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Flood hazard modelling in Tsholotsho district, Zimbabwe

By

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Abstract
Among all natural hazards, floods pose the greater threat to property, safety and economic well being of human communities the world over. This study focused on understanding the nature of flooding in areas that are outside of streams. Normally, flooding has been dealing with bursting of river banks but in Tsholotsho flooding has occurred in areas that are located far away from defined drainage networks. The study established the nature of problems associated with flooding as a preamble to flood hazard modelling. Logistic regression was applied in a spatial database that had been developed and managed within a GIS to estimate the prediction power of the environmental variables (height above channel base, slope of drainage basin, distance from the nearest stream and soil type) for flood occurrence. The results indicate that height above channel base significantly (p < 0.05) predicted flood hazard for Hambeni and Sheleni while distance away from the nearest channel was significant (p < 0.05) in predicting flood hazard for Ntibu. The flood hazard map represents flood occurrence for each pixel. The developed flood hazard map will be useful in mitigating the loss of property from future flood disasters in Hambeni, Ntibu and Sheleni.

Key words: Flood, flood hazard, flood hazard map, GIS
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LIST OF ABBREVIATIONS AND ACRONYMS

CPU-Civil Protection Unit
DEM-Digital Elevation Model
GIS-Geographic Information Systems
GDP- Gross Domestic Product
GPS-Global Positioning System
GWP- Global Water Partnership
IFM- Integrated Flood Management
ILWIS- Integrated Land Water Information System
IRIN-SA- Integrated Regional Information Network for Southern Africa
ITCZ- Inter Tropical convergence Zone
IWRM-Integrated Water Resources and Management
JPI -Johannesburg Plan of Implementation
MDGs-Millennium Development Goals
OCHA- Office for the Coordination of Humanitarian Affairs Integrated Regional Information Network for Southern Africa
RS- Remote Sensing
SADC- Southern Africa Development Community
SPSS- Statistical Package for Social Sciences
TIN -Triangular Irregular Network
UN- United Nations
USA- United States of America
WB-World bank
WMO-World Meteorological Organisation
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WSSD - World Summit on Sustainable Development

ZINWA - Zimbabwe National Water Authority

ZDF - Zimbabwe Defence Forces

ZRP - Zimbabwe Republic Police
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DECLARATION

I…………………………………………….. Hereby declare that the work contained in this thesis is the result of the author’s original work it is submitted for the Masters degree in Integrated Water Resources Management (IWRM), Department of Civil Engineering in the University of Zimbabwe, Harare. To the best of my knowledge, it has not been submitted before, for any degree or examination in any University.

Date………………………………..

Name……………………………… Signed………………………………………..
DEDICATION
To my daughters Kudzai Janet and Isheanesu Nicola, husband and sisters Christine, Liliosa, Joyce and Pamela……..with God all things are possible (Mark 10:27).
CHAPTER ONE: INTRODUCTION

1.0 Introduction

Natural hazards are in the form of floods, landslides, volcanoes, earthquakes, tsunamis, cyclones and drought. Floods are the most frequent of the natural hazards globally (40%) followed by tropical hurricanes (20%), earthquakes (15%) and drought (15%) (Burton et al., 1978). In terms of global distribution, Miller (1997) observed that the majority of floods (44%) occur in Asia, 27% in America, 13% in Africa, 10% in Europe and 5% in Oceania. Natural disasters’ associated annual economic losses increased from US$75 billion in the 1960s to US$659.9 billion in the 1990s without including indirect losses (Chen, 2007). At country level, among all the natural hazards in the United States of America, floods pose the greatest threat to the property, safety and economic well being of human communities (Brody et al., 2007). When quantifying flood loss in the United States of America, Nelson (2008) found out that, throughout the last century, flooding has been one of the most costly disasters in terms of both property damage and human casualties to the extent that the 1993 Mississippi River flood in Midwest killed 47 people with economic loss ranging between US$15 and US$20 billion. In Zimbabwe, more than 70% of all natural disasters are related to weather, climate and water (WMO, 2007).

Natural changes as well as those brought on by development activities affect flood plains and there is need to understand and to identify appropriate development and natural resource management practices for these areas. Although development planners have the knowledge on how often, on the average, the flood plain will be covered by water, for how long, and at what time of the year, but lack of space for the expansion of urban settlement and the rapid rise in population even in rural areas has increased demand for land which has resulted in encroachment into the floodplains (Australian Government, 2008). Most urban and rural authorities do not have the necessary finances to put up the necessary flood mitigation measures in the flood plains or even plan the rural settlements properly so that they reduce losses associated with flooding events (Chen, 2007). Therefore delineating floodplains and other areas subject to flooding is a valuable input for proposing compatible development activities.

Although flooding cannot be wholly prevented, its impacts can be reduced through appropriate planning and management. Damaging effects of flood disaster on lives and property can be reduced by structural (dams and weirs) and non-structural (legal instruments, public education, forecasting and early warning systems and rescue operations) measures. Despite the structural flood mitigation measures being in place, communities in the flood prone areas of Zimbabwe are still being adversely impacted on by the floods. Non-structural measures encourage living with floods and emphasis is on regulation of human activities through land use plans. There is therefore need to reduce the flood impacts on ecosystems and human settlements through flood hazard mapping.

Geographical Information Systems (GIS) is one of the techniques that can be used in flood level forecasting and management in order to assist in the reduction of human and economic losses through the delineation of the areas at risk of being flooded. Institutions
such as the World Bank (WB) and the recently developed Southern Africa Development Community (SADC) regional water policy are recommending land use plans which are a proactive flood mitigation measure. An assessment of the flooding event by the community coupled with GIS provides valuable input in policy formulation to reduce vulnerability and strengthen people’s capacity to cope with the disaster or risk they may be facing (Meijerink et al., 1994).

1.1 Problem statement
A knowledge gap exists in Zimbabwe on the spatial modeling and subsequent development of flood hazard mitigation tools for flat plains such as Tsholotsho that are prone to flooding which in no way is ever associated with the usual phenomena of overtopping banks of drainage channels.

1.1.1 Justification
Floodplain management and risk analysis is still at its infancy in Zimbabwe because the country was considered as a flood safe zone until the cyclone Eline induced floods of 2000-2001 (Government of Zimbabwe, 2005). Tsholotsho was one of the worst affected districts by the cyclone induced floods of 2000-2001 in Zimbabwe. Southern Africa IRIN-SA, (2001) indicated that Gwayi River burst its banks following heavy rains in March 2001 claiming the life of one person, washing away houses, fields and roads in the Sipepa communal lands, affecting an estimated community of 5,000. In 2006, 53 households (about 300 people) lost their homes to floods in the same area and other affected areas in Tsholotsho (OCHA, 2006).

There is continued threat to livelihoods for communities in the flood prone areas due to lack of a flood hazard model for Tsholotsho which can be used by planners and policy implementers to reduce vulnerability to flood hazard. Madamombe (2004) identified demarcation of the vulnerable areas in the flood prone areas of the Zambezi valley, as a measure that would alleviate flood disasters and safeguard villagers’ livelihoods. The development of a flood hazard model has so far been undertaken in Muzarabani (Muwira and Mwurwira, 2005), Chikwarakwara and Shashe (Rurinda, 2006). Undertaking the same process in Tsholotsho will assist in strengthening the implementation of policies aimed at reduction of flood damage in the study area. Recurrent flooding is a serious obstacle to development for flood prone areas. Being a natural event, floods will continue to occur in Tsholotsho, therefore it is important that flood mitigation tools are put in place to minimise the threats to vulnerable communities.

1.2 Main objective
To develop a flood mitigation tool through flood hazard modelling for the low lying areas of Tsholotsho district
1.2.1 Specific objectives

1. To identify problems associated with flooding in Tsholotsho (Hambeni, Ntibu and Sheleni)
2. To statistically explore the factors hypothesized to affect flood hazard as a preamble to the modeling of flood hazard
3. To statistically explain flood hazard as a function of environmental factors (height above channel base, slope of drainage basin, distance from the nearest stream)
4. To develop flood hazard maps as mitigation tools for Hambeni, Ntibu and Sheleni

1.3 Research questions

1. What are the problems associated with flooding in the study area?
2. What is the relationship between flood hazard and environmental factors (height above channel base, slope of drainage basin, and distance from the nearest stream)?

1.4 Hypothesis

Null hypothesis (H₀): there is no significant relationship between flood occurrence/non occurrence at a particular point with environmental factor X….where X is height above channel base, slope of drainage basin, distance from the nearest stream or soil type.

1.5 Structure of the report

Chapter One outlines the scope of the research, highlighting the research problem, questions, objectives and hypothesis to be tested. Chapter Two focuses on literature review which is relevant to the research while the description of the study area is in Chapter Three. The methods and materials are in Chapter Four while Chapters Five and Six outline the results and discussion followed by conclusions and recommendations respectively.
CHAPTER TWO: THE NATURE OF FLOODING-LITERATURE REVIEW

2.0 Introduction

Biswas (2005) lists floods as one of the natural disasters currently affecting developing countries much more than the developed in social and economic terms and sees the situation not likely to change in the foreseeable future. Zimbabwe is one such country which falls in the category described, therefore proactive steps need to be taken to minimise the effect of floods in flood prone areas in the country. Floods are acknowledged to be among the most manageable of disasters (Keys et al., 1996) unlike sudden impact disasters such as an earthquake or bushfires, which occur for the most part in predictable areas and, as a result, can be more easily planned for. Natural hazards can not be averted, but their consequences can be minimized by implementing mitigation strategies and reducing the potential impact to areas, which are most vulnerable. Proactive steps against hazards include recognising which areas have the greatest hazard potential; measuring the likelihood of the various hazards occurring in the priority areas; modelling the impact of hazards; estimating the potential loss to communities; and collecting data when a hazard occur to help prepare for future events (Australian Government, 2008).

2.1 Flood definition

Several authors have put forward a number of definitions of a flood relating to overtopping of river or stream banks, inundation by tidal waters or water from any source, statistical occurrence and economic loss. An analysis of the definitions shows that the authors adopt those definitions that are relevant to their study areas. For the lower Limpopo basin, Mozambique and United Nations Development Programme (UNDP) (2000) defines a flood as an unusually high stage of a river where the river channel becomes filled with water and above which it overflows its banks. Most countries in Asia are affected by both riverine floods and tidal waters so Chen (2007) defines a flood as the submerging with water of a normally dry land area from overflow of inland or tidal waters from the usual and rapid accumulation of runoff of surface waters from any source. The US Geological Survey Kansas Water Science Centre (undated) defines a flood as an overflow or inundation that comes from a river or other body of water and causes or threatens damage. When carrying out an impact assessment of flooding in the Nuna valley in Bangladesh, Leslie (2006) defined flooding as water being found where it is not wanted.

Floods can also be defined according to their statistical occurrence and in this respect a hundred-year flood is a flood having a magnitude that is reached in a particular location on average once every hundred years so that in any given year there is a one percent statistical chance of the occurrence of a hundred-year flood (US Geological Survey Kansas Water Science Centre, undated). Zimbabwe’s State of Environment Report (SOER) defines a flood as an overflowing or influx of water beyond its normal confines (Chenje, Sola and Paleczny, 1998). Seth, (undated) defines a flood as the abnormal
accumulation of water leading to socio-economic and environmental loss. In this study Chen (2007) and Seth’s (undated) definitions of a flood shall be adopted.

2.2 Causes of floods

Numerous factors affect stream flow, and therefore the potential for flooding. Most important are the amount and type of precipitation, the nature and condition of the drainage basin, and climate. Climatic conditions include severe thunderstorms, tornadoes, tropical and extra-tropical cyclones (many of which can be exacerbated by the El-Nino phenomenon), monsoons, ice jams as well as structural failure of reservoirs. Although flooding occurs most commonly from heavy rainfall when natural, watercourses do not have the capacity to convey excess water, floods are not always caused by heavy rainfall. Dam failure is one way in which an area downstream can be flooded even in dry weather. Floods can also occur as a result of backflow of water from a flooding river without any rains falling, which was the case in Namibia in the Caprivi region in 2004 (Nheta, 2003). Factors which influence whether a flood will occur, include volume, spatial distribution, intensity and duration of rainfall over a catchment, the capacity of the water course or stream network to convey runoff; catchment and weather conditions prior to a rainfall event; ground cover; topography and tidal influences (Villanculos, 2006; Matiki, 2005).

2.2.1 Environmental factors that contribute to flooding

Stream flow at any given point in a channel depends on the interaction of a number of factors, the most important of which are: distribution, intensity and duration of precipitation, vegetative cover, soil type and depth, geology of an area and topology; which includes area, slope and channel characteristics (Teller, 1967). Poor land use can impact on water resources by altering the hydrology (run off, infiltration and recharge rates) and increase soil erosion leading to increased sediment transport and deposition (Hirji et al., 2002) The environmental factors whose relationship with flooding will be established include: soil type, slope, distance away from the stream or channel and height above channel base. The other environmental factors which are equally important in determining flooding in an area include geology of an area, vegetation and topology (Miller, 1997).

Different types of soil have different rates of infiltration and water holding capacities of which if the infiltration capacity is exceeded, overland flow results (United Nations, 1997). Soils are derived from the rock types in a particular area and therefore geology directly affects the rate of infiltration of water (deep percolation). Pervious rocks allow increased deep percolation while the less pervious ones like granite result in increased overland flow. Land cover does impact on soil’s infiltration capacity. Runoff is typically low in areas where the percentage of vegetation cover is high, as vegetated areas allow high infiltration until the earth is saturated as runoff is spread over a long period while increased overland is expected for bare ground.

Where the ground is pre-saturated, such as following a long wet period, medium rainfall events can cause flooding as runoff begins almost immediately. There is evidence that land use changes influence the hydrological regime of various river basins.
Flood hazard modelling for Tsholotsho district, Zimbabwe

(Ashagrie et al., 2006) which triggers the risk to flooding as a result of increased runoff and subsequent flood levels especially where vegetation is removed to make room for settlement or agriculture. The passage of water tends to be retarded in basins with many natural storage areas such as lakes and wetlands and even those with artificially created storage. Slope plays an important role in the time of concentration, which is the time between the centre of excess rainfall and the inflexion point on the recession limb of the hydrograph.

The Government of Zimbabwe (2007) has listed the following factors as the causes of flooding in Tsholotsho; the generally flat terrain, highly silted rivers and streams, high rainfall intensity over a short period of time, construction of settlements in floodways and floodplains and geology. Tsholotsho is a generally flat area with two major rivers, Gwayi which is part of the Zambezi and Amanzamnyama which flows into Botswana. One of the areas that are flooded (Sheleni) falls within the Gwayi River catchment although there are no noticeable streams in two of the study areas (Ntibu and Hambeni). The flatness of the terrain leads to accumulation of runoff and as a result heavy downpours result in flash floods because the underlying granite rock does not allow downward movement of water giving rise to the dendritic drainage pattern (Government of Zimbabwe, 2007). Although Tsholotsho is a semi-arid area, the rainfall is unevenly distributed in space and time leading to some of the areas being more prone to flooding than the others. The geology of Tsholotsho and the slope described before has a bearing on the soil infiltration capacity which tends to be reduced and this increases the time that seepage should reach a river system as interflow or base flow (Miller, 1997).

2.3 Types of floods

The most common types of floods in Zimbabwe are riverine, rain induced flash floods and the floods that occur as a result of dam failure. Riverine flooding occurs in relatively low-lying areas adjacent to streams and rivers. A flash flood is a local flood of short duration (usually less than six hours) with a relatively high peak discharge generally resulting from heavy rainfall in the immediate vicinity and there is usually little or no advance warning (Miller, 1997). Flash floods can occur after a heavy storm, after a period of drought when heavy rain falls onto very dry, hard ground that the water cannot penetrate and they can occur almost anywhere. Although flash floods are localized, they pose a significant threat to the loss of human life and property because of their unpredictability and the short duration of the event. Miller (1997) observed that during flash flood events, the capacity of the drainage system has insufficient time to cope with the downpour. An area which has not been flooded in the past is not excluded from possible flooding in the future. Tsholotsho is one area that is semi arid and experiences extreme variations in rainfall such that most of the flooding in the flood prone areas of the district is due to high rainfall intensity falling over a very short period of time and falling on generally flat terrain (Government of Zimbabwe, 2007).
2.4 Problems caused by flooding

Floods have the greatest damage potential of all natural disasters worldwide and affect the greatest number of people (UN, 2004). When floods occur in less developed nations they can effectively wipe out decades of investments in infrastructure, seriously cripple economic prosperity and result in thousands of deaths and epidemics. Depending on the context, flood flows can be a problem or a disaster. Floods are a problem when the magnitude and impacts of their occurrence exceeds the ability of affected communities to cope or they become a disaster when an event leads to a serious disruption of the functioning of a community or society causing widespread human, material, economic and or environmental losses, which exceed the ability of the affected society to cope using their own resources. Such destruction can impact negatively on socio-economic development of the immediate community and the environment and the country at large. Barret and Curtis (1992) define a disaster as a serious, damaging effect on human life, property or activity which results from the impact of a hazard that has exceeded its critical levels.

The socio-economic impacts of floods include loss of life and property, mass migration of people, food shortages, shortage of clean water supplies (deterioration of water quality), loss of proper sanitation facilities and increased incidence of waterborne diseases (World Meteorological Organisation, 2007). It is clear that flood losses reduce the asset base of households, communities and societies by destroying standing crops, dwellings, infrastructure, machinery and buildings (UN, 2004). Matiki (2005) observed that flooding also exacerbates poverty because of the loss of property and other necessities which would have been accumulated over a long period of time, such that any income available in the home when floods occur would have to be used to meet the immediate demands when it could have been used for other necessities. Matiki (2005) also observed that flooding has a negative impact on school attendance because school children can not cross flooded rivers. The environment has its own share of problems that are brought about by floods and these include mass migration of wildlife, inundation of ecologically sensitive areas and environmental degradation.

Although floodplains expose their occupants to floods, they offer an enormous advantage of irrigating agricultural fields as well as bringing in deep fertile alluvial soils which increase agricultural outputs. According to the World Meteorological Organisation (WMO, 2004) floodplains do support high population densities and the Gross Domestic Product (GDP) per square kilometre is high like in the case of the Netherlands.

2.5 Response with management

According to the Global Water Partnership (2000), flood management is a broad concept that focuses on reducing flood hazards through a combination of policy, institutional, regulatory and physical measures, while recognizing that floods can never be fully controlled. This takes into account the beneficial uses of floods, which are difficult to quantify in human and economic terms but which sustain natural systems that also have economic, social, and cultural and ecosystem values and functions (Fox, 2003). Flood mitigation measures can be implemented to reduce the physical extent of flooding,
relieve the effect of a flood on humans and the community, reduce the tendency towards flood damage in different areas and reduce the risk of flooding and in this way, income stability can be assured.

Traditional and integrated approaches are used in flood management. In traditional (structural) flood management, the focus is on reducing or controlling floodwaters and susceptibility to flood damage through construction of structures such as dams, flood basin widening of riverbed, weirs and levees as well as modification of the river channel. The approach however is problem driven and is carried out in isolation. The nonstructural flood mitigation measures include public education and information programmes, forecast and early warning systems, flood zoning, flood insurance, rescue operations, floodplain building codes, floodplain buyout programs and mortgage limitations (Nelson, 2007; Australian Government, 2008). There is now a growing realization that the predominantly engineering approach to flood control has not provided its intended benefits in terms of protection from floods (Fox, 2003), as a result of the amount of damage that has occurred in recent events therefore the focus in now on Integrated Flood Management (IFM) which is a proactive approach to flood mitigation that combines both structural and non-structural measures. IFM encourages participation of the affected communities in coming up with solutions to mitigate floods.

The Johannesburg Plan of Implementation (JPI) of the World Summit on Sustainable Development (WSSD) highlights the need to mitigate the effects of drought and floods. Some of the measures that are recommended include improved use of climate and weather information and forecasts, early warning systems, land and natural resources management, agricultural practices and ecosystem conservation in order to reverse current trends and minimize degradation of land and water resources among others. This therefore means that poor countries face challenges in a number of ways as a result of floods, which become critical when it comes to the attainment of the Millennium Development Goals (MDGs) especially given the fact that floods result in water quality deterioration and loss of proper sanitation facilities among some of their effects.

2.6 Issues of concern-hazard and vulnerability

2.6.1 Hazard

Flood hazard measures the probability of a flood occurring within a specific period of time at a particular place (Leslie, 2006; Maiti, 2007). A hazard is a condition (natural or anthropogenic) of the environment which can exert an adverse influence on human life, property or activities (Barret and Curtis, 1992). Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur because of the flooding, such as disruption of services, health impacts such as famine and disease, and tertiary effects such as changes in the position of river channels. The impact of a hazardous event depends on the elements at risk, such as population or buildings and their associated vulnerability to damage or change as a result of the event.
Through flood hazard mapping one is able to determine the areas susceptible to flooding when discharge of a stream exceeds the bank-full stage or causes economic losses. Using historical data on river stages and discharge of previous floods, along with topographic data, maps can be constructed to show areas expected to be covered with floodwaters for various discharges or stages (Nelson, 2007).

### 2.6.2 Flood Vulnerability

Vulnerability to natural hazards is an integral factor in understanding the true extent of risk. Vulnerability is the degree of loss resulting from a potential phenomenon or the impact a hazard has on people, infrastructure and the economy. It relates to the physical characteristics of a geographical area, which render it likely to be affected by, promoted by, or protected from, the impact of a particular hazard on account of nature, construction and proximity to hazardous terrain or a disaster prone area. It also designates a combination of socio-economic factors that determine the degree to which someone’s life and livelihood are exposed to loss or damage by a specific identifiable threat or event in nature or society. The WMO (2004) also asserts that the degree of vulnerability to floods is highest in developing countries where the poor suffer most as sheer necessity forces them to occupy the most vulnerable areas.

At a micro level, water disaster vulnerability and poverty are interrelated, and poor households are particularly vulnerable to floods (Fox, 2003). While poor nations and the poor as a social class are more at risk, the extent of vulnerability varies according to the ability of different groups or individuals to secure alternative livelihood options and ensure the flow of resources – financial, social and political – to maintain livelihood security (Ahmed, 2004). People the world over have accepted the risk of living with floods and there are many examples of communities, which have adapted their way of living to cope with floods while deriving economic and social gain. Ahmed (2004) observed that in such communities, houses are built to allow for flooding during the wet season, people use boats to travel when roads are impassable, and the whole cycle of planting and cropping is linked to the rise and fall of rivers. Part of any successful coping strategy involves the construction of flood defenses in various forms which reduces vulnerability.

With a better understanding of the behavior of streams, the probability of flooding, and areas likely to be flooded during high discharge, humans can undertake measures to reduce vulnerability to flooding through non-structural measures such as floodplain zoning, floodplain building codes, floodplain buyout programs and mortgage limitations (Nelson, 2007; Australian Government, 2008).

### 2.7 Techniques applied to flood studies

Traditionally, gathering and analyzing hydrologic data related to floodplains and flood-prone areas has been a time-consuming effort requiring extensive field observations and calculations (Leslie, 2006). Various techniques and methodologies have been developed to capture flood extent and to map the flooded extent using various data sources before, during and after a disaster. The methods which use historical data of flood events to
delineate the extent and recurrence interval of flooding include but are not limited to probabilistic methods, deterministic, the frequency based approach, GIS and RS.

The probabilistic methods have been in use for a long time and they relate the maximum flood peak to the probability of occurrence (Maidment, 1993) which is usually very low. The figure however, is usually very low where the return period of 10,000 years ($p = 0.0001$) is used. The return period of a flood is the average interval of time within which the magnitude of a given flood will be equaled or exceeded in one time. It has been observed that the period of record for a flood using the probabilistic methods is 100 to 500 times longer therefore resulting in the non existence of a relationship with the physical factors that influence flood flow. The other short coming of the method is that a return period of 10,000 years is arbitrarily too long.

Deterministic methods involve the development of a mathematical model to simulate the rainfall-runoff process. This means that such methods make use of the unit hydrograph principle in flood flow generation where equations that govern the different aspects of storm-flow generation are used to define the shape of the unit hydrograph (Maidment, 1993). However, this method does not acknowledge the modified behaviour of storm flow response from rainfall timing in cases of storm transposition (Maidment, 1993). The set back of the probabilistic and deterministic approaches was also observed in their failure to predict the 1993 Mississippi River flood and the 1987, 1988 and 1998 Bangladesh flood and the 2000 flood for the Limpopo River.

The frequency based approach is the predominant method used in most flood plain delineation studies when the potential for loss of life is considered negligible in terms of historical floods. The peak flood discharge and corresponding water levels are established for various frequencies of occurrence or return periods of events such as once in 25 years. Associated estimated damages are established for each probability to a record of peak flows over a period of years (frequency analysis), a detailed survey (cross sections, slopes and contour maps) along with hydraulic roughness estimates is required before the extent of flooding for an expected recurrence interval can be determined. The concept of return period states that for the T-year event, $Q_T$ is the average chance of exceedence once every T years over a long record. If $X$ is equaled or exceeded r times in N years then the equation for the determination of the return period of a flood ($X$) is given in the equation below:

$$ T (X) = \frac{N}{r} \quad \text{Equation 1 (Shaw, 1988).} $$

Where:

- $T (X)$ is the return period and
- $N$ years
- $r$ times

The probability of an annual maximum equaling or exceeding $X$ in any given year is given by:
\[ P(X) = \frac{1}{T(X)} \] \text{Equation 2 (Shaw, 1988).}

Where:

- \( P(X) \) is the probability of equaling or exceedence
- \( T(X) \) is the return period

The probabilistic, deterministic and frequency based approaches require that the following data and maps are available to produce flood hazard map: the selected base (topographic) map with the surface water system, flood inundation maps and slope maps and hydrologic data in the form of frequency analysis data (including river discharge and historical flood data), flood frequency and damage reports, stage-area curves, cross sections and hydraulic roughness. Related maps such as soils, physiography, geology, hydrology, land use, vegetation, population density, infrastructure, and settlements are also required. This dynamic approach requires extensive long term field surveys, with a network of gauging stations that can develop the data needed for precise risk assessments. Such extensive long term information is seldom available for river systems in less developed countries (Leslie, 2006). To obtain hydrologic data, one must contact the appropriate hydro meteorological agencies of government to secure available data and maps.

For large areas, such as major river valleys, time and funds available are often limited. Therefore, it is usually not possible to conduct expensive detailed hydrologic data gathering, analysis, and mapping activities during a planning study. Satellite RS systems provides an economically feasible alternative means of supplementing traditional hydrologic data sources. Comprehensive and multi-temporal coverage of large areas in real time and at frequent intervals is also achieved with the same technique as images of an area can be analyzed for certain flood-related characteristics (Leslie, 2006). Comparison of images from an earlier or later date is possible and this forms the basis for the determination of changes in the study area. This technology combined with real time ground information can be used to monitor, assess and predict floods. Real-time data is data collected by automated instrumentation and telemetered and analyzed quickly enough to influence a decision that affects the monitoring system. The Integrated use of GIS and RS has been performing a very important role in monitoring, controlling, relieving and assessing natural disasters, especially flood disasters. Therefore, traditional sources of acquiring hydrological data can be supplemented with GIS and RS to acquire quantitative and qualitative flood hazard information. GIS and RS can be used separately to produce flood hazard maps and the outputs can be compared for accuracy.

In this study GIS was used to produce flood hazard maps for Hambeni, Ntibu and Sheleni. Spatial data stored in the digital data base of the GIS such as a digital elevation model (DEM) can be used to predict the effects of future events. The extent of inundation
and the depth of flooding can be forecasted and be used in conjunction with flooding data for an evacuation strategy, rehabilitation planning or damage assessment. GIS combines data from different sources and of different types and is therefore an important tool in hazard and risk assessment. One of the attractions of GIS to a user is the ability to create a map by turning layers of spatial information on and off. Spatial information and GIS have allowed important new analysis and views of the flood intelligence to be incorporated in the preparation for, and execution of, flood emergency management. Displaying data graphically, including spatial views, communicates concepts and scenarios quickly and efficiently in an environment where speed and accuracy are paramount.

2.8 Flood mitigation and institutional framework for flood management in Zimbabwe

The most common flood mitigation measures in Zimbabwe are structural mostly in the form of dams and weirs, which suggests that response to flood events in Zimbabwe is reactive (Madamombe, 2004). Disaster preparedness in Zimbabwe is the responsibility of the Civil Protection Unit (CPU), which falls under the Ministry of Local Government, Public Works and National Housing. There is a working party comprising the following Government departments: health, foreign affairs, water, and mining, state security and information with other organizations related to floods being co-opted as and when required. The working party is subdivided into subcommittees, which are early warning unit-weather and flood forecast, (Meteorological Department and ZINWA), rescue and security (Zimbabwe Defence Forces (ZDF), Zimbabwe Republic Police (ZRP), Civil Aviation and Ambulance services) and the health and social services unit (Ministry of Health).

The Government of Zimbabwe tasks the Department of Civil Protection of Zimbabwe with the responsibility of ensuring optimal emergency preparedness and disaster prevention at the individual, community, sectoral, local authority and national level through regulatory mechanisms and coordinated strategic planning for emergencies (Government of Zimbabwe, 2005). The Meteorological Services Department is responsible for early notification of civil protection authorities ahead of the severe weather event to allow for proactive disaster management. Adequate lead-time is necessary for mobilisation of resources and especially in cases where resettlement is necessary. Resettlement and evacuation of people in flooded areas is mostly the responsibility of the ZDF and the ZRP.

Civil protection authorities in Zimbabwe require additional information from the hydrological service as these have the expertise with regards the hydrology of the country including the state of rivers and dams. The water authorities also assist disaster management by providing guidance on the most vulnerable areas to flooding which underscores the importance of strong interaction between the Meteorological Services Department, the Zimbabwe National Water Authority (ZINWA) and the Department of Civil Protection before, during and after the severe weather event (WMO, 2007).
The national policy for disaster management in Zimbabwe is that every citizen of the country should assist wherever possible to avert or limit the effects of disaster where the central government initiates hazard reduction measures through sector ministries, with local administration taking the responsibility for implementing and maintaining its effectiveness (Madamombe, 2004). The system uses existing government, private and non-governmental organizations whose regular activities contain elements of prevention and community development and stakeholders participate in flood management at the local level. The policy came into effect soon after the recent cyclone induced floods to try and address the weaknesses identified in the management of flood events and such a change in policy reflects a major shift towards integrated floodwater management approach (Madamombe, 2004).

There are legal instruments in support of disaster preparedness, which includes the Water Act of 1998, which promotes IWRM and the Civil Protection Act [Chapter 20:06] which spells out the legal instruments for disaster management as well as the power that individuals and organisations have during flood disaster events (Government of Zimbabwe, 2005).
CHAPTER THREE: DESCRIPTION OF STUDY AREA

3.0 Introduction and general description of study area

The study was conducted in Tsholotsho district, one of the seven districts in Matebeleland North province in Zimbabwe to the north western part of Zimbabwe. Part of Tsholotsho district drains into the Gwayi River. Gwayi River is part of an international river basin, the Zambezi and it also forms one of the seven catchments in Zimbabwe. There is a communal tenure system in Tsholotsho. Most of the land is used for agriculture. Tsholotsho district has a population of 119,681 with a population density of 16 persons/km². Tsholotsho district is located 19°46'00" south and 27°45'00" east. Tsholotsho district covers 7,844 km². Figure 3.1 shows the geographical location of Tsholotsho district in relation to the other districts in Zimbabwe. Field data was collected in wards 6 (Sheleni) and 12 (Hambeni and Ntibu).

Figure 3.1: Map showing Tsholotsho district in Zimbabwe
Flood hazard modelling for Tsholotsho district, Zimbabwe

Figure 3.2: Map showing the study area in Tsholotsho district
3.1 Climate
The study area falls within agro-ecological region IV, receiving on average about 650mm per annum (Meteorological Office, 2008; Myers, Heinrich and Rusike, 2004). The low and erratic rainfall that is characteristic of the study area makes it prone to drought and floods (Government of Zimbabwe, 2007). Rainfall episodes in Tsholotsho are short and intense, especially during the summer season between late November and April. It is during this period that most parts of Tsholotsho are particularly prone to flooding. The Mean Annual Runoff (MAR) for Gwayi River at gauging station A38 for the period 1966 to 2006 is 138.7 with a Coefficient of Variation (CV) of 2 (ZINWA, 2008). Figure 3.4 shows the mean annual rainfall for Tsholotsho for the period 1990 to 2005.
Extreme rainfall events for Tsholotsho district were recorded for the rainfall seasons of 1973/1974, 1977/1978, 1980/1981, 1987/1988, 2000/2001 and 2005/2006 (Meteorological Office, 2008; ZINWA, 2008) as shown in Figure 3.5. Historically, flood-producing high rainfalls have occurred most commonly between December and March, and are associated with tropical cyclones and the movement of the ITCZ to the south of the Zambezi River. The mean annual temperature for Tsholotsho is 27.8 °C (Meteorological Office, 2008; Torence, 1981) with the maximum monthly temperatures being experienced between October and February. The flooding period also coincides with the cropping season. Weather forecasts by the Zimbabwe meteorological office have not been as accurate which resulted in people not taking the forecast seriously leading to inadequate preparation and consequently loss of life and property during flooding events.
3.2 Soils

The Gwayi River areas (Sheleni line) in ward 6 characterized by rich black soils which fall within a 2km wide belt of the Gwayi River. Soils in the rest of the study area are mainly derived from felsic (gneissic) rocks giving rise to the deep Kalahari sands. (Myers et.al, 2004). Myers et.al. (2004), describe soils in Tsholotsho as falling in the following categories; gleyic arenosols, eutric fluvisols, eutric vertisols and ferralic arenosol according to the Food and Agricultural Organization’s (FAO) soil taxonomy. The characteristics of these soils are described in Table 3.1 below.
Table 3.1: Physical characteristics of soils found in Hambeni, Ntibu and Sheleni

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Colour</th>
<th>Texture</th>
<th>Depth</th>
<th>Drainage</th>
<th>Permeability</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arenosols</td>
<td>brownish or yellowish</td>
<td>loamy sand or coarser</td>
<td>up to at least 100 cm</td>
<td>rapid drainage and low moisture holding capacity</td>
<td>permeable to water</td>
<td>basic</td>
</tr>
<tr>
<td></td>
<td>colors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluvisols</td>
<td>Dark brown</td>
<td>Coarse sand</td>
<td>&lt;30 cm</td>
<td>Well drained</td>
<td>Good</td>
<td>Neutral to basic</td>
</tr>
<tr>
<td>Vertisols</td>
<td>Dark grey over black</td>
<td>Clay heavy clay texture with a high proportion of swelling clays (montmorillonite)</td>
<td>&gt; 130 cm</td>
<td>Poorly drained</td>
<td>Restricted</td>
<td>neutral to basic</td>
</tr>
<tr>
<td></td>
<td>Dark colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: FAO. Undated.

3.3 Land use

Land use in the area of study include settlement, croplands, grazing and woodland. Agriculture is the main source of livelihood in Tsholotsho. Tsholotsho district has vast indigenous hardwoods like teak, which are mainly confined to the Kalahari sands while the clays support the thorn acacia and grasslands. Kalahari sands also support the Mopane trees (*Colophospermum mopane*) and *Acacia* species.
CHAPTER FOUR: METHODS

4.1 Problems associated with flooding in the study area
Data collection was conducted from 31 January to 15 March 2008. The data collection sheets were in the form of questionnaires with the information sought being on aspects such as flood occurrence at a particular location, how frequent the flood events are, land use and the impact of floods on households. During data collection the oldest person in a household was targeted for interviews as that was the person with in-depth knowledge on the subject. The interviews were semi structured. All the homesteads were targeted for the study in all the villages where the research was conducted. Verification of the problems that are associated with flooding in the study areas was done with the Ministry of Local Government officials based at Tsholotsho center. The data on flood condition was recorded in binary form (1 and 0 for presence and absence of flooding respectively). Authority to conduct the study was obtained from Tsholotsho Chief Executive Officer, ZRP and the respective councillors and village heads. Information on the problems that affect households in the three study areas was collected using the template on Appendix 1.

4.2 Flood hazard modeling
The first stage of determining flood hazard involved the collection of field data of areas that were affected by the 2000-2001 flood event using a GPS. A 90m DEM which was obtained from the Department of Geography and Environmental Science of the University of Zimbabwe was used to derive slope, flow direction, flow accumulation and stream network for the determination of height above channel base (using DNR Hydro) and distance away from the stream (using the find distance algorithm). Height above channel base, distance away from the stream, slope of drainage basin and soil type were used to model flood hazard. Data that was collected in the study area was entered into a spreadsheet to produce a point map which was entered into a GIS. Distance had a bearing on the output; therefore data analysis was done for the individual study areas to produce flood hazard maps for each study area. Appendix 2 shows the template that was used to collect information on flooding condition in the respective study areas.

4.3 DEM filling, slope, flow direction and flow accumulation derivation and stream network delineation
After filling the DEM, it was used to calculate slope, flow direction, flow accumulation and stream channel network with the outputs being grid maps. Slope is the maximum rate of change in value from one cell in relation to its neighbours and this was measured as a percentage to produce a slope grid. Flow direction is the direction of flow of water off each pixel following the steepest slope and it determines the flow accumulation. The flow direction grid had values ranging from 1-128. Flow accumulation estimates the amount of water that is available for runoff which concentrates and accumulates into river channels. Flow accumulation was calculated for streams with more than twenty-five cells of flow accumulation. Flow accumulation was important in producing the stream network for the
study areas. Appendices 5, 6 and 7 show the generated stream network for Hambeni, Ntibu and Sheleni respectively.

4.4 Derivation of height above channel base

Stream channel network data was used together with the DEM to derive the height of each place in the study area above the nearest channel base. The TIN (Triangular Irregular Network) model algorithm was used to interpolate height above channel base and the interpolated height above channel base was subtracted from the DEM. The channel bed level itself would have a height above nearest channel bed of zero while on the channel slopes the height increases relative to the DEM. TIN is a significant alternative to the regular raster of a DEM. DNR hydro was used to produce values for height above channel base using the point on grid overlay.

4.5 Derivation of distance away from the stream

The stream network layer was used to produce a grid for distance away from the stream for Hambeni, Ntibu and Sheleni in Integrated Land and Water Information System (ILWIS) 3.3 Academic (ITC, 2003). Figure 4.1 shows the variation of distance away from the nearest stream for Ntibu.

Figure 4.1: Map showing distance away from the nearest stream for Ntibu. Coordinates are in meters UTM Zone 35 South
4.6 Derivation of slope
The DEM was used to derive slope as a percentage using the DNR hydro extension.

4.7 Soil type
Data on soil type was obtained by analysing a DEM obtained from the Department of Geography and Environmental Science. The data was entered in binary form for presence and absence of the particular soil type in a given study area. Appendices 8, 9 and 10 show the variation in soil type for Hambeni, Ntibu and Sheleni.

4.8 Data analysis
Data was analyzed statistically using binary logistic regression. Binary logistic regression was used to spatially predict flood hazard. Logistic regression which is a multivariate statistical analysis technique used to identify the most important predictor variable of flood occurrence and to generate a formula for the probability of flood occurrence. Binary logistic regression is used when the dependent variable is a presence/absence type and the independents are both continuous and categorical. Logistic regression makes no assumption about the distribution of the independent variables. It requires that observations are independent and that the independent variables are linearly related to the logit of the dependent variable. Graphs were used to illustrate the probability of flooding. Data manipulation, analysis and management were done in Microsoft Excel 2003, Arc view 3.2, ILWIS 3.3 Academic (ITC, 2003) and SPSS 13.0.

4.9 Flood probability and flood hazard maps
The flood probability and flood hazard maps were processed in ILWIS 3.3 Academic (ITC, 2003).
CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Results

5.1.1 Problems associated with flooding in the study area

Figure 5.1 illustrates the problems that are associated with a flooding event in Tsholotsho. The problem that is commonly brought by flooding in Hambeni, Ntibu and Sheleni is associated with food shortages. The second most prevalent problem in Sheleni is the destruction of huts which is closely followed by non attendance at school. Households in Ntibu listed flooding of fields as the second most prevalent problem after food shortages followed by non attendance at school by those of the school going age especially primary children. In Hambeni, flooding of fields and non attendance at school emerged as the second most common problem. In all the three villages, the least problem that floods bring in the communities was the loss of household property. Appendices 3 and 4 illustrate some of the problems associated with flooding in Hambeni and Ntibu.

<table>
<thead>
<tr>
<th>Name of village</th>
<th>Frequency of problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hambeni</td>
<td>livestock loss</td>
</tr>
<tr>
<td></td>
<td>hut destruction</td>
</tr>
<tr>
<td></td>
<td>food shortages</td>
</tr>
<tr>
<td></td>
<td>household property loss</td>
</tr>
<tr>
<td></td>
<td>flooding of fields</td>
</tr>
<tr>
<td></td>
<td>impassable roads</td>
</tr>
<tr>
<td></td>
<td>non attendance at school</td>
</tr>
</tbody>
</table>

Figure 5.1: Frequency of problems brought about by flooding in Hambeni, Ntibu and Sheleni
5.1.2 Flood hazard analysis for Hambeni, Ntibu and Sheleni

5.1.2.1 Variation of distance away from the nearest stream for Hambeni, Ntibu and Sheleni

Figure 5.2 shows variation of distance away from the stream as a predictor of flooding for Hambeni, Ntibu and Sheleni. The 25th percentile for Hambeni, Ntibu and Sheleni with respect to distance away from the stream is 55 meters, 40 and 30 meters respectively. The 75th percentile is lower for Sheleni at 20 meters while for Ntibu 75% of the area is within 170 meters of the stream. Fifty percent of the area in Hambeni and Sheleni is within 80 meters of the stream while for Ntibu 50% of the area is within 100 meters of the streams. Ntibu has the highest range of values for distance away from the stream followed by Hambeni with the least being observed in Sheleni.

![Variation of distance away from the stream versus place of study](image)

Figure 5.2: Variation of distance away from the stream versus place of study

5.2.1.2 Variation of height above the channel base for Hambeni, Ntibu and Sheleni

Figure 5.3 shows variation of height above channel for Hambeni, Ntibu and Sheleni. The minimum height above channel for Sheleni and Hambeni is 0.0 meters. Seventy-five percent of the area under study in Sheleni has a height above channel which is below 1.0 meters while in Hambeni 75% of the area is below 1.2 meters above channel base. The
75\textsuperscript{th} percentile for both Hambeni and Sheleni is below the median for Ntibu. The range of values for the three study areas is almost the same.

\textbf{Figure 5.3: Variation of height above channel base versus place of study}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{height_above_channel_base.png}
\caption{Variation of height above the channel base for Hambeni, Ntibu and Sheleni.}
\end{figure}

5.1.2.3 Variation of height above the channel base for Hambeni, Ntibu and Sheleni

Figure 5.4 illustrates the variation of slope for Hambeni, Ntibu and Sheleni. Twenty-five percent of Sheleni has a slope which is almost 0.2\%, while Ntibu and Hambeni have 25\% of the area within 0.4\% and 0.8\% respectively. Sheleni has the highest range of slope (0.2\% - 5.3\%) with the least being observed for Hambeni (0.2\% - 3.7\%). The median ranges from 1.2\% through 1.6\% for Sheleni, Ntibu and Hambeni respectively.
Figure 5.4: Variation of slope versus place of study

5.1.2.4 Flood hazard for Hambeni, Ntibu and Sheleni

Table 5.1 illustrates that:
- distance away from the nearest stream in Ntibu is a significant (p< 0.05) function of predicting flood hazard.
- height above channel base and slope explain flood hazard in Sheleni.
- only height above channel base was significant (p < 0.005) in predicting flood hazard for Hambeni.
- height above channel and slope were not significant (p > 0.005) in predicting flood hazard in Ntibu.
- distance away from the nearest stream was not significant (p> 0.005) in predicting flood hazard for Sheleni.
- slope and distance away from the nearest stream were not significant (p> 0.005) in predicting flood hazard for Hambeni.
Table 5.1: Binary logistic regression relationship between flooding condition and distance away from the stream for Hambeni, Ntibu and Sheleni

<table>
<thead>
<tr>
<th>Place</th>
<th>Environmental variable</th>
<th>B</th>
<th>S.E.</th>
<th>P. Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntibu</td>
<td>Distance away from the nearest stream</td>
<td>-.017</td>
<td>.007</td>
<td>.011</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>4.596</td>
<td>1.296</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Height above channel base</td>
<td>.324</td>
<td>.620</td>
<td>.601</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>1.775</td>
<td>.663</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>slope</td>
<td>-.241</td>
<td>.389</td>
<td>.536</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>2.450</td>
<td>.804</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td>Arenosols</td>
<td>2.058</td>
<td>.434</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Fluvisols</td>
<td>2.058</td>
<td>.434</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Vertisols</td>
<td>2.058</td>
<td>.434</td>
<td>.000</td>
</tr>
<tr>
<td>Sheleni</td>
<td>height above channel base</td>
<td>-.106</td>
<td>.409</td>
<td>.014</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>2.246</td>
<td>.518</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Distance away from the nearest stream</td>
<td>-.011</td>
<td>.006</td>
<td>.057</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>2.718</td>
<td>.775</td>
<td>.000</td>
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<tr>
<td></td>
<td>slope</td>
<td>-.583</td>
<td>.262</td>
<td>.026</td>
</tr>
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<td></td>
<td>Constant</td>
<td>2.639</td>
<td>.684</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Arenosols</td>
<td>24.987</td>
<td>14210.361</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>Fluvisols</td>
<td>-21.203</td>
<td>14210.361</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>Vertisols</td>
<td>-24.987</td>
<td>14210.361</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>(constant)</td>
<td>3.784</td>
<td>1.011</td>
<td>.000</td>
</tr>
<tr>
<td>Hambeni</td>
<td>height above channel base</td>
<td>-.1941</td>
<td>.954</td>
<td>.042</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>2.717</td>
<td>1.217</td>
<td>.026</td>
</tr>
<tr>
<td></td>
<td>slope</td>
<td>-.020</td>
<td>.500</td>
<td>.968</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td>.808</td>
<td>.995</td>
<td>.417</td>
</tr>
<tr>
<td></td>
<td>Arenosols</td>
<td>.773</td>
<td>.494</td>
<td>.117</td>
</tr>
<tr>
<td></td>
<td>Fluvisols</td>
<td>.773</td>
<td>.494</td>
<td>.117</td>
</tr>
<tr>
<td></td>
<td>Vertisols</td>
<td>.773</td>
<td>.494</td>
<td>.117</td>
</tr>
</tbody>
</table>

5.1.2.5 Flood probability and flood hazard for Ntibu

The binary logistic relationship between flooding condition and distance away from the stream resulted in the following significant (p < 0.005) function for Ntibu:

\[
P = \frac{\exp(4.596 - 0.018 \times x)}{1 + \exp(4.596 - 0.018 \times x)} \tag{Equation 3}
\]

where x is distance away from the stream.
Figure 5.5 shows that there is a 50% chance of being flooded for an area that is more than 250 meters away from the nearest stream given the 2000 flood magnitude.

**Figure 5.5: Flood probability as significantly (p<0.05) predicted by distance away from the stream for Ntibu**

Equation 5.1 was applied to the distance away from the stream map in ILWIS to determine the probability (P) of an area being inundated with water in a flood event. The resultant map was used to produce a flood hazard map for the area as shown in Figure 5.6 which illustrates that most of Ntibu falls in the high flood hazard zone. The flood safe areas in Ntibu have a probability of flooding that is between 16% and 33%.
5.1.2.6 Flood probability and flood hazard for Hambeni and Sheleni

The environmental factors that were significant ($p<0.05$) in predicting flood occurrence in Sheleni were tested for independence using Spearman’s Rank test. Table 5.2 shows that there is positive correlation between height above channel base and slope for Sheleni. Therefore the two environmental factors cannot be used in one logistic regression model for flood hazard for Sheleni. Height above channel base was more significant ($p = 0.014$) in predicting flood occurrence than slope ($p = 0.026$) therefore the more significant environmental factor (height above channel) was used to predict flood hazard for Sheleni (Table 5.1).

*Figure 5.6: Classified flood hazard map as a function of distance away from the stream for the 2000 flood for Ntibu. Coordinates are in meters UTM Zone 35 South.*
Table 5.2: Spearman’s Rank test for height above channel and slope for Sheleni

<table>
<thead>
<tr>
<th>Spearman’s rho above channel base</th>
<th>Correlation coefficient</th>
<th>Sig. (2-tailed)</th>
<th>N</th>
<th>Height above channel base</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient</td>
<td></td>
<td>.291*</td>
<td></td>
<td>1.0000</td>
<td>.291*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.035</td>
<td>53</td>
<td></td>
<td>.035</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>53</td>
<td></td>
<td></td>
<td>53</td>
</tr>
</tbody>
</table>

*: Correlation is significant at the 0.05 level (2-tailed).

The binary logistic relationship between flooding condition and height above channel base resulted in the following significant (p < 0.005) functions for Sheleni and Hambeni respectively:

\[
P = \frac{\exp(2.2460 - 1.006 \times x)}{1 + \exp(2.2460 - 1.006 \times x)} \text{ Equation 4}
\]

\[
P = \frac{\exp(2.717 - 0.941 \times x)}{1 + \exp(2.717 - 0.941 \times x)} \text{ Equation 5}
\]

where \( x \) is the height above channel in meters.

Figure 5.7 shows that the probability of a point being flooded is higher for Hambeni compared to Sheleni given a flood of magnitude of the 2000 flood. The lower the height above channel base, the higher the probability of an area being flooded. For example at a height above channel of 2 meters there is above 60% chance of a point being inundated for Hambeni while for Sheleni a point has just above 40% chance of being inundated. There is a 0% probability of a point being flooded beyond 9 meters from the stream.
Equations 5.2 and 5.3 were applied to the height above channel base maps in ILWIS to determine the probability (P) of an area being inundated with water in a flood event. The resultant maps were used to produce flood hazard maps for Hambeni and Sheleni as shown in Figure 5.6 and Figure 5.7 for respectively. Figure 5.8 and Figure 5.9 shows that both Hambeni and Sheleni fall in the high hazard zones although large proportions of Hambeni are in the high hazard zone compared to those in Sheleni. Areas with a probability of flooding that lies between 60% and 68% are flood safe areas in Hambeni while in Sheleni flood safe areas have a probability of flooding that is between 25% and 60%.
Figure 5.8: Flood hazard map as a function of height above channel for the 2000 flood for Hambeni. Coordinates are in meters UTM Zone 35 South.
Discussion

5.2.1 Problems associated with flooding in the study area

The results indicate that the most frequent problem that is caused by flooding in Hambeni, Ntibu and Sheleni is food shortages. Flood waters may cover the ground for some days after a flooding event such that those households which depend on some forest products (non-timber forest products) for food are negatively impacted upon. As indicated by the results, flood waters may also destroy huts where food is stored, which increases the problem of food shortages for affected communities. Fields may be flooded as a result of them being close to the streams which increase the impact of the floods on the affected communities in relation to food shortages as it may affect the yield for a particular growing season reducing the amount of food available to households. Shelter for most of the villagers in the three study areas is constructed using poles and dagga which increases the chances of destruction of such structures when flooding occurs. The
destruction of shelter leads to loss of household property for the affected communities because the shelter that is dominant in the study areas is vulnerable to floods. Impassable roads are one problem that is brought about by flooding in the study areas. The roads in the study area are constructed using gravel which can easily be washed away when the area is flooded leaving behind channels that allow water to pass through. Impassable roads negatively impact on communities because they would not be able to access services such as schools, clinics and other essential services which further explain the non attendance at school by school children.

5.2.2 Flood hazard for the management of floods

The results indicate that distance away from the stream significantly (p < 0.05) predicted flood hazard for Ntibu. This means that the closer an area is to a stream the higher the probability of flooding. Through the analysis of the variation in distance away from the nearest stream for Hambeni, Ntibu and Sheleni, the tendency to flooding would be high for Sheleni compared to Ntibu because the highest number of points in the area was within 0.0 meters away from the nearest stream but the flood model indicated that distance away from the stream is significant (p < 0.05) in predicting flood hazard for Ntibu than Sheleni and Hambeni. Data collection for flooding condition depended on the response of people in the areas under the study such that there is a high chance of sampling error which could compromise the model.

The significance of height above channel in predicting flood hazard can be explained by the fact that both Sheleni and Hambeni have a minimum height above channel of 0.0 meters with 75% of the area in both study areas having a height above channel which is below 1.2 meters. This distance is generally low and will therefore increase the vulnerability of the community to flooding. Height above channel was not a flood hazard predictor for Ntibu although half of the area had a height above channel base which was greater than 1.2 meters and just above 2 meters. Such figures indicate that most of the settlements in Sheleni and Hambeni were located either in a flood plain or floodway. Field observations indicated that Sheleni is located in a floodplain of the Gwayi River while Hambeni is located in a floodway. The settlement is located within a meander such that vulnerability to flooding is increased. When the Gwayi River overtops its banks, the meander tends to hinder movement of water within the confines of the river which forces water to flow through areas of low flow resistance, which is the floodplain. The low figures of height above channel base can be explained by the fact that height above channel base is affected most by human activities such as poor agricultural practices and deforestation that lead to soil erosion and later siltation of streams and rivers (Ashagrie, 2006). Both flood plains and flood ways are generally very flat areas therefore making the areas prone to flooding. The spatial extent of the floodplain or flood way could be higher in Hambeni than in Sheleni explaining why the probability of flooding is high in the former.

Mharapara (1995) observed that floodplains support agricultural activities because of moisture availability and nutrients which encourage recession agriculture therefore supporting livelihoods especially in rural areas which improve people’s livelihoods. This lures people especially the poor into the floodplains (WMO, 2004) and it therefore
explains why the majority of households in Hambeni and Sheleni are located in the high hazard zones respectively.

The non significance of soil type and slope in predicting flood hazard for Hambeni, Ntibu and Sheleni could be as a result of the area under consideration being small such that there are no variations in soil type and slope for each of the areas. The non significance of height above channel base for Ntibu and distance away from the nearest stream for Hambeni could be explained by sampling error. The non significance of height above channel base and slope for Ntibu, distance away from the nearest stream and slope for Hambeni and distance away from the nearest stream for Sheleni in predicting flood hazard is however contrary to findings by other researchers where these factors were shown to predict flood hazard (Nelson, 2007: United Nations, 1997).
CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions
The development of a flood hazard map for Hambeni, Ntibu and Sheleni was carried out using GIS. The general conclusion that can be drawn from this study is that height above channel base significantly \( p < 0.05 \) predicted flood hazard for Hambeni and Sheleni while distance away from the nearest channel was significant \( p < 0.05 \) in predicting flood hazard in Ntibu. It can also be concluded that the most common problem brought by flooding in Hambeni, Ntibu and Sheleni is associated with food shortages. The other problems in the three study areas include destruction of huts, flooding of fields, and non-attendance at school, livestock loss, impassable roads and loss of household property. The results described in this study gave an insight into potential flood hazard in Hambeni, Ntibu and Sheleni which can be used to manage flood events that will occur in future by such organizations as the CPU as it indicates inundation characteristics of flood plains. The flood hazard map represents flood occurrence for each pixel. The digital flood hazard map can be updated from time to time therefore making it an effective flood management tool.

6.2 Recommendations for further research
There is need to use the flood hazard model that was developed in this study to develop the flood risk map for Hambeni, Ntibu and Sheleni. This research used a statistically based model so it is also important to assess the use of a hydrological/physically based model to determine the runoff conditions that would constitute a flood for the three study areas in Tsholotsho where the amount of water available for runoff is determined as well as the flow of the water within the basin.
REFERENCES


FAO., Undated. Lecture notes on the major soils of the world. Natural Resources Management and Environment Department http://www.fao.org/docrep/003/y1899e/y1899e06.htm accessed 19/05/08 10:00hrs


Flood hazard modelling for Tsholotsho district, Zimbabwe


Seth S. M., (Undated). Role of Remote Sensing and GIS inputs in physically based hydrological modelling. National Institute of Hydrology INDIA http://www.gisdevelopment.net/application/nrm/water/overview/wato0006pf.htm accessed 03/12/07 13:00hrs


ZINWA- Research and data division, 2008. Mean Annual Runoff for gauging station A38 on the Gwayi River.
## APPENDICES

### Appendix 1: Questionnaire-Flood Management in Tsholotsho

**Village:** ……………………………………………………………

**Ward:**…………………………………………………………

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
</table>

### Personal Information

1. Sex
   - 1. Male
   - 2. Female

2. Age (years)

3. When did you start living in this area (year)?

### Flood events in the area


5. When in 2001 did the floods occur?
   - December
   - January
   - February
   - March
   - Other (specify)………

6. What was the flood level in 2001
   - a. 2001……………………………………………..

7. What was destroyed in the two respective years?
   - a. 2001……………………………………………

8. What problems did the 2001 flood bring?
   - a. 2001……………………………………………

   - Crop destruction leading to low harvests
   - Road destruction
   - Loss of properties
   - Drowning of animals and human beings
   - Contamination of drinking water
   - No problem
   - Other (specify)……………………………………

### Health

9. Did anyone in the household get sick after flood events?
   - 1. Yes
   - 2. No

10. If yes, what was the disease?
    - Diarrhoea
    - Malaria
    - Dysentery
    - Typhoid
    - Trauma
    - Others (specify)……………………………………

11. How many were affected by each of the diseases mentioned?
    - Diarrhoea
    - Malaria
    - Dysentery
    - Typhoid
    - Trauma
    - Others (specify)……………………………………

12. Were they treated?
    - 1. Yes
    - 2. No

13. If yes, where did they receive treatment?
    ………………………………………………………..
### Water and sanitation

<table>
<thead>
<tr>
<th>Question</th>
<th>Before flooding?</th>
<th>During flooding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. What was the source of water before flooding?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Were the toilets flooded during the floods?</td>
<td>1. Yes</td>
<td>2. No</td>
</tr>
<tr>
<td>16. What was the height/level of the flood?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cultivation

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Do you own land for cultivation?</td>
<td>1.</td>
<td>2.</td>
</tr>
<tr>
<td>18. How much of the cultivated land was flooded?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Flood mitigation measures that are in place in the area

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Is there anything that you do on your own to mitigate the negative effects of floods?</td>
<td>1.</td>
<td>2.</td>
</tr>
<tr>
<td>20. If yes, what do you do?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Rank the land use planning activities that can mitigate the negative effects of floods on your livelihoods</td>
<td>1.</td>
<td></td>
</tr>
</tbody>
</table>

### Flood warning systems

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. Are there any early warning systems for flood management in this area?</td>
<td>1.</td>
<td>2.</td>
</tr>
</tbody>
</table>

### Other sources of information

- Radio
- Television
- Newspaper
- "D. A’s office"
- Indigenous Knowledge
- Traditional institutions
- Telephones
- Other (specify)…

### Who is involved in flood management in your area?

- Government
- Traditional leaders
- NGOs
- Church
- Local disaster committee
- Volunteers
- Other (specify)…

### What made you stay in this area?

- Flatness of the area
- Soil fertility
- Proximity of water
- Other (specify)…
Appendix 2: Data collection template-Flood occurrence, land use and number of people per household in Tsholotsho

Date………………………………  Ward……………………………
Village…………………………………………..

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Flooding condition 2001</th>
<th>Land use</th>
<th>No. of people per household</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Appendix 3: Photograph showing a flooded road in Hambeni
Appendix 4: Photograph showing a sinking hut in Ntibu

Appendix 5: Map showing generated stream network for Hambeni. Coordinates are in meters UTM Zone 35 South
Appendix 6: Map showing generated stream network for Ntibu. Coordinates are in meters UTM Zone 35 South
Appendix 7: Map showing generated stream network for Sheleni. Coordinates are in meters UTM Zone 35 South
Appendix 8: Map showing variation in soil type for Hambeni. Coordinates are in meters UTM Zone 35 South
Appendix 9: Map showing variation in soil type for Ntibu. Coordinates are in meters UTM Zone 35 South
Appendix 10: Map showing variation in soil type for Sheleni. Coordinates are in meters UTM Zone 35 South