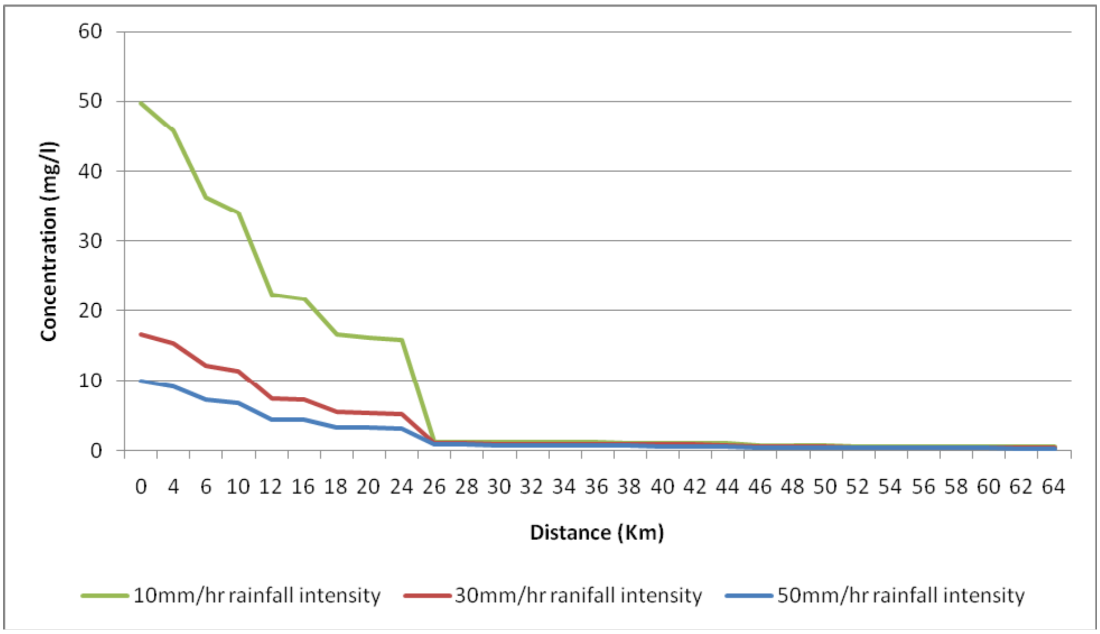


Figure 6.6 Concentration of conservative pollutant as distance increases downstream from the point source for three different rainfall conditions

The concentration-distance graph (Figure 6.6) shows very large differences in the concentration of the pollutant in the first 26 kilometres for the three stream flow conditions. However, after 26 kilometres from the pollution source, the differences in concentration for all stream flow conditions are insignificant for all flow conditions. This is because of the increase in the volume of flow generated from the tributaries in the different sub-catchments.

6.6 Conclusion

In this third case study, it has been demonstrated that GIS and remote sensing data can be successfully applied to water resource management, particularly in a water pollution incident, to accurately predict the downwards movement of a pollutant and to estimate the concentration changes. Many parameters were assumed and these assumptions may yield completely different results from the actual scenario. However, the basic ideas and methods were sufficient to demonstrate how GIS and remote sensing can be used for generating essential quantitative information for water resource planning. If the appropriate data were available, it is conceivable that analysis could have been taken further e.g. travel-time of the pollutant and the effected community in a given period could have been predicted and mapped.

CHAPTER 7

DISCUSSION

In this chapter the results of this study are discussed in relation to other studies and the current literature as well as in relation to the study objectives.

7.1 Data Availability and Suitability

Reviewing the availability and suitability of spatial data for GIS-based analysis, the results of the study revealed the inadequacy of free spatial data in Zambia. Some essential data were of low quality, out-of-date and lacking metadata. For example, important differences in terms of accuracy were observed in the available road and river network datasets. These datasets also had gaps and were not accompanied by any metadata.

This situation has arisen for a number of reasons:

- Lack of collaboration - Government organisations involved in planning and collection of natural resource data create and maintain spatial data for their own and their client's needs. The data are gathered using different specifications, standards and policy frameworks. This diversity of standards, policies and approaches make data comparison and integration very difficult.
- Data acquisition was difficult and time consuming - This is most likely because none of the local organisations make all their data available over the internet for public view and data sharing. The available data are neither in a form or manner that can enhance their use in environmental studies and logical environmental decision-making.
- Lack of documentation on data and information generated within the different organisations.
- Many data sets are obsolete and therefore potentially unreliable.

Other studies have also recognised these difficulties. For example, Bishop et al. (2000), drew upon their experiences in Bangkok, where they examined the status of spatial data for cities in developing countries, to conclude that the development of large scale digital databases as basic infrastructure for a range of GIS applications is very difficult. This is because spatial data are generally not available in digital form and base maps are often outdated. They attributed these findings to a lack of appreciation of what GIS can do, lack of resources and trained personnel, inefficient bureaucratic processes, lack of data, and lack of hardware and software vendor support.

Rybaczuk (2001) also found similar results in a study conducted in Jamaica to evaluate the suitability of community-oriented GIS for environmental conservation and management. In this study, data accessibility, high disparities in wealth and education, nucleated political control over local funding and investment and poor resourcing in terms of capital and infrastructure were reported as the major issues impeding the efficient use of GIS in environmental management.

Aagesen (2005) also recognised similar difficulties. As in the aforementioned studies, he observed that, in most developing countries, spatial data are frequently in a form of unscaled sketches and the existing scaled cartographic products are often outdated or classified as restricted information and therefore unavailable for widespread use.

Even so, this present study has still demonstrated that GIS can serve as a basis for generating quantitative information for enhancing decision-making in natural resource management in Zambia. For countries with limited geospatial data like Zambia, GIS and remote sensing data are excellent tools for building spatial databases.

7.2 Results of the Example Case Studies

To demonstrate how GIS can provide pertinent quantitative information for enhancing decision-making, the data collected from government sources and databases from other organisations were used and three applications were presented in selected regions in Zambia as example case studies.

The first case study illustrated a change detection technique that integrated GIS and remote sensing data for efficient analysis of deforestation. The relationship between the deforestation process and a set of deforestation-influencing factors (slope, elevation and proximity to roads) was analysed and a deforestation risk map for the study area was generated. In addition, GIS was used to identify trends and changes in land cover over time. This study demonstrated the ability of GIS to extract complete and accurate information from remote sensing data and to analyse the types, location and rates of land cover change.

In the second case study, the abilities of GIS to identify areas that are at potential risk to extensive soil erosion and to provide information on the estimated value of soil loss at various locations, were demonstrated. This study involved the integration of the Revised Universal Soil Loss Equation (RUSLE) in a GIS environment to assess soil loss and identify risk erosion zones. The annual soil loss was estimated on a pixel-by-pixel basis and the spatial distribution of soil loss in the study area was obtained. GIS was also used to estimate the value of the soil conservation based on land cover in the catchment. The results of this case study would provide very useful quantitative information for decision-makers to plan appropriate soil conservation measures in the area.

In the third case study, GIS network capabilities were used to model a hypothetical pollution incident starting from a mine location on the Kafue River. The downstream movement of a pollutant in the river was predicted and pollution concentration changes were estimated. Although the results of this case study were based on a number of assumptions, the basic ideas and methods were sufficient to demonstrate the effectiveness of GIS for generating essential quantitative information for water resource planning.

From a technical perspective the results of the three case studies suggest that a GIS-based analysis can provide good quantitative information to support and facilitate decision-making in various aspects of natural resources management. Along with remote sensing, they provided quantitative information concerning the three environmental problems assessed. This information permitted the successful analysis and the effective interpretation of each environmental problem. Furthermore, GIS provided a very useful environment to undertake the tasks of data compilation and analysis. Benefits of GIS were the ease of data update, data management and data presentation. At the same time, it allowed vast amounts of information of different themes and from diverse sources to be integrated. It seems, therefore, that GIS-based analysis of natural resource issues offers great opportunities to fill the existing data gaps in natural resource information in Zambia.

The case studies also illustrated the potential for using digital data sets accessed through the internet for GIS analysis. With the increasing availability of spatial data such as high resolution satellite data from IKONOS (one metre resolution) or QUICKBIRD (2.4 metres resolution), the internet has become a versatile source of detailed information for supporting various applications in natural resource management and planning. For example, free Google Earth high resolution images can be downloaded and registered in GIS environment and used as reference images for visual interpretation and classification of lower resolution satellite imagery. This point was clearly demonstrated in the first case study.

Tanser (2006) explains that the increasing availability of remotely sensed data sets and other digital databases through the internet, combined with the declining hardware and software prices, have encouraged the widespread use of GIS in developing countries. Nevertheless, under no circumstance should it be assumed that the effort required for data collection has been replaced by simply ‘surfing’ the internet. More data remains to be collected. Furthermore, data errors in geographic databases, available through the internet, are a major concern. Therefore, basic data collection, careful appraisals of the existing data sets and more research in this area are needed in order to ensure efficient and reliable applications of GIS.

Evidence from the case studies also revealed that several layers generated in Zambia, such as roads, rivers and administration boundaries varied in terms of scale, projection, classification and accuracy. This finding supports Aagensen's (2005) assertion that the available data in developing countries requires critical examination before they are incorporated into any GIS-based project.

The results of the case studies also have implications for the use of GIS and remote sensing technology in the context of tools for computer analysis and technical expertise. It is evident that GIS and remote sensing techniques require tools and expertise to ensure that they are used correctly. This present study was possible because of the knowledge and skills acquired in GIS and remote sensing while the author studied at Massey University – an institution where the tools and expertise needed to produce accurate spatial data were available. Therefore, the availability of capacity, in terms of computer software and hardware, and skills to perform the technical work as well as apply the available data in various natural resources management aspects, is clearly imperative.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

In Zambia, the management of natural resources, including their conservation, is of critical importance because they are the base upon which Zambia's economy and people depend. However, the efficient management of natural resources is hampered by a lack of reliable data.

This study demonstrates how GIS can provide quantitative data for enhancing decision-making in natural resource management in Zambia. The study has shown that Zambia, like many developing countries, lacks a strong tradition of cartography and mapping and has problems with data availability and data quality. However, this study has demonstrated that, where data can be obtained, there is no reason why GIS should not be used very successfully.

In this study it was shown that while there are data sources in existence where spatial data can be obtained, most of the available data layers are inadequate for GIS analyses for natural resource management. Most of these data have been created at very large scale (1:1,000,000; 1:500,000 and 1:250,000) which is unsuitable for regional planning. In this regard, more data should be collected. Furthermore, the study revealed that several of the available data layers generated in Zambia, such as road networks, river networks and administration boundaries are incomplete and therefore, unsuitable to support decision-making at regional level. In this regard, the availability of high resolution satellite images offers the necessary ground reference for starting the improvement of the existing layers. These require tools and expertise to be used correctly.

The study has also demonstrated the importance of developing well-structured digital databases to study specific environmental problems. Bringing together different data sets in a GIS-based database made it possible to answer many questions with regards to the assessed environmental issues.

The study has also demonstrated that accessing timely and appropriate spatial data through the internet can enhance the potential of using GIS for natural resource management in Zambia. Satellite images from public domain databases can now be easily downloaded and distributed without extra charge. Along with GIS, satellite images substantially reduce the time and cost of producing up-to-date natural resource data, compared with traditional data collection methods. Nevertheless, this does not mean that these technologies should substitute traditional approaches of data collection – both methods are important and complement one another.

Overall, the study has shown that while obstacles remain to the use of GIS and remote sensing in Zambia, there is no doubt that they can be used successfully to fill existing data gaps in decision-making in natural resources management. The study has not addressed the challenging issues of how to develop, implement and deploy GIS technology in the existing conditions of data, technology infrastructure, people and institutions. These are issues that need to be addressed in future research.

8.2 Recommendations

Based on the outcomes of this study, the following recommendations are presented:

- The Zambian Government should embrace GIS and remote sensing as essential tools to assist in filling the data gaps and augment decision-making in natural resources management. This will require an increase in financial investment and a greater effort across all aspects of the technologies, including training, so that the outcome of adopting the technologies will be effective.

- Existing data sets in Zambia should be subjected to systematic and thorough appraisal before incorporating them into GIS for any environmental analysis. Several existing data layers (e.g. road network, river network, soils, land cover) need to be improved, in terms of scale and level of completeness, in order to ensure that they are suitable for use in any GIS-based project.

- The Survey Department of the Zambian Ministry of Lands, the official mapping agency (which has the objective of developing digital topographic database standards and base maps to be utilised for various environmental and natural resource management applications), should work hand-in-hand with other organisations in the country to collect socio-economic and environmental data that can be incorporated into GIS analysis.

- The governments of developing countries like Zambia should make better use of data that are available from various sources worldwide. In this regard, capacity needs to be developed to perform the technical work as well as to apply the available data to various natural resource management aspects.

- As a first step towards Zambia improving its GIS-based decision support, regional scale natural resources-based GIS projects, similar to the three case studies in this study, should be undertaken to introduce GIS and remote sensing concepts and to allow local GIS users to gain experience in the technologies.

- The best available high resolution images, such as one metre resolution images from IKONOS® or 2.4 metres resolution images from QUICKBIRD®, should be used to obtain spatial information required to support detailed environmental analysis.

- Although GIS and remote sensing data offer great potential for understanding natural resource issues, they should not completely replace traditional methods of data collection. A combination of traditional methods and remote sensing data collection will provide a useful and efficient approach for natural resources management and planning.

In the case of Zambia, these recommendations could be implemented by the Survey Department of the Ministry of Lands. This could improve the Department’s success in providing usable spatial datasets to other private and government organisations such as the Ministry of Tourism, Environment and Natural Resources. Consequently, this could improve access to geo-spatial information in Zambia and further enhance decision-making in various aspects of natural resource management.

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APPENDICES

Appendix A

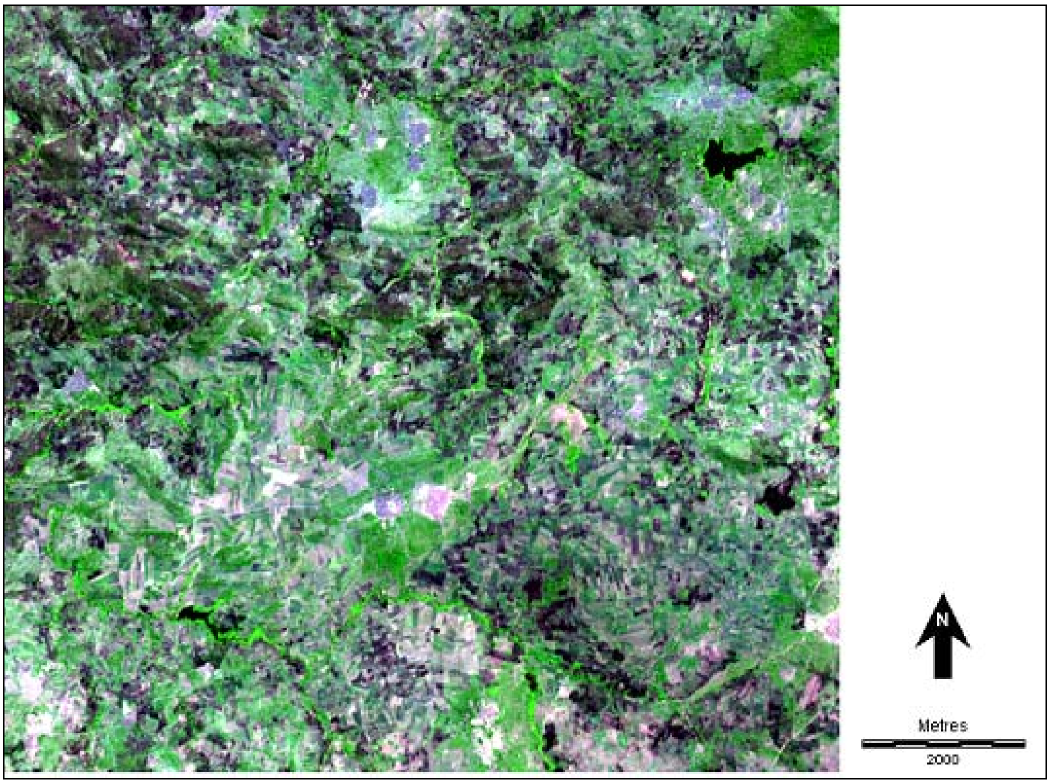

Figure A.1 False colour composite image for 2000

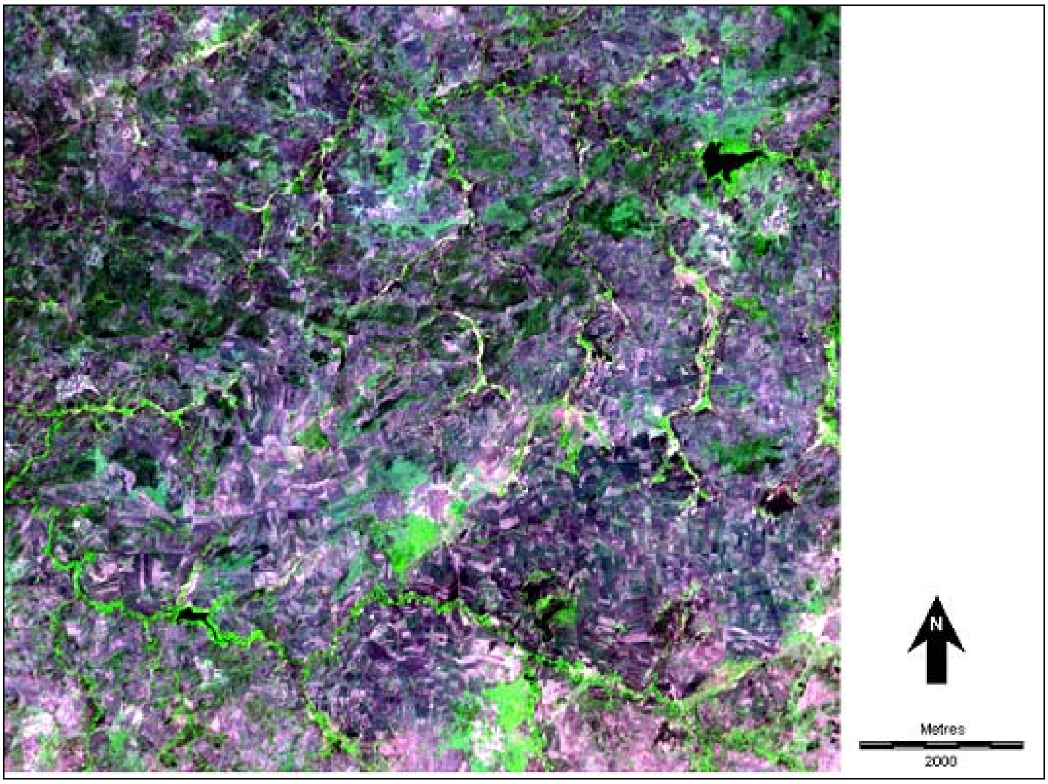

Figure A.2 False colour composite image for 2006

Appendix B

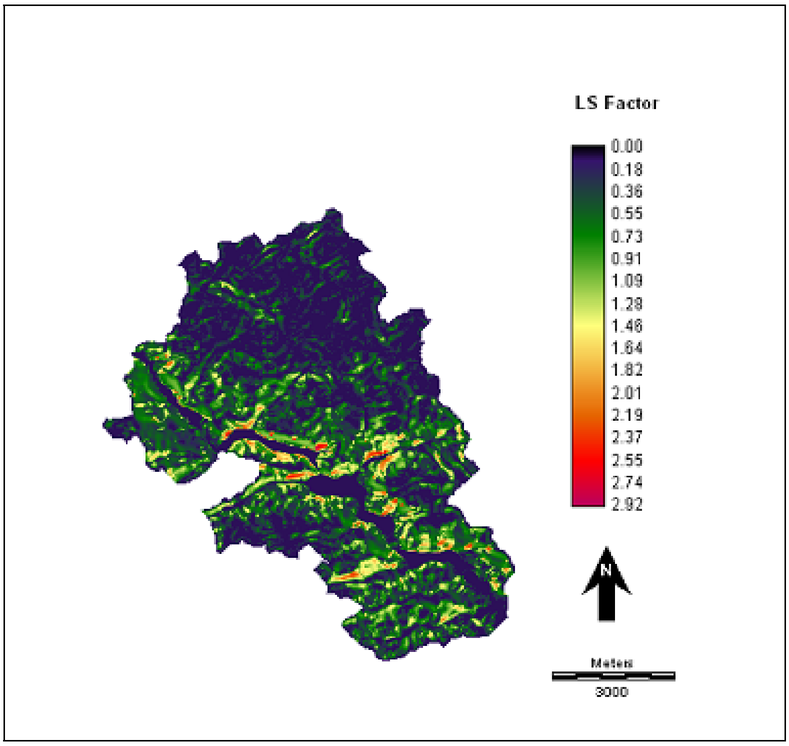

Figure B.1 Grid surface of the sub-catchment showing the distribution of the LS factor

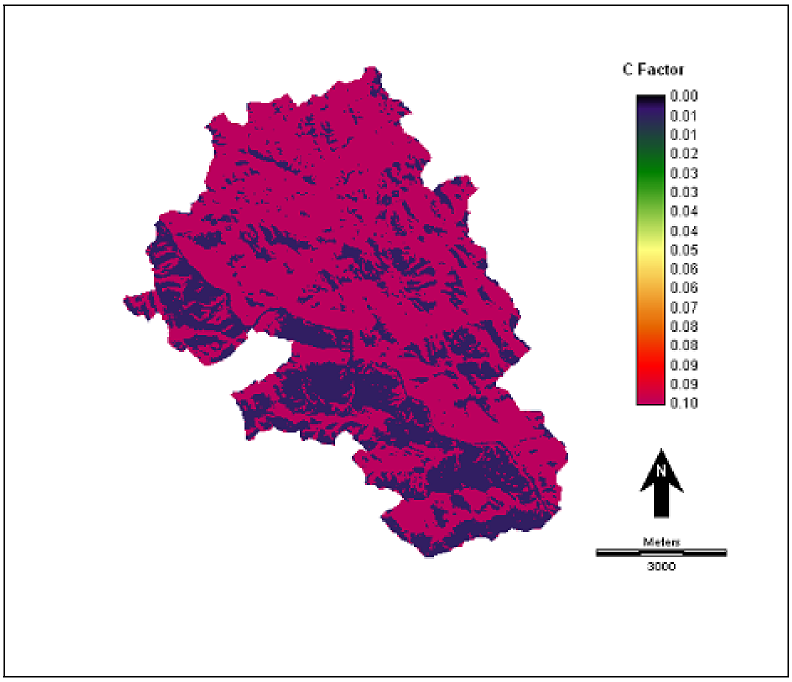

Figure B.2 Grid surface of the sub-catchment showing the distribution of the C- factor