CATCHMENT AREA: A CASE OF GOKWE NORTH DISTRICT.

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MIDLANDS STATE UNIVERSITY

FACULTY OF SOCIAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

A Dissertation submitted to the Department of Geography and Environmental Studies in partial fulfilment of the requirements for a BSc Honours Degree in Geography and Environmental Studies

May 2016

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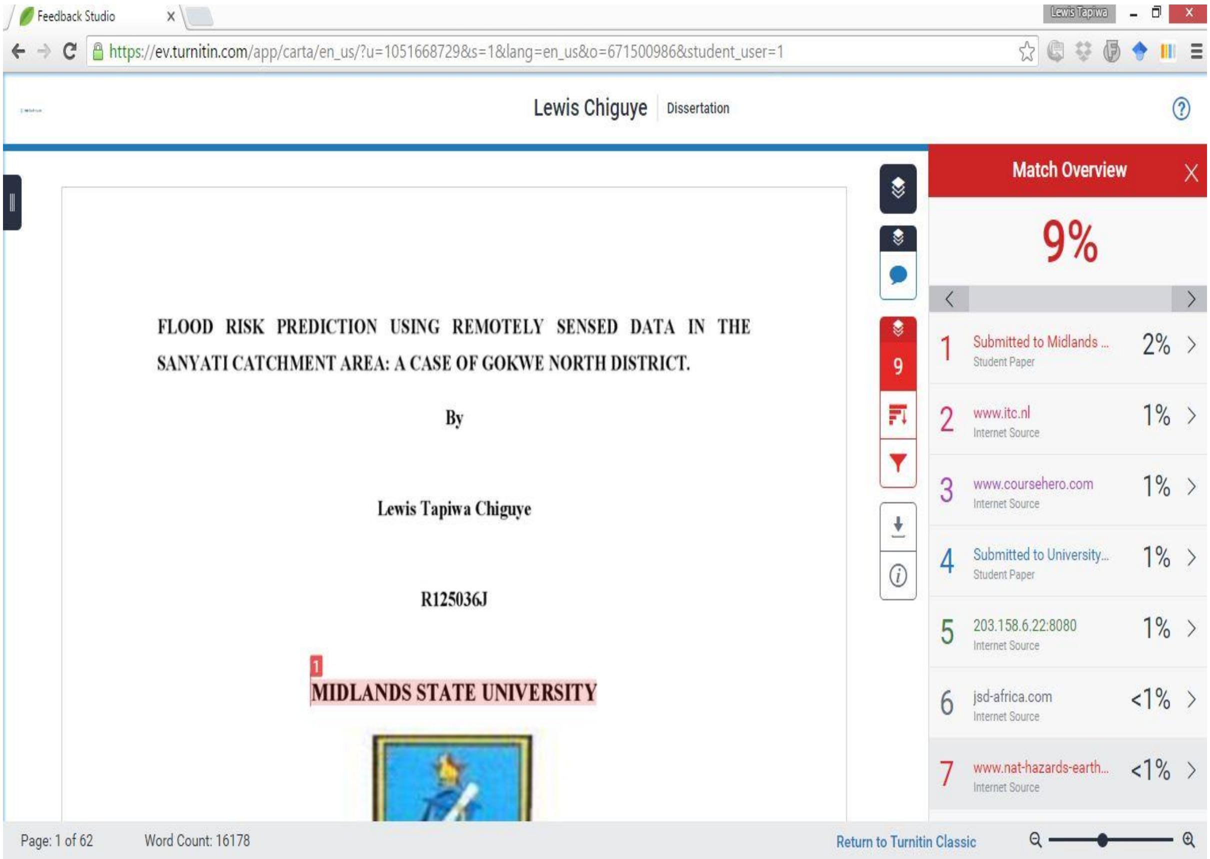
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By

Lewis Tapiwa Chiguye

(R125036J)

Submitted in partial fulfilment of the requirements of the Bachelor of Science Honours Degree in Geography and Environmental Studies.

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DEDICATION

I dedicate this research to my late parents and sister in-law. You may be gone, but you’re not forgotten.

ABSTRACT

The research aspired to estimate the potential damage a future flood can cause in Gokwe North District. The study made use of both quantitative and qualitative techniques to acquire data. This approach integrated GIS, remote sensing, semi-structured interviews and field observations in collecting data. Two Landsat images (path 171 row 72) for two different years (2005 and 2015) were accessed from U.S. Geological Survey's Earth Explorer database. To analyse the LULC changes in the study area, these images were processed in ENVI 5.1 by exploring the K-Means in unsupervised classification method. Change detection techniques were used to compute class statistics as well as accuracy assessment. An SRTM DEM which provide data at 90m contour interval was accessed from CGIAR-CSI website and preprocessed in ArcGIS 10.1 to remove unwanted regions. The preprocessed DEM was used to calculate flow direction and map flood risk in Ilwis 3.3. Results obtained from LULC classification and flood risk mapping were inputted into SPSS software to analyse the relationship between land use and flood risk in the district. The results indicate that there were notable changes in LULC in Gokwe North District from 2005-2015. Cultivated land and built up area had significant increases whilst vegetation and water decreased. Low lying areas in the district such as Simuchembu, Madzivazvido and Nenyunka were identified to be at greater risk from flooding, Gokwe North District as a whole is a high flood risk area since it is low lying. All LULC classes in the district, that is, vegetation, cultivated land, built-up area and water have high risk levels as they often occur in lowlands. Areas close to streams are also exposed to greater risk because when the stream gets flooded these will be the first areas to be washed away. From hypothesis testing it was discovered that there is a relationship between land use and flood risk. The study recommends that organizations dealing with flood issues such as ZINWA, Meteorological Department, Civil Protection Unit of Zimbabwe and local Councils should embrace and consolidate GIS and remote sensing in flood monitoring. This would help improve the current state of flood monitoring in Zimbabwe because GIS and remote sensing have the capacity to provide information for areas of poor accessibility or lacking in ground measurements. More so use of GIS and remote sensing is an economic and efficient method of flood risk prediction because much of the data can be accessed freely.

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First and foremost, I would like to express my heartfelt gratitude and deep appreciation to my supervisor, Dr. M. Matsa for the patient guidance and mentorship during the period I conducted my research until the time the document was finally consolidated. The research was not easy without his support and guidance, his door was always open for me. I am not shy to admit that he has molded me to be a better scientific researcher. Thank you very much for your support and guidance.

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Without the support of my brothers and sister both financially and morally, I would never have succeeded. You were always there for me when I needed your support and you were always encouraging me soldier on.

Above all, my humble thanks goes to the Almighty GOD for his love and mercy have taken me this far.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEFINITION OF TERMS

Digital Elevation Model – is a digital model representing Earth's surface terrain height variation.

Geographic Information System – is a system designed for the entry, management, analysis and presentation of georeferenced data.

Georeferencing – the process of assigning spatial coordinates to data such that it can be located in space or on earth.

Remote sensing – the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by device that is not in contact with the object, area, or phenomenon under investigation.

Remotely sensed data – data that has been collected by a sensor that is not in direct contact with the object being sensed.

Image Classification – the process of assigning pixels to nominal (thematic) classes.

Unsupervised classification – the process of assigning pixels to nominal classes by using a clustering algorithm which automatically detects and defines the number of clusters in a feature.

ABBREVIATIONS AND ACRONYMS

DEM – Digital Elevation Model

GIS – Geographic Information System

GPS – Global Positioning System

LULC – Land Use and Land Cover

LULCC - Land Use and Land Cover Change

OLI – Operational Land Imager

SPSS – Statistical Package for Social Sciences

SRTM – Shuttle Radar Topography Mission

TM – Thematic Mapper

UNOCHA – United Nations Office for the Coordination of Humanitarian Affairs

ZimStat – Zimbabwe Statistics

CHAPTER 1: INTRODUCTION

1.1 Background

Earthquakes, floods, drought and other natural hazards continue to cause tens of thousands of deaths, hundreds of thousands of injuries, and billions of dollars in economic losses each year around the world (Diley, 2005). Flooding is the most common environmental hazard worldwide. This is attributable to the vast geographical distribution of river floodplains and low-lying coastal areas. It occurs in more than one-third of the world's land area, in which 82% of the world's population resides. In terms of global distribution, Diley (2005) observed that the majority of floods occur in Asia (India and China), followed by North Africa, then eastern United States, Europe and Oceania. According to Carter (2012) floods can be described according to speed (flash flood) or the cause of flooding. Some floods can occur suddenly and retreat quickly. Others take days or even months to build and discharge.

A flood is a hazard that can occur in many countries all over the world. Floods cause enormous damages and economic losses every year. A flood is defined as, "the covering of normally dry land by water that has escaped or been released from the normal confines of: any lake, or any river, creek or other natural watercourse, whether or not altered or modified; or any reservoir, canal or dam" (Carter, 2012). A flood can be simply defined as a natural event or occurrence, where a piece of land or an area that is usually dry suddenly gets submerged under water. According to O`Connor and Costa (2004) flooding is not always caused by heavy rainfall. Flooding can be caused by river overflow, torrential rainfall, dam failure, ice and snow melts, and lack of drainage in an urban area. In coastal areas, flooding can be caused by a storm associated with a tropical cyclone, a tsunami or a high tide coinciding with higher than normal river levels.

Zimbabwe is particularly prone to a number of natural and man-made hazards such as droughts, floods, veld fires and storms (PreventionWeb, 2012). Although year to year droughts have been experienced in previous decades, the current decade (2005-2015) has seen floods of unprecedented magnitudes. In Zimbabwe, amongst all natural disasters, flooding is identified as the most frequent natural hazard (Reliefweb, 2000). It is one of the most devastating natural hazards which leads to the loss of lives, property, resources and the displacement of people. Flooding in most areas in Zimbabwe results from heavy rainfall periods which exceed the capacity of water bodies to store and convey excess water.

Flooding conditions are mostly experienced when the rainfall season is at its peak, which is around January and February. OCHA (2013) proposes that floods mainly affect low-lying areas of the country like Muzarabani and Mbire in Mashonaland Central, Tsholotsho in Matebeleland North, Gokwe North and South districts in Midlands and Chivi and Chiredzi in Masvingo. This is so because, water moves from higher ground to lower ground. Thus lower ground areas are a lot more likely to experience floods, riverine flooding is experienced in low-lying areas adjacent to streams and rivers.

Gokwe North district in the Midlands province is traditionally identified as a flood prone area in Zimbabwe. Floods have been frequent in the area for the past years. The area is frequently affected by seasonal flooding (OCHA, 2013), which occurs in most years normally in January or February, at the peak of the rainfall season. Expansion of rivers during the wet season poses a serious threat to lives, crops, livestock, property and cause damages such as collapse of bridges, destruction of schools and roads, destruction to water supply systems. There is need to have proper mechanisms in place for its mitigation and effective response.

Flood risk prediction is the act of forecasting or predicting the chances of a flood occurrence and the impact the flood will have on communities if it occurs. It identifies areas within a development that are at risk of flooding based on factors that are relevant to flood risks. This study suggests the use of remotely sensed data (satellite images and digital elevation models) to understand the probability of a flood occurrence and its consequences. Demirkesen et al (2007) assert that, the introduction of satellite remote sensing data has made easier the appreciation of geomorphological and geologic factors of floods, apart from the hydrological understanding available from meteorological and hydrological data. Satellite remote sensing is useful because of its high spatial resolution and capacity to provide information for areas of poor accessibility or lacking in ground measurements. Accordingly this solves the problem of inadequate data source in developing countries. In addition, use of remotely sensed data is an economical and efficient method for mapping flood hazard.

1.2 Statement of the problem

Floods have continued to cause damage to lives and livelihoods in Zimbabwe, and this has affected many communities across the country. Most communities are vulnerable to flooding and the consequences associated with it, but they are not sufficiently prepared in case of a disaster. Gokwe North district in the Sanyati catchment is a flood prone area. Its wards, Nenyunga (Ward 29) and Nembudziya (Ward 13, 23 and 24) are constantly at risk in cases of flooding along Ume, Sasame, Bvumbvudze and Sengwa rivers. In these areas consequences from previous flooding incidences include crop damage, property destruction, infrastructural damage, casualties and loss of life though to a lesser extent. Although there are problems already existing, it is also necessary to predict risk before a flood occurs. A flood risk is the probability of harm that a flood can actually cause and the potential consequences if it occurred. Flood risk prediction is the act of forecasting or predicting the chances of a flood occurrence and the impact the flood will have on communities if it occurs. The understanding of hazards associated with floods is fundamental for planning purposes. Ground measurements of precipitation and water flow or level can be used to assess the risks associated with flooding. In developing countries the hydro-meteorological data used to generate flood models is commonly insufficient, inaccurate and limited. Remote sensing data such as satellite images and digital elevation models (DEM) can be utilized in risk assessment because of their high spatial resolution and capacity to provide information for areas of poor accessibility or lacking in ground measurements (Ho et al., 2010). Moreso use of remote sensing data can prove to be an economical and efficient method. This study seeks to estimate the potential damage a future flood can cause in Gokwe North district.

1.3 Objectives of the study

1.3.1 General Objective

- To estimate the potential damage a future flood can cause in Gokwe North district.

1.3.2 Specific Objectives

- To establish the land use and land cover of Gokwe North district.
- To map areas with higher potential of flooding in Gokwe North district.
- To analyse the relationship between land use and flood risk in Gokwe North district.

1.4 Hypothesis

H_1 – There is a relationship between land use and flood risk.

H_0 – There is no relationship between land use and flood risk.

1.5 Justification/ Significance of study

Losses from natural disasters have dramatically increased during the last few decades, and in terms of economic losses, floods have been the most severe event type. Floods cause fatalities, loss of property, displacement of people and damage to the environment and the economic development. Many attempts have been done in the developed world to predict flood risk and reduce flood damage. On the contrary; in developing countries, few attempts have been done to predict risk. Flood management strategies in developing countries have been targeted towards compensation of people of the affected areas after a flood occurrence. Little attention is paid on formulating intellectual land use planning strategies to reduce flood induced disaster. Flood risk prediction identifies the areas at risk and estimates the potential damage a flood will cause in the identified areas. It is an important tool for appropriate land use in flood prone areas.

In spite of the fact that flooding cannot be completely prevented, its impacts can be reduced through appropriate planning and management. Destructive effects of floods on livelihood and property can be reduced by structural measures (dams and evacuation shelters) and non-structural measures (policies and laws, public awareness programmes, rescue operations, forecasting and early warning systems). In Zimbabwe flood prone areas are still being negatively affected by floods even though structural flood mitigation measures have been taken. Non-structural measures are mitigation and or adaptation measures that do not involve physical construction, but uses knowledge and practice to reduce risks and impacts of floods. Flood risk prediction would be a major step for implementing non-structural remedial measures.

The development of a flood monitoring model has so far been undertaken in Muzarabani (Murwira and Murwira, 2005), Chikwarakwara and Shashe (Rurinda, 2006). Undertaking of a process which moves along the same lines with these studies though focusing more on risk in Gokwe North will be of service in strengthening the implementation of non-structural measures aimed at reduction of flood damage in the study area. Efforts towards minimising the damage caused by floods will benefit the community. The community will benefit through reduced fatalities, damage to property and economic losses. Overall, this study will be a step towards reducing the burden of flood damage in Gokwe North district.

1.6 Study area

The study was carried out in Gokwe North district which lies between the latitudes 17° 31' 48" and longitude 28° 54' 36". The area is the northern part of the two administrative districts in Gokwe. Gokwe North district is located in the north-western part of Zimbabwe in the Midlands Province. The growth point for the district is Nembudziya.

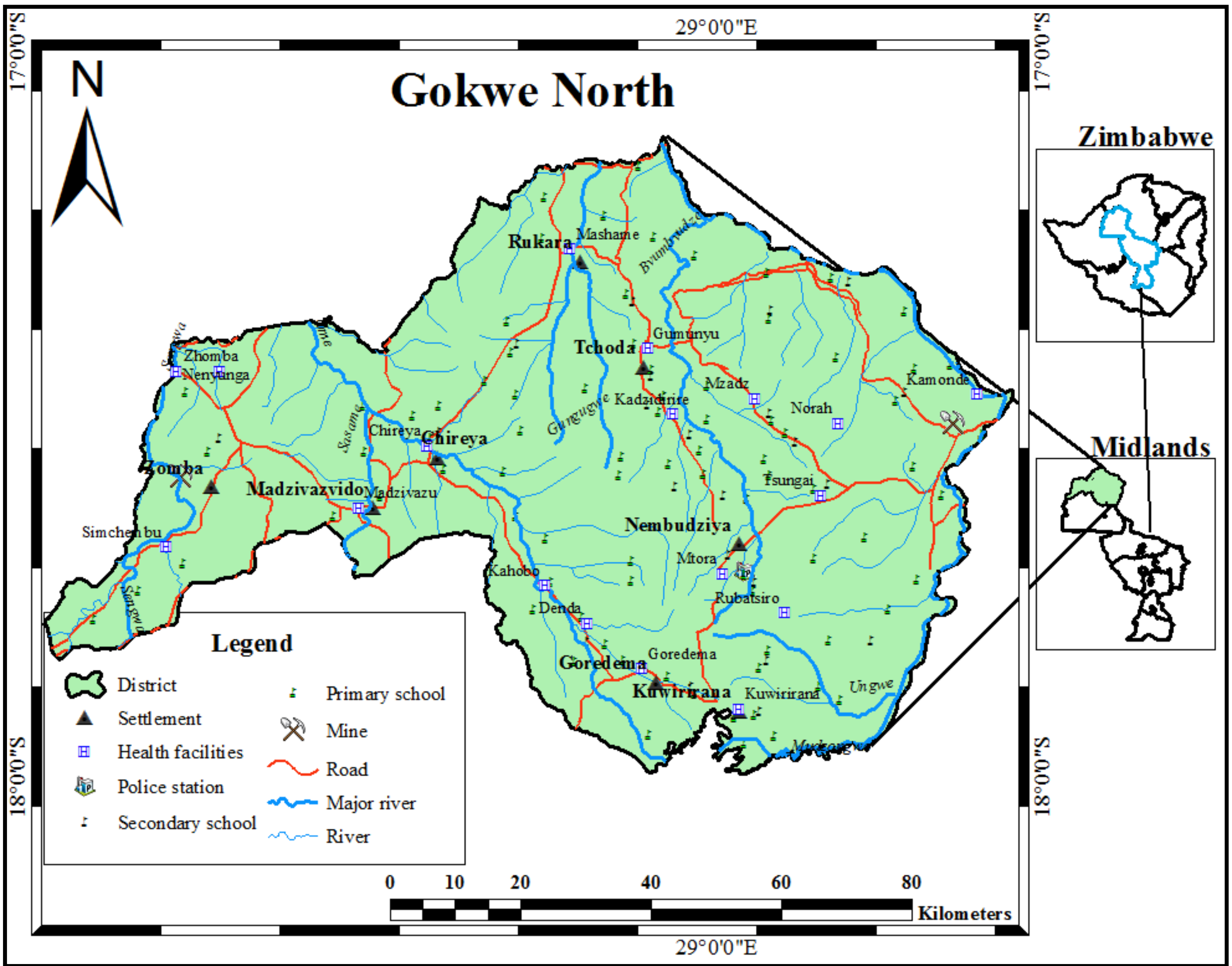

Figure 1.1: Map of Gokwe North district

(Source: Field work)

1.6.1 Physical characteristics of the study area

Gokwe North district is found in the Sanyati catchment. The district falls under agro-ecological region IV. The district experiences semi-arid to arid conditions. The annual rainfall for the area varies between 600mm to 800mm. Temperatures for the area range between 22°C and 34°C. The prevailing wind direction in Gokwe North district is South-east. The drainage pattern in Gokwe North is dendritic and has a number of major rivers which include Ume, Sasame, Gunguwe, Sengwa and Sanyati. The soils in the area vary from sialic, lithosols to sodic of which sodic soils are predominant. The sodic soils are inherently unstable and prone to gullying as well as extensive and severe sheet wash erosion. The soils together with the comparatively flat terrain support the growth of tree species such as *Acacia, Combretum* and the dominant species *Colopospermum Mopane.* Grass species include *Brachiaria* and *Eragrostis.* Landuse in the area vary from settlement, croplands, grazing lands and woodland. The area is surrounded by Chirisa forest in Gokwe South and Chizarira national park in Binga. Gokwe North is delimited by Sanyati River to the east. To the south it is bounded by Sanyati and Gokwe South districts. Kariba and Hurungwe border the district to its northern boundaries. To the western side, Gokwe North district is bordered by Binga.

1.6.2 Socio-economic description of the study area

Gokwe North district has an estimated population of 244 976 as of the year 2012 which is 1.9% of the country's total population (ZimStats, 2012). The proportion of male and female population is 48% and 52% respectively. The backbone of Gokwe North's economy is cotton farming. Though it is the hub of cotton farming, cultivation of other crops and livestock rearing are other farming activities done in the area. According to the Parliament of Zimbabwe (2011), cotton is grown for cash whilst maize, millet, sorghum and groundnuts are for domestic consumption. Even though food is available from commercial sources, older practices such as the growing of traditional crops like maize and operation of gardens close to water sources still remain important for household food security. Some villagers in the community operate gardens and sell their produce as a source of income to both locals and neighbouring cities like Kwekwe and Kadoma. In terms of livestock cattle, goats and donkeys are kept, cattle and donkeys have significant importance as they are used as draught animals. Due to harsh weather conditions and the decline of cotton prices on the market some villagers in Gokwe North district have resorted to brick moulding as a source of livelihood. The area is easily accessible; for road transport there is a wide range of public transport, for air transport there is an aerodrome for small private planes. The road infrastructure has however gone bad due to the frequently occurring floods.

CHAPTER TWO: LITERATURE REVIEW

2.1 Remotely sensed data

Congalton and Green (2008), define remotely sensed data as data that has been collected by a sensor that is not in direct contact with the area being mapped. Remotely sensed data is readily available in digital format in the form of aerial photographs, satellite imagery and digital elevation models amongst others and this makes it easy to edit for computer aided analysis. A digital elevation model (DEM) is a digital representation of a land surface in a computer (Skidmore, 1989). Mather and Tso (2009) endorse this definition by defining a DEM as a representation of terrain height variation. Satellite images are images of the earth captured by satellites at regular intervals (Chuvieco et al, 2010).

Information derived from remotely sensed data is mostly used in decision making processes. Congalton and Green (2008) state that, remotely sensed data is useful in diverse terrestrial and atmospheric applications such as environmental modelling and monitoring, land use or land cover mapping and the updating of geographical databases. In present day, remotely sensed data are being employed to provide users with maps of the spatial distributions of environmental features and phenomena and a means for monitoring changes in the world around us (Estes and Loveland (1999). Singh (1989) proposes that one of the major applications of remotely sensed data obtained from Earth orbiting satellites is change detection because of the repetitive coverage at short intervals and consistent image quality. A further feature of remote sensing applications in recent years which has shown encouraging results is the use of combinations of data derived from different sensors or from different time periods, plus terrain and other data extracted from geographic information system (GIS) databases (Mather and Tso, 2009).

2.2 Land use and land cover

Land use refers to man's activities on land which are directly related to the land (Clawson and Stewart, 1965). These man's activities or land use activities include agriculture, building construction, wildlife management and recreation. Land cover does not encompass land usage which comes under land use. Land cover basically refers to the interpretation of land features that are visible on the surface of the earth (Lillesand et al, 2014). Land cover classification includes land features like natural vegetation, rock outcrops, soil, water bodies and artificial constructions. Land use data are needed in the analysis of environmental processes and problems that must be understood if living conditions and standards are to be improved or maintained at current levels (Veerendra and Latha, 2014). Land use change may affect land cover, while changing land cover may similarly affect land use.

2.2.1 Land use and land cover change

Land use and land cover change (LULCC) is a general term for the human modification of Earth’s terrestrial surface (Rahman, 2013). Land use change is the alteration in the organization of land whilst land cover change is the alteration of the surface of the earth from one state to another. LULCC are widespread, accelerating and significant processes driven by human actions but also producing changes that impact humans (Agarwal et al, 2002). According to Giri (2012), LULCC can be characterized as conversion or modification. LULC conversion denotes the change from one category to another and LULC modification implies a change in condition within a LULC category. Land use and land cover change are strongly linked. The environmental impacts of land use change and their contribution to global change occur through physical processes associated with land cover change (Briassoulis, 2003).

As described by Guardiola (2009), land use and land cover change are a result of either anthropogenic intervention (deforestation, afforestation, urbanization, agriculture intensification) or climate variability. LULCC is a complex process which is caused by the mutual interactions between environmental and social factors at different spatial and temporal scales (Hassan et al., 2015). According to Ellis and Pontius (2007), LULCC can occur through the direct and indirect consequences of human activities to secure essential resources. An example of such an activity is the burning of land areas during a hunting expedition which clears land for other activities like agriculture and this will result in extensive deforestation. Demographic issues such as migration to rural or urban areas promotes land use change to built-up areas and cultivated lands. Agriculture promotes the conversion of natural forests into croplands as people aim to earn a living and generate income from subsistence and commercial farming respectively. Lack of regulatory laws on resource extraction also promotes change in LULC. Briassoulis (2003), points that without legislation resources may be over exploited, for instance, excessive deforestation can take place leading to conversion of natural forests to cultivated lands.

Some of the consequences of LULC change include, loss of biodiversity, climate change and pollution. Change of land from a primary forested land to a farming type, results in the loss of forest species within deforested areas (Ellis and Pontius, 2007). Guardiola (2009) assert that LULCC is responsible for the release of greenhouse gases to the atmosphere, thus global warming. This is largely attributable to the conversion of vegetated lands to built-up areas and croplands. Agricultural activities such as use of herbicides and pesticides release toxicants which when eroded by water pollute surface waters and cause damage to aquatic ecosystems. When these toxicants remain in the top soil they modify the pH levels of the soil thus reducing productivity of the soil (Nyamapfene, 1985).

2.2.2 Change detection

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Lillesand and Kiefer, 2000). Basically, it involves the ability to quantify temporal effects using multi-temporal data sets. Change detection involves the comparison of images from a given location at two or more points in time (Lefsky and Cohen, 2003). Singh (1989) proposes that one of the major applications of remotely sensed data obtained from Earth orbiting satellites is change detection because of the repetitive coverage at short intervals and consistent image quality. It shows the current state of land cover and how changes in land use might have enhanced environmental problems. Change detection has proved useful in land use change analysis, assessment of deforestation, analysis of changes in vegetation phenology, disaster monitoring, damage assessment and other environmental changes.

2.3 Flooding

A flood is defined as any high flow, overflow, or inundation of water that causes or threatens damage (O'Connor and Costa, 2004). According to Carter (2012), technically flooding is streamflow that rises above the stream banks and exceeds the capacity of the channel. Flooding is a high flow of water that causes economic loss or loss of life.

2.3.1 Causes of flooding

The increase in river discharge which causes water to overflow (flood) onto areas surrounding the channel (floodplain) can be triggered by several events. Flooding can occur owing to prolonged rainfall over several days, intense rainfall over a short period of time, or when water from an existing source moves too quickly (Willige, 2007). The most common cause of flooding in Zimbabwe and the world as a whole is prolonged rainfall (Murwira and Murwira, 2005). Floods occur when soil and vegetation cannot absorb all the water. Water then runs off the land in quantities that exceed the capacity of river channels, natural ponds and constructed reservoirs such as dams. Floods can occur in low-lying and flat areas.

2.3.2 Types of floods

Floods are generally grouped into the following types; flash floods, fluvial flooding, coastal flooding and urban floods. According to Carter (2012) floods can be described according to speed (flash flood) or the cause of flooding.

Flash floods are often the result of heavy rains of short duration. A flash flood is a very direct response to rainfall with a very high intensity or sudden massive melting of snow. According to Karamouz et al (2012), flash floods cover relatively small areas as compared to other types of floods. The concentration of water on a small area is high such that the water level rises fast on a small area. Flash floods are mostly caused by intense rainfall, dam failure and snow melt. Water in a flash flood travels at a very high speed and can carry with it heavy objects.

Fluvial or riverine floods are floods which occur when rivers overflow their banks and inundate areas that are normally dry (Willige, 2007). The water can cover enormous areas and areas downstream may be affected, even when these areas didn't receive much rain. In a situation where the overland flow reaches cultivated lands or areas with slumpy soils, it can result in a muddy flood. Riverine floods are mainly a result of sustained or intense rainfall.

Coastal flooding is caused by extreme tidal conditions including high tides, storm surges and tsunamis (Thompson, 1964). In simple terms, coastal flooding is when the coast is flooded by the sea. In a coastal flood the water level drops and rises with the tide (Karamouz et al., 2012).

As defined by Thompson (1964), urban flooding is the inundation of land or property in a built environment. Flooding in urban areas can be caused by flash, coastal or river floods. However in most cases urban flooding is a result of neither of these but instead it is caused by a lack of drainage in an urban area. It occurs when the sewage system and drainage canals do not have adequate capacity to drain away the amounts of rain that are falling. In urban areas there is often little open soil that can be used for water storage hence all the precipitation needs to be transported to surface water or the sewage system.

2.3.3 Effects of flooding

A flood is a natural event that can have far reaching effects on people and the environment (Powell, 2009). Effects of floods can be classified into primary, secondary and tertiary. Primary effects of floods are those associated with direct contact with water. Streams with higher velocities can damage houses and bridges. Humans that get caught in the high velocity flood waters are often drowned by the water. Erosion can undermine bridge structures and buildings causing their collapse. Flooding of farmlands in most cases results in crop and livestock loss.

Secondary effects of floods include services, health impacts such as famine and diseases. Drinking water supplies may be polluted, especially if sewerage treatment plants are flooded. This may result in disease and other health effects, especially in under developed countries. Transportation services may be disrupted as roads and bridges are inundated thus becoming difficult to cross or these may be swept away by floods. Prolonged floods interfere with drainage and economic use of lands (Carter, 2012).

Tertiary effects include changes in the position of river channels. Location of river channels may change as the result of flooding, new channels develop, leaving the old channels dry. Rapid runoff causes soil erosion as well as sediment deposition problems downstream. Sediment deposited by flooding may destroy farm land but silt deposited by floodwaters could also help to increase agricultural productivity.

2.3.4 Flood risk

A flood risk as defined by Carter (2012), is the probability of harm that a flood can actually cause and the potential consequences if it occurred. Risk is a combination of probability and consequences. The consequences may be victims and damage to homes, businesses and nature. For a risk to be probable, there has to be people, land features amongst other things that can be negatively affected by a flood otherwise in their absence there is no risk. If the probability of a major flood is high and the consequences are severe then there is a “high” risk. This is so because the flood would cause many casualties and a lot of damage. If the probability of a flood is small and the consequences are small then there is “low” risk. Some of the common flood risks include destruction of infrastructure, food shortages, decline in agricultural output, disruption of public services and disease outbreaks. In most places the risk of flooding is not constant throughout the year but varies seasonally (Futter et al, 1991).

2.3.5 Flood risk prediction

Flood risk prediction is the act of forecasting or predicting the chances of a flood occurrence and the impact the flood will have on communities if it occurs (Demirkesen et al, 2007). It identifies areas within a development that are at risk of flooding based on factors that are relevant to flood risks. Flood risk prediction also estimates the potential damage a future flood will cause in the areas identified.

In agreement with Yoshimura et al (2008), flood risk prediction can utilize two approaches that is qualitative and quantitative. Quantitatively, the risk is given a value and numerical expressions of risk are given. Qualitative approach does not assign values to risk levels. Instead risks are ranked and assigned into categories.

2.4 Role of GIS and Remote Sensing in risk prediction

Geographic Information System (GIS) is a system designed for the entry, management, analysis and presentation of georeferenced data (Estes and Loveland, 1999). Georeferenced data is data that has been assigned spatial coordinates such that it can be located in space or on earth. Spatial data stored in the digital data base of a GIS such as aerial photographs, digital elevation model and satellite images can be used to predict the effects of future events. GIS is one of the techniques that can be used in flood forecasting and management in order to reduce human and economic losses (Pawaringira et al, 2008). In this study GIS was used to map flood risk in Gokwe North District.

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand et al, 2014). Remotely sensed data is readily available in digital format in the form of satellite imagery and digital elevation models amongst others and this makes it easy to edit for computer aided analysis in a GIS. In this study remote sensing was used to obtain the terrain, establish LULC and to detect LULC changes in the study area.

According to Merchant and Narumalani (2009) GIS and remote sensing comprise the two major components of geographic information science (GISci), an overarching field of endeavor that also encompasses global positioning systems (GPS) technology, geodesy and traditional catography. The synergy that exists between remote sensing and GIS technologies is built on the foundation that, for many applications, remote sensing can be employed effectively and efficiently to update GIS data layers (Star et al, 1991). More so, data layers in a GIS can, when appropriately employed, improve the interpretability and information extraction potential of remotely sensed data. Many advances in LULC mapping are originating from new methods of analysis founded on integration of remote sensing and GIS. According to Pawaringira et al (2008), the integrated use of GIS and RS plays an important role in monitoring, controlling and assessing natural disasters, especially flood incidences.

The concept of predicting flood risk has been applied in many countries in the developed world. Most of these studies used statistical approaches and these made little or no use of GIS and remote sensing. In Japan, Yoshimura et al (2008) used a statistical approach to predict flood risk. The statistical approach perfomed a 29-year quality-consistent simulation of river discharge using observed surface meteorological forcings and a river discharge simulation system. In the United Kingdom, Futter et al (1991) also used a statistical approach to predict flood risk. This approach made a comparison of the cox regression and conditional distribution model.

In Zimbabwe, the concept of predicting flood risk has also been implemented. Though these attempts made use of GIS and remote sensing to improve real-time flood prediction and warnings, they largely focused on assessing flood damage. Pawaringira et al (2008) focused on understanding the nature of flooding in areas that are outside of streams in Tsholotsho. The study made use of logistic regression in a spatial database that had been developed in a GIS. The flood hazard maps that were produced from this research are used in mitigating flood damage. In 2005 Murwira and Murwira developed a flood warning model for Mzarabani in the Zambezi Catchment. The model used GIS and remote sensing to identify flood-prone and flood-safe areas in near real time. The model was multifaceted as it focused on a number of aspects, which are, flood hazard, flood risk, runoff conditions that constitute a flood and lastly rainfall and runoff indicators that can be used for flood early warning.

2.5 Research gap

Several attempts have been made to reduce the impacts of flooding at a global scale. In the developed world flood risk prediction is not a new attempt to minimize flood damage. Studies have been done in the United Kingdom by Futter et al (1991), in Japan by Yoshimura et al (2008), in America by Morss et al (2005) and in Germany by Apel et al (2009) to mention a few. On the other side; in developing countries, few or no attempts have been made towards predicting flood risk. This prompted the research to apply the concept of flood risk prediction at a local level in Zimbabwe.

In Zimbabwe flood risk prediction is still at its infancy. Studies which have been undertaken that are related to flood risk have largely focused on flood warning (Murwira and Murwira, 2005 and Gwimbi, 2007) and flood hazard modelling (Rurinda, 2006 and Pawaringira et al 2008). This study has similar intentions with these studies because it seeks to strengthen the implementation of non-structural measures in minimizing flood damage in Zimbabwe. The study seeks to provide flood warning like the model by Murwira and Murwira (2005), however it differs in the sense that it focuses mainly on flood risk prediction. More so, the research was conducted in a different location to test its applicability in a different environmental setting.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Design

De Vaus (2001) defines a research design as the overall strategy that the researcher chooses to integrate the different components of the study in a coherent and logical way. It ensures that the researcher effectively addresses the research problem. A research design forms the blueprint for the collection, measurement and analysis of data (De Vaus, 2001). Hatch and Farhady (1982) define a research design as a plan that describes how, when and where data will be collected and analyzed. Put simply a research design is a detailed outline of how an investigation will take place. It ensures that the evidence obtained enables the researcher to effectively address the research problem logically and as clearly as possible. This study heavily relied on quantitative research techniques as it used Remote Sensing and Geographic Information Systems (GIS) in most of its processes. GIS is an essential tool for analyzing and representing quantitative spatial data. According to Fraenkel et al. (1993) quantitative research is used to quantify the problem by way of generating numerical data or data that can be transformed into usable statistics.

Though the study relied heavily on quantitative techniques, the researcher found it crucial to complement it with qualitative techniques. This was done mainly to facilitate a deeper understanding of the flooding concept. Flood risk and damage analyses rely on qualitative and quantitative datasets with spatial distribution characteristics (Eleutério, 2012). The two research techniques assisted in bringing together environmental, engineering and socio-economic aspects of floods. Quantitative research instruments which include satellite images, digital elevation models (DEM) and field observations were helpful in collecting numerical and measurable data to explain observations of this research. On the other hand, qualitative instruments like interviews and archival documents were handy in gathering background information as well as information about the last flood that affected the district. Use of these instruments in conjunction guarantees a high level of reliability and validity of information gathered as the researcher got to understand flooding from two different perspectives.

3.2 Target Population

De Vaus (2001) defines a target population as the entire group of individuals or objects to which a researcher is interested in generalizing the conclusions. A target population as defined by Castillo (2009), is the whole group of individuals, that is, the main focus of a scientific query. A target population usually consists of individuals or objects that have similar characteristics or have common attributes that bind them together. It was on this group of individuals that the researcher carried out a study on, and it was primarily for the benefit of this population that research was done. In this study the target population comprised of the local people of Gokwe North District, the local chiefs in the community, the local authority Gokwe North Rural District Council and ZINWA (Sanyati Catchment). The researcher targeted the local people and the head of the community because they are the people who experience the floods each time they occur so they have information on the severity of the previous floods and how they affected their community. The rural district council is also part of the community, it is responsible for local planning and management of the district's infrastructure. Accordingly, the RDC would be helpful with information pertaining to infrastructural damage due to flooding. The researcher also targeted ZINWA (Sanyati Catchment) because it is the government entity responsible for managing the country's water resources. The parastatal's '*Hydrology Department'* captures, processes, analyses, archives and disseminates data pertaining to surface water resources hence it was useful in providing information for the flood risk prediction system.

3.3 Sampling Procedure

A sample is any part of the fully defined population (Trochim, 2006). A population sample makes it possible for the researcher to conduct the study to individuals from a population such that the results obtained can be used to come up with conclusions that can be applicable to the total population (Banerjee and Chaudhury, 2010). Research experiments or studies are usually carried out on a sample of individuals rather than the whole population. Population sampling as defined by Teddlie and Yu (2007) is the process of selecting a number of individuals from a population and use these selected individuals to test a hypotheses. The selected sample population will be a representative of the entire population. Banerjee and Chaudhury (2010) assert that a representative sample is one in which each and every member of the population has an equal and mutually exclusive chance of being selected. Researches are done for the benefit of the community, but due to the large sizes of populations a researcher cannot test every individual as it is time consuming and expensive thus the need for sampling strategies.

The researcher made use of the purposive sampling technique to gather data on flooding in Gokwe North District. According to Tongco (2007) the purposive sampling technique is a type of non-probability sampling that is most effective when one needs to study a certain cultural domain with knowledgeable experts within. Maxwell (1997) defined purposive sampling as a type of sampling in which particular settings, persons, or events are deliberately selected for the important information they can provide that cannot be acquired from other choices. The researcher saw this technique appropriate for the study because these knowledgeable experts in the target population had the information required and they knew the key issues about flooding in Gokwe North District. Purposive sampling may also be used with both qualitative and quantitative research techniques hence it was befitting to the study since both research techniques were used. Informants were deliberately chosen after considering their capability to provide required information.

3.4 Sources of Data

Data collection is crucial in research, as the data is meant to contribute to a better understanding of a theoretical framework (Bernard, 2002). To gather up information for the flood risk prediction system the researcher applied the triangulation technique in data collection. Triangulation as defined by Jick (1979) is the combination of methodologies in the study of the same phenomenon. Accordingly the researcher triangulated by combining primary and secondary sources of data in data collection. In this study the researcher obtained information through desktop research and field surveys. According to ITC (2010) in practice, it is always not feasible to obtain spatial data by direct capture as factors of cost and available time may be a hindrance. This study heavily relied on spatial data for information about the study area and analysis.

3.4.1 Primary Data Source

Primary sources are original materials on which a research is based (Storey and Jones, 2004). They are direct evidence concerning a topic under consideration. Primary sources of data present information in its original form, neither interpreted nor evaluated by other writers. Primary data is collected from the research population in a study area. This data can be obtained through interviews, field surveys, photographs, observation, statistics and scientific data to name but a few.

3.4.1.1 Satellite Image

Satellite images are collected by sensors on board a satellite and then relayed to earth as a series of electronic signals (Gopi, 2007). Historical satellite images for Gokwe North District were obtained through the U.S. Geological Survey’s Earth Explorer database (http://earthexplorer.usgs.gov/). The database provides remotely sensed Landsat imagery of the earth's surface free of charge for any intended use. The researcher used 2 Landsat images (path 171 row 72) for two different years (2013 and 2015). Landsat images are in most cases the most preferable because they can be easily obtained. Landsat imagery is good for identifying land use or land cover because the light spectrum used in capturing the images makes it easy to pick very minute detail and phenomenon on the earth's surface, hence the images are heavily enriched with detail. Table 3.1 shows dates of imagery for the downloaded satellite images and the dates they were accessed.

Table 3.1: Satellite image information

Image Number	Spacecraft ID	Sensor_ID	WRS PATH/ WRS ROW	Cloud Cover	Imagery Date	Date Accessed
1	Landsat_4-5	Thematic Mapper (TM)	171/72	0.00	14/11/2005	27/11/2015
2	Landsat_8	OLI_TIRS	171/72	0.00	10/11/2015	28/11/2015

3.4.1.2 Digital Elevation Model (DEM)

In this study the researcher used a Digital Elevation Model based on Shuttle Radar Topography Mission (SRTM) which provide data at 90m contour interval. The CGIAR-CSI (Consultative Group on International Agricultural Research - Consortium for Spatial Information) GeoPortal is providing corrected SRTM 90m digital elevation data for the near global coverage. The researcher acquired SRTM DEM for this project from CGIAR-CSI website (http://srtm.csi.cgiar.org/) since data from this site has been processed to fill voids and to facilitate its ease of use by a wide group of potential users. More so the data is currently free of charge to download thus being economical for the researcher. Jarvis et al., (2004) assert that SRTM derived DEMs provide greater accuracy than DEM derived from interpolation of topographic contours at 1:50 000 scale (Topographic DEM), but do not necessarily contain more detail.

3.4.1.3 Field Survey

Field surveys of natural or water resources are frequently carried out to check (ground truth) and supplement information derived from the interpretation of aerial photographs and satellite imagery. Ground truth is the accuracy of remotely sensed or mathematically calculated data based on data actually measured in the field (ESRI, 2014). Ground truthing is done in order to make corrections of data obtained from analogue maps such that it matches what currently exists on the ground. It also helps in verifying feature location. Often, sample areas are chosen within a study area for more detailed investigations. The researchers' field survey was comprised of interviewing local people and observations of land cover. The researcher made random land cover observations in areas in Gokwe North district to get an insight of land cover in the area and to ground truth what he had observed in satellite images. In the field, the researcher obtained data on land cover through physical observation and also made use of a digital camera to capture pictures at random sites. A Global Positioning System (GPS) was also used to get the geographic location of the random sites where land cover pictures were captured.

3.4.1.4 Interviews

During the field work, the researcher purposively interviewed informants who had access to the information needed and those who had firsthand experience of flooding in Gokwe North District. Those interviewed were the Hydrologist and the River technician at ZINWA's Hydrology Department and 3 local chiefs in Gokwe North District (chief Siamuchembu, chief Nenyunga and chief Chireya).These interviewees were either directly or indirectly linked to Gokwe North District thus were in a position to respond to the interview questions. Interviews helped in understanding the districts historical flood experiences, flood frequency, land use, flood severity and flood induced losses. Interviews were conducted with the selected participants using an interview guide with semi-structured questions. Apart from sticking to the semi structured questions, the researcher would also ask if the participants had any questions or comments to add to what they had been interviewed about. This assisted in closing down the interview as well as getting extra information which had been missed by the interview questions.

3.4.2 Secondary Data Source

Secondary data are derived from existing sources of information and have been collected for other purposes, often not connected with the investigation at hand (ITC, 2010). A secondary data source is an already existing source of information. These analyze, evaluate and interpret information contained within primary sources. Such sources of information include official statistics, government reports, web information, historical data and previous research on similar research areas.

3.5 Data Analysis and Presentation

Data analysis means to organize, provide structure and elicit meaning. Data analysis commenced concurrently with data collection as some of the data collection techniques such as interviews were meant for verification and validation of analyzed data. In the analysis of data collected the researcher mainly intended to establish the land use and land cover (LULC) of Gokwe North District and identify areas with higher potential for flooding in the district. This helped to establish the relationship between land use activities and flood risk.

3.5.1 Image processing and classification

Land use and land cover (LULC) of Gokwe North District was established through the classification of satellite images. Before classification, Landsat images were pre-processed to normalize them so as to allow quantitative comparison between images. The images for 2005 and 2015 were first calibrated, layer stacked, classified and then analyzed for accuracy in ENVI 5.1. The calibration process sought to convert digital numbers (DN) to reflectance. After being calibrated, layer stacking process was performed on the two images. Landsat scenes are made of separate bands of data, each representing a section of the electromagnetic spectrum. These bands are useful in identifying features of interest. The researcher created a composite image by merging bands that are useful when looking at LULC and these are the red, green and blue (RGB) bands. According to ITC (2010) in Landsat 4-5 (TM) and Landsat 8 OLI, the green band is useful for assessing plant vigor because it emphasizes peak vegetation, blue band is useful for bathymetric mapping because it distinguishes soil from vegetation and red band discriminates vegetation slopes.

A subset image of Gokwe North District was created by overlaying and masking the RGB composite layer with a shapefile of the district. Unsupervised classification of the subset image was executed using ENVI 5.1 to establish LULC of the district. The images were classified into a maximum of 20 unsupervised classes from 5 iterations using the K-Means algorithm. Color mapping was performed to further subgroup the LULC classes into four general classes and this was derived from visual interpretation of the 20 unsupervised classes.

Post classification was performed to assess accuracy of the classification process, detect changes in LULC and compute statistics. Accuracy assessment of Gokwe North District classification was done using ground reference points. Ground truth regions of interest identified during field observations were used to measure the accuracy of the classified maps. The classified images were then exported as shapefiles to ArcGIS which was to produce map layouts of LULC in Gokwe North District. The classified images were analysed using change detections and computed statistics were analysed in SPSS.

3.5.2 DEM processing and risk mapping

Flood risk mapping was achieved through DEM processing and quantifying risk. To isolate Gokwe North District in the DEM, DEM data was clipped in ArcGIS 10.1 using the raster processing tool in spatial analyst. The clipped DEM raster was exported to ILWIS 3.3 for hydrological processing and risk mapping. To identify areas with greater potential of flooding the researcher mapped flood risk in ILWIS. With the objective of producing a flood risk map the researcher had to first quantify risk. Risk was quantified to get an estimate of the potential damage a future flood can cause to land features. This was achieved by awarding values to LULC classes with respect to their importance. Built up areas are the most valuable since they provide housing to people and are the location of infrastructure which is likely to be at risk. Cultivated land is second in importance because the crops are a source of livelihood. Vegetation is third because it contains natural forests, natural habitats and grazing lands. Last but not least in terms of importance was area covered by water. After being quantified, flood risk was mapped using the slicing image processing method.

3.6 Research Ethics

During the research process the researcher remained obedient to the system of principles governing morality and acceptable conduct. The researcher obeyed the law and maintained confidentiality and anonymity at all levels of the research. Satellite images were obtained from the U.S. Geological Survey's Earth Explorer database (http://earthexplorer.usgs.gov/). The website hosts a database where individuals are allowed to download data for free after registering and creating an online account on the database. The researcher complied with these requirements and registered an account through which he was able to download satellite images for use in this study. A Digital Elevation Model was accessed from CGIAR-CSI (Consultative Group on International Agricultural Research – Consortium for Spatial Information) website (http://srtm.csi.cgiar.org/). The CGIAR-CSI GeoPortal provides corrected SRTM digital elevation data for free.

The researcher also conducted interviews as a method of data collection. Before carrying out the interviews, the researcher first sought permission from the local authorities to conduct interviews in their area. In carrying out the interviews the researcher would first brief the interviewee about the project being carried out and the reasons why they were being interviewed. More so, before being interviewed the interviewees were asked to sign an ethics form. The ethics form was signed as proof that the interview was conducted with the interviewees' consent and no one was forced to answer any questions or to be interviewed. Anonymity and confidentiality of participants was respected, interviewees were assured that information they provided would not be traced back to them in any form of dissemination.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Demographic characterization of respondents

4.1.1 Gender of respondents

Eight interviews were executed and responses to the interview questions were analyzed. All of the interviewees, that is, the chiefs and hydrologists were male and no female was found in the position of the targeted interviewees. Overall, the whole community whose grievances were presented to the researcher by those interviewed consists of 118 181 males and 126 795 females. Even though all the responses were from male respondents these results do not have a masculine bias. Those interviewed stood as representatives of the whole community and they are the knowledgeable experts who are in key positions that could provide flood related information about the district.

4.1.2 Age of respondents

Age of respondents was not really a crucial issue in the research. What mattered most was that the respondent was in a position capable of having access to the information needed. However in the case of the Chiefs interviewed, age was important, the older the chief was, the more he was believed to have diverse flood experience in the community and could retell how it occurred and its effects. All of the interviewed chiefs were above 6o years of age whilst other interviewees were in the 31-40 age group.

4.1.3 Level of education

All of the respondents had managed to achieve a certain level of education even though others had gone further than others. All chiefs had managed to get primary education and only one had managed to get secondary education. Other respondents who were in positions gained through academic excellence had all obtained tertiary education, with the highest being a university degree. Majority of the interviewees are married, though a few are widowed.

4.2 Current land use and land cover of Gokwe North District

This data depicts an estimate of the current LULC of Gokwe North District. It covers the period from the date of the latest classified image to present, that is, from 2015 to 2016. Land use and land cover maps of Gokwe North District were created from unsupervised classification. The spatial extent of LULC in the district after satellite image classification for both years (2005 and 2015) brought forth LULC classes. The satellite images were categorized into four classes, i.e. vegetation, cultivated land, built up area and water. Table 4.1 shows the LULC classes and their descriptions.

Table 4.1: Land use/ land cover classes and their description

Class number	Class name	Description
1	Vegetation	Areas that are covered by trees, shrubs, and grass such as forests, riparian zones, woodlands, grazing lands and grasslands.
2	Cultivated land	Land used for cultivation purposes and fallow lands.
3	Built up area	Settlements, buildings and roads.
4	Water	Rivers, tributaries, streams and water channels in the area.

4.2.1 Land use and land cover analysis of Gokwe North District

Table 4.2 shows the current LULC distribution for Gokwe North District. From the study it was revealed that the major LULC category in Gokwe North District is vegetation.

Table 4.2: LULC distribution for Gokwe North district

Class	Area (Km^2)	Percentage of total area
Vegetation	2680.76	36.88
Cultivated land	2479.39	34.11
Built up area	1714.88	23.59
Water	393.96	5.42
Total area	7268.99	100

By means of unsupervised classification the researcher was able to establish the areas covered by each LULC class and its percentage of the total area of Gokwe North District. Among these LULC classes vegetation and cultivated land occupy higher percentages of the total area in the district. Water covers the least area in the district as it only covers 5.42% of the total area.

4.2.2 LULC status of Gokwe North District in 2005

Figure 4.1 is a map produced from unsupervised image classification for Gokwe North District in 2005. The map shows the densities of each LULC class in the district in 2005. The classification results (Figure 4.2) indicate that vegetation, cultivated land, built up area and water occupy 4 813.88, 977.61, 1 013.69, 463.81 km^2 of area respectively.

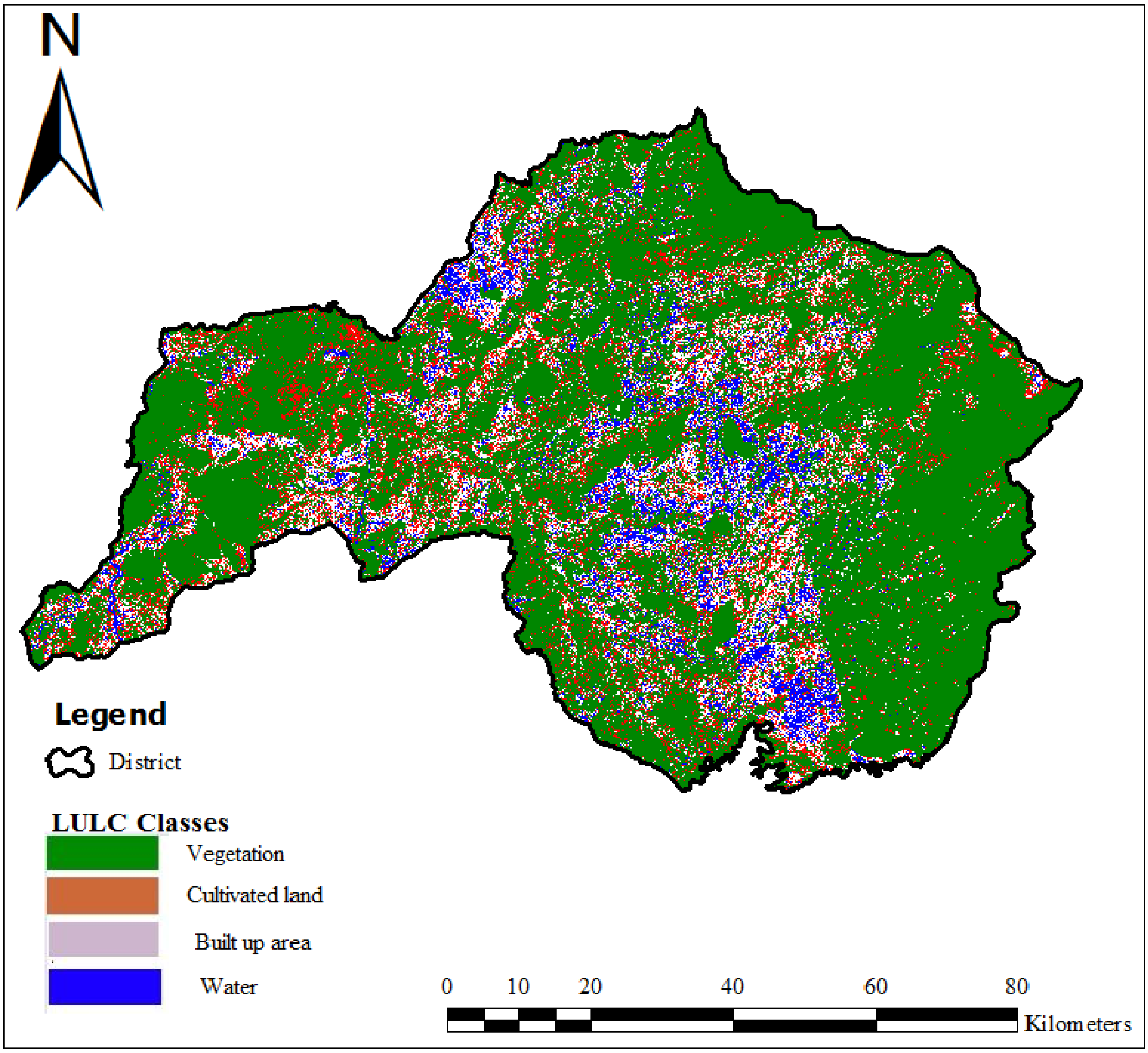

Figure 4.1: Unsupervised classification LULC map of Gokwe North District in 2005

(Source: Field work)

Figures 4.1 and 4.2 reveal that in 2005 about 66.22% (or 4 813.88 km2) area of Gokwe North District was under vegetation, 13.45% (977.61 km2) under cultivation, 13.95% (1 013.69km2) under built up land and 6.38% (463.81 km2) was buried in water. Density of areas under vegetation as shown in Figure 4.1 was easily noticeable in all parts of Gokwe North District. Concentration of cultivated lands was more pronounced at the central part and extending to the western part of the district. Built up land was sparsely distributed in the district and had no specific areas of greater concentration. Concentration of water bodies are more pronounced in the south-eastern part extending northwards in the western direction of the district.

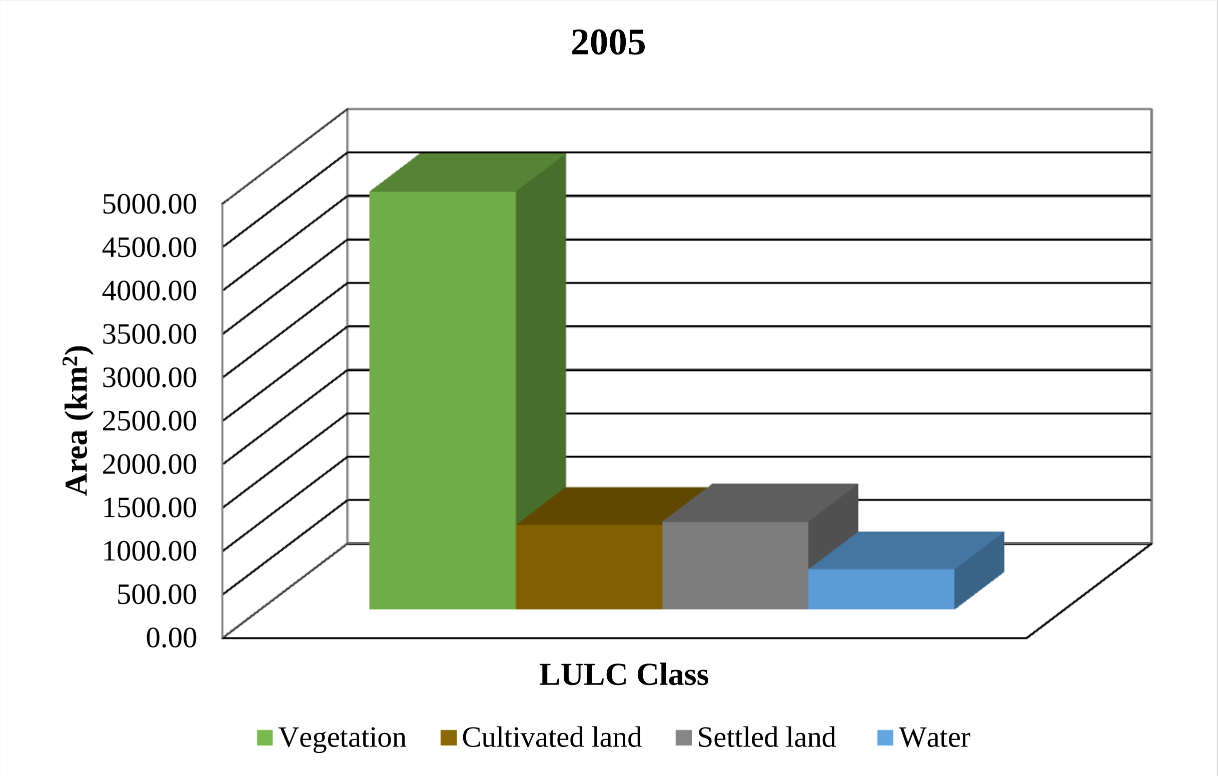

Figure 4.2: 2005 LULC classes areas in km2

(Source: Field work)

4.2.3 LULC status of Gokwe North District in 2015

The satellite image of 2015 was categorized into the same type and number of classes as that of 2005 such that post image classification became possible. Figure 4.3 shows the densities of each LULC class in the district in 2015. The classification results (Figure 4.4) indicates that vegetation, cultivated land, built up area and water occupy 2 680.76, 2 479.39, 1 714.88, 393.96 km^2 of area respectively. Figure 4.3 and 4.4 reveal that in 2015 vegetation and cultivated land had larger areas in the district. There is a slight difference of 2.77% between the percentage areas of these two LULC classes. Built up area has a low percentage cover, however the least percentage area (5.42%) is buried under water.

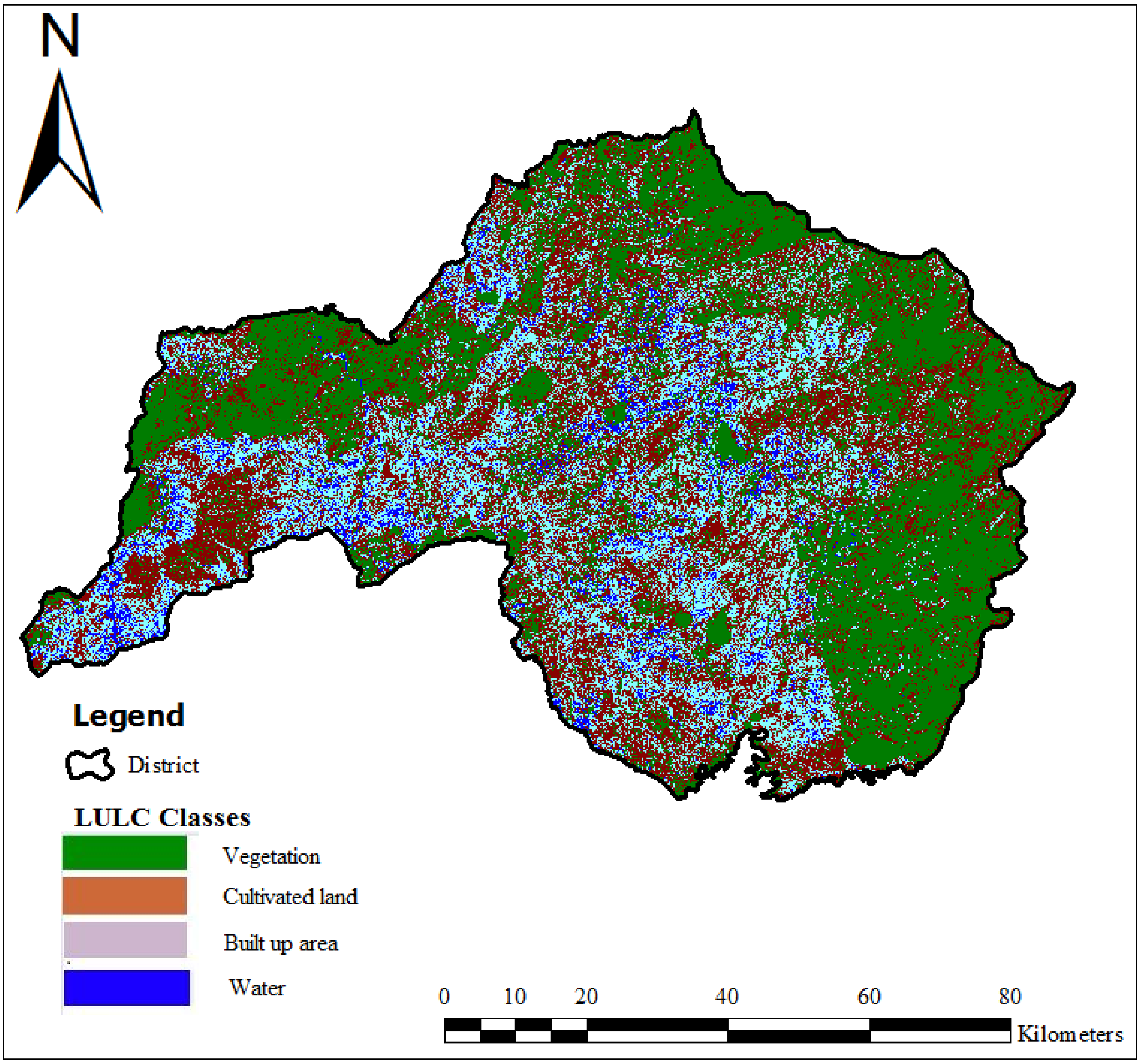

Figure 4.3: Unsupervised classification LULC map of Gokwe North District in 2015

(Source: Field work)

Vegetation occupies the highest percentage of the study area and its density as indicated on Figure 4.3 is more pronounced in the south-eastern part stretching along the districts borders to the northern and upper north-west part of the district. Concentration of cultivated land is now more noticeable all over the district but it is heavily concentrated on the lower north-western, top north-eastern and the northern part of the district. The resettlement of people after the fast track land reform to part of Chirisa Game Park was a contributor to the extension of cultivated lands in this direction. Built up land though still sparsely concentrated have become more easily noticeable to the southwestern and northeastern part of the district. Increase in built up area size is attributable to resettlement which caused people to occupy land in once unsettled areas and start building homes and other infrastructural services there. Water occupies the lowest percentage of the study area but still remains heavily concentrated in the south-eastern part extending in the north-west direction of the district.

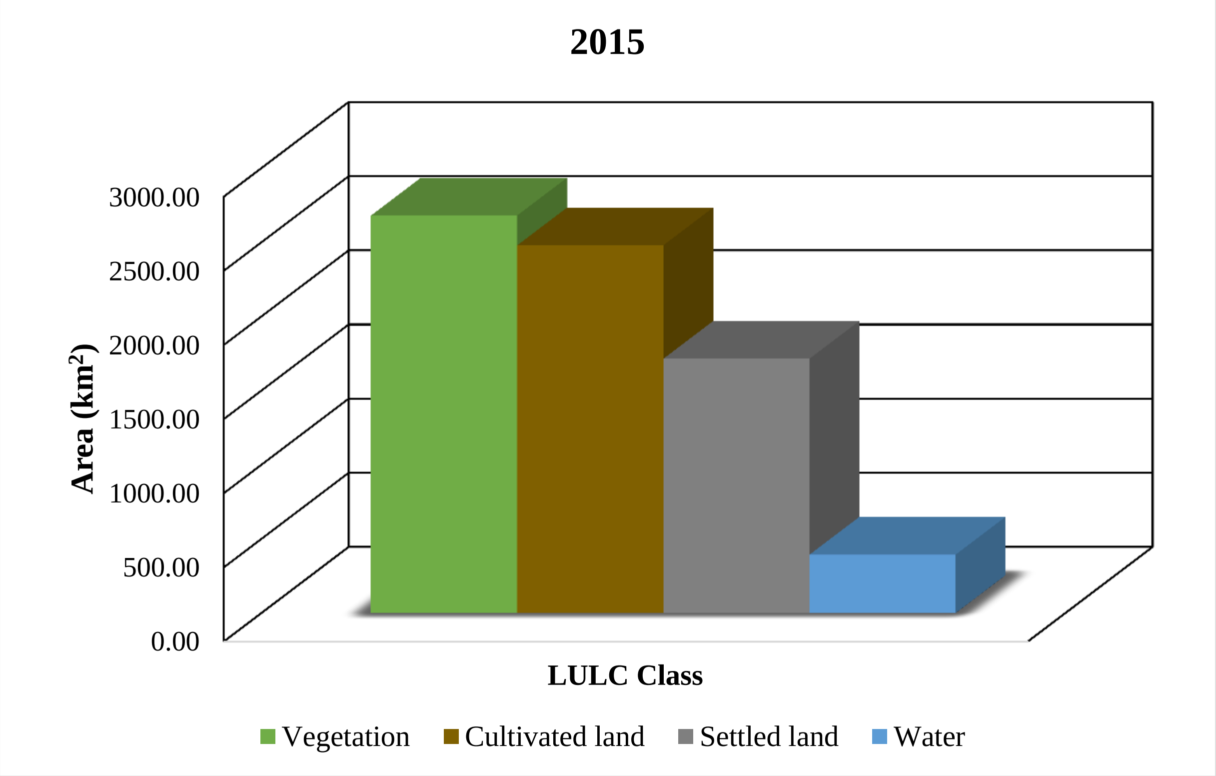

Figure 4.4: 2015 LULC classes areas in km2

(Source: Field work)

4.2.4 Land use/ Land cover accuracy assessment

Confusion matrix was used to check accuracy of the classified images by comparing the classification results with ground truth images. Images were captured by the researcher during the field visits. These were scenic images of places in the district which were captured at random points. These images were later used to calibrate remotely sensed data, they also assisted in the analysis and interpretation of data from Landsat imagery. The researcher also used high resolution imagery from Google Earth as reference data sets (test ROIs) for assessing accuracy of the satellite images.

4.2.5 Land use/ Land cover change between 2005 and 2015

To calculate change detection the researcher computed the difference by subtracting the initial state area from the final state area (that is, *final state – initial state*). A positive change means that the LULC class gained area while a negative change means that the LULC class was reduced in area. The LULC changes deduced from comparison of classified satellite images for the years 2005 and 2015 are presented in Table 4.3 and on Figure 4.5.

Table 4.3: LULC results of the study area and comparison of both the years 2005 and 2015.

Class	Initial state (2005)		Final state (2015)		Relative change	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Vegetation	4813.88	66.22	2680.76	36.88	-2133.12	-29.34
Cultivated land	977.61	13.45	2479.39	34.11	1501.8	20.66
Built up area	1013.69	13.95	1714.88	23.59	701.19	9.64
Water	463.81	6.38	393.96	5.42	-69.85	-0.96

These classification results indicated that in the last decade, from 2005 to 2015, cultivated land and built-up area of Gokwe North District have increased at the rate of 20.66% and 9.64% respectively. On the other hand, it was deduced that areas under vegetation and water have lessened by about 29.34% and 0.96% respectively.

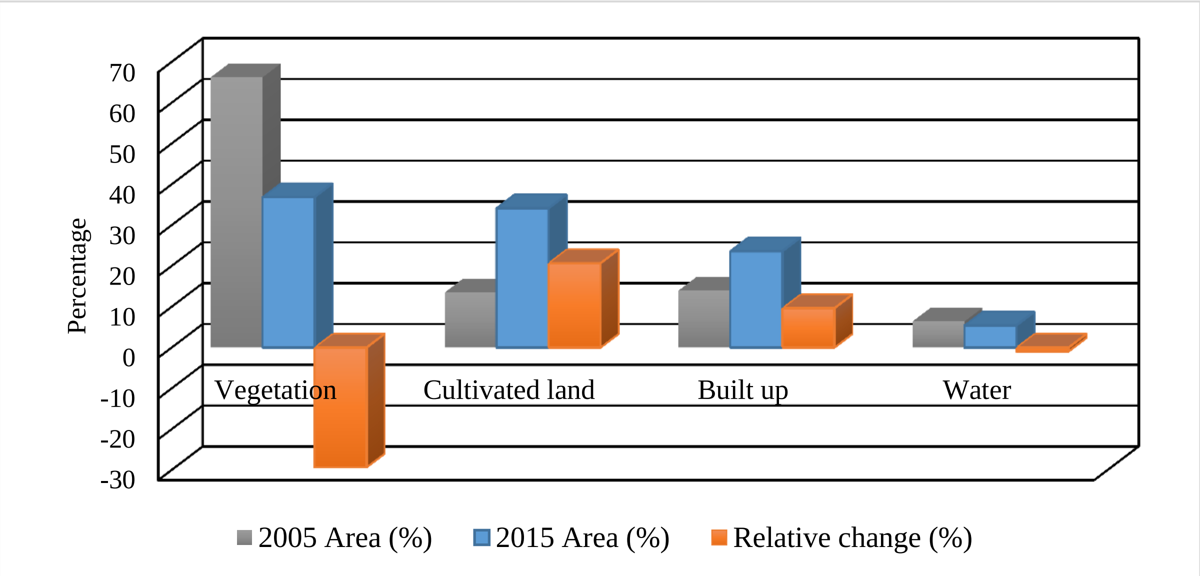

Fig 4.5: LULC comparison of both years and relative change as a percentage.

(Source: Field work)

Cultivated land had significant gains as it increased by 20.66% (1501.8 km^2) in area. Cultivation experienced major gain at the expense of other LULC classes. Owing to the desire of community members to increase the size of their fields for farming, cultivation was observed to be extending into the area of vegetation and water. Cotton farming is a main income generating activity in the district and it is the major reason for extension of cultivation lands.

An increase was also observed in built-up area as it gained space by 9.64% (701.19 km^2). This increase is for the most part attributed to infrastructural development on once vegetated lands. Development of the district has seen the construction of infrastructure in the form of roads, bridges and emergence of new buildings such as schools, clinics, houses and shops. The fast track land reform programme saw people in Gokwe North District being resettled to less crowded areas. In 2012 Gokwe North District acquired 25 000hectares of land from Chirisa Game Park located on the southwestern part of the district. 700 families crowded in areas under chiefs Sayi, Nemangwe and Chireya benefited from the programme. Accordingly a part of the game park which was once vegetated was converted into a built-up area.

Vegetation cover experienced the greatest loss of -29.34% as it reduced from 4 813.88 km^2 in 2005 to 2 680.76 km^2 in 2015. LULC of vegetated land is largely due to land clearance and conversion to another land use such as croplands. The decrease in vegetation cover is due to deforestation activities through which vegetated land was converted into cultivated and built up land. This coincides with Ellis and Pontius (2007) affirmation that, change of land from a primary forested land to a farming type results in the loss of forest species within deforested areas. It was noted from the interviews in the district that as people accumulate wealth their livestock units tend to increase for they see livestock as an investment option and also make use of cattle in their farming activities. This increase in livestock ownership resulted in overgrazing of the available pastures as the livestock herds exceeded the carrying capacity of the grazing lands thus reducing vegetation cover.

A slight decrease of -0.96% was observed in water. This can be attributed to siltation of rivers and other water bodies in the area. Extension of cultivated land into areas near water also encourages erosion of the soil loosened during land preparation processes and this eroded soil increases the surface area of water as silt. The reduction of vegetation cover also contributed to the increase in surface runoff and in turn the rate of soil erosion rose hence enhancing siltation of water reservoirs. This corresponds with Ellis and Pontius (2007) who stated that

LULCC can occur through the direct and indirect consequences of human activities to secure essential resources.

4.2.6 Factors influencing land use and land cover change

From unsupervised classification of Landsat images, interviews and field observations the researcher was able to deduce a couple of factors causing land use or land cover change in Gokwe North District. Some of these factors are population growth, agriculture, infrastructural and commercial development, deforestation and soil erosion. These support Guardiola (2009) assertion that land use and land cover change are either a result of anthropogenic intervention or climate variability.

Agriculture is the major economic activity in Gokwe North District, as confirmed by Chief Nenyunka, Simuchembo and Chireya in interviews conducted. Leading agricultural activities are cotton farming and livestock rearing. During field visits, the researcher observed that a large number of farmers in Simuchembo and Mubila villages of Gokwe North District left certain pieces of their farming land idle and these would be used as pastures for their livestock. This is one cause of the extension of cultivated land over the decade because farmers are stretching their farming lands into vegetated areas to create space for grazing their livestock inside their fields. The chiefs also said they are continuously distributing land to community members who will be congested in certain areas and need land to farm on. This corresponds with Verbeek and Jackson (1995) observation that floodplains support agricultural activities because of moisture availability and nutrients which encourage recession agriculture therefore supporting and improving livelihoods especially in rural areas. This attracts people to floodplains and this explains why the majority of households and farming lands are located near streams. Some of the land allocated to people include forestland, grasslands and vegetated areas along streams thus deforestation comes into the picture. Agriculture has a direct link with deforestation because there is the cutting down of trees and destruction of vegetation during land preparation processes.

The population of Gokwe North district has grown from 214 359 people in 2002 to 244 976 people as of the year 2012 (ZimStats, 2012). Population growth imposes pressure on the community to seek more space to settle on and farm. As a result of the increase in settled land due to population growth, more livestock units are kept by the people and this has a negative effect on vegetation as it promotes overgrazing.

For the past decade, Gokwe North district has been developing and it is still developing. Even though the rate of development is slow, infrastructural and commercial development is taking place in the district. Chief Simuchembo confirmed that built-space was indeed a growing land use category as he is often distributing land to locals or external investors who use it to build clinics, churches and entertainment places amongst other uses.

Soil erosion by water is another cause of LULC in the district. Erosion rates are high in Gokwe North District, top soils have been eroded to the extent that gulley's are formed especially on roadsides. Erosion is mainly a result of deforestation which leaves surfaces bare and fragile to surface runoff which washes away top soil. Soil erosion is also a factor of slope, in relatively flat areas erosion is moderate. On steep and low lying areas near Nenyunka and Sengwa, erosion is severe as evidenced by gulleys formed and silt evident in rivers.

4.3 Flood risk mapping in Gokwe North District

Figure 4.6 shows the proportion of flood risk in the area. Gokwe North District as a whole is at greater risk from flooding since a larger percentage of the area is bound between the 'very high risk' and 'high risk' categories. A smaller percentage of the district is slightly safe from flooding and these are mainly highlands. More often than not areas under LULC categories like vegetation, cultivation and built up areas are at greater risk from flooding. This could be attributed to the areas being low lying and close to rivers that always flood.

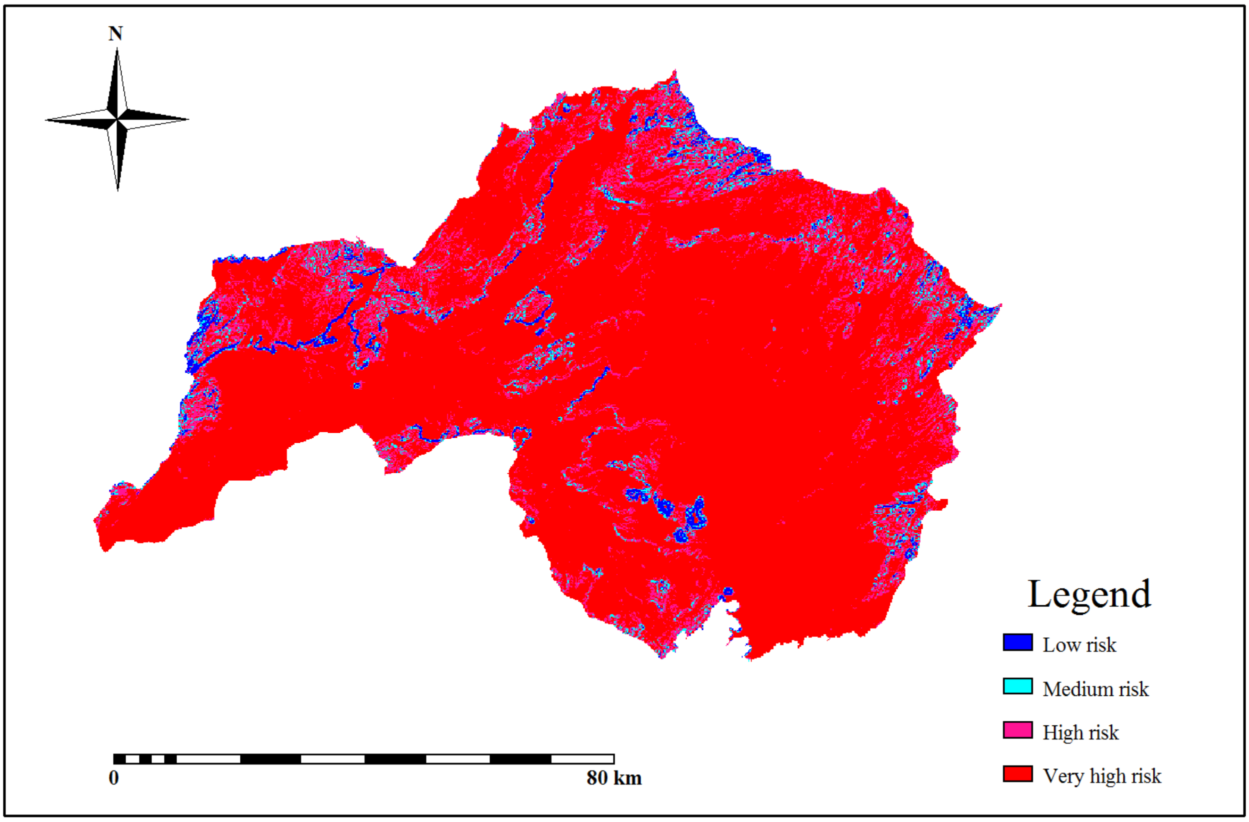

Figure 4.6: Flood risk prone areas in Gokwe North District

(Source: Field work)

4.3.1 Flood risks in the area

The results indicate that the highest risk imposed on people in Gokwe North District by flooding is the lack of accommodation. During and after a flood event water may cover the ground such that huts may collapse or get washed away. People sheltered by these huts are negatively impacted on as they become homeless. In the flood of 1997, Zunguzira, Mugombiro and Chazengwa villages had 20, 56 and 49 households destroyed respectively. From the interview one chief recalled that in 2013 in Nenyunka village about 50 households were affected by flooding. Another Chief reported that when Sengwa River burst its banks, homesteads and crops were washed away.

Loss of accommodation also leads to loss of property and lives because people and property will be sheltered in these homes when the flood occurs. As described by respondents in the interviews, livestock, croplands and huts used for food storage may be destroyed causing food shortages in the community. In Kudyawabaya village under chief Chireya, vehicles were swept away at bridges, people and animals drowned in attempts to cross flooded rivers and roads. Chief Simuchembu claimed that people drowned in attempts to cross flooded bridges during the flood of 1997 which is the most high risk flood that affected the area.

Decline in agricultural output is another flood risk in Gokwe North District. Water in motion can flatten or uproot crops, or cover them with silt. Heavy rains and flooding caused major damage to agricultural lands by washing away crops or leaving them heavily damaged. As reported by the Department of Civil Protection (DCP), in January 2013, in Ward 29 (Nenyunka), 50 households lost their entire maize crops, some livestock and farming equipment at their irrigation site along Sengwa River. This corresponds with Powell (2009) who stated that flooding of farmlands in most cases results in crop and livestock loss.

Since much of the ground will be covered in water, waterborne diseases outbreaks have become common in the district. Periods with standing water (inundation) create breeding grounds for mosquitos and from these malaria is spread throughout the district. The prevalence of malaria in Gokwe North District has led to an increase in mortality rates in the area. Animals died due to foot and mouth diseases.

Flooding also disrupts public service facilities such as schools, clinics, dams, bridges and roads. This coincides with Carter (2012) observation that prolonged flooding interfere with drainage and economic use of lands. Chief Chireya alleged that six primary, four secondary schools and a clinic were damaged. From these schools teacher's houses and laboratories were destroyed. Other institutions that faced enormous damage are Chitekete ZRP offices, Gokwe North RDC, Kadzidirire Rural Health Centre and D.D.F offices. Roads and bridges are washed away or become impassable as they are buried in water. A bridge in the Tadzimirwa area under Chief Goredema was damaged by floods in 2000. Most interview respondents were in agreement that most bridges in the community were damaged by floods, especially Cyclone Eline of 2000. This affects the community as they become unable to access crucial services such as clinics and schools for children. More so damage to roads makes the flooded zones remote and it becomes difficult for relief to reach these areas as they are inaccessible.

4.3.2 Areas with high potential of flooding in Gokwe North District

A greater percentage of Gokwe North District is prone to flooding. This is so because the district is generally a low lying area with many rivers that easily fill up beyond bank full discharge. Figure 4.7 shows the direction of flow of water in the district. Much of the water is flowing into the district and this is because rivers in Gokwe North are tributaries being fed by major streams in the Sanyati Catchment such as Sasame, Sanyati, Ume, Bvumbudze and Sengwa. The combination of water flowing mostly into the area and the area being low lying leaves the whole district with higher potential of flooding.

Gokwe North District generally has poorly drained and slumpy soils and in the event of heavy rainfall, these soils easily fill up beyond their capacity hence permitting soil erosion and accumulation of silt in rivers. From field observations, the researcher discovered that the soils in Gokwe North District vary from sialic, lithosols to sodic of which sodic soils are the predominant type. In accordance with Nyamapfene (1985), sodic soils are slumpy and subsequently unstable and are poorly drained since they are less permeable. Due to their low permeability the infiltration rate of these sodic soils is quite low similar to that of clay loam soils. These characteristics make the soils more vulnerable to severe sheet wash erosion and gullying. Chief Nenyunka said that in his area Zhomba has a huge gully about 75 meters wide and is still increasing due to lateral and headward erosion. From the interviews with the chiefs in the district, it can be concluded that Gokwe North District oftentimes receive late rains and these will be heavy rains which inturn flood the area.

Low lying areas and those near rivers are at greater risk from flooding as the rivers always fill up beyond their capacity and overflow onto dry land on every heavy rainfall occasion. This matches the discovery by OCHA (2013) that floods mainly affect low lying areas of the country like Mzarabani, Mbire, Gokwe, Tsholotsho and Chivi. Areas such as Sengwa, Simuchembo, Zomba, Madzivazvido, Chireya and Goredema have greater potential of flooding due to their proximity to Sengwa, Sassame and Ume rivers. In previous flooding incidences in these areas, farming lands, roads and bridges were eroded away. In one flood incident, Sengwa River burst its banks, washed away crops and homesteads and people had to be evacuated to higher ground. Sengwa and Ume rivers are highly silted owing to their location in low lying areas and enhanced runoff generation as water moves downslope. Accordingly these rivers easily get flooded and in most cases livestock, crops and homes are washed away by floods.

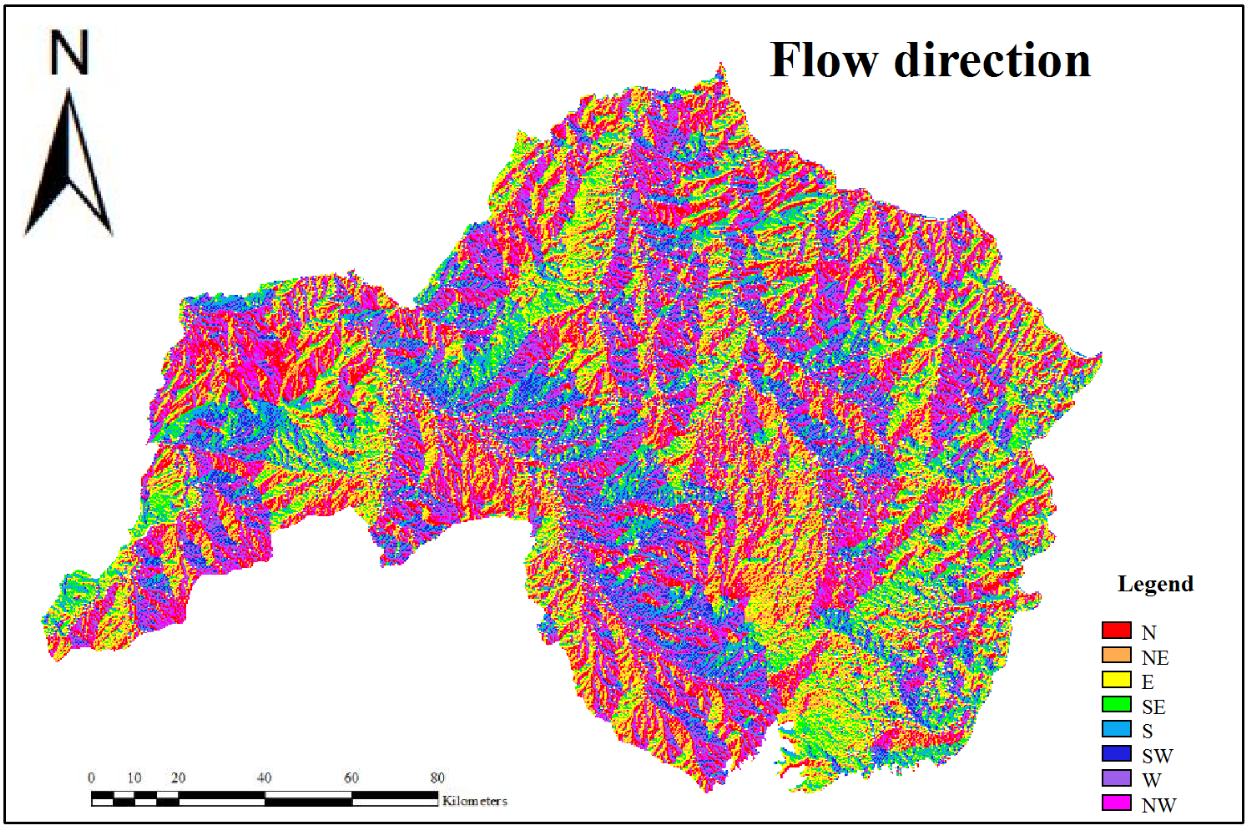

Figure 4.7: Flow direction of runoff

(Source: Field work)

4.3.3 Relationship between land use and flood risk in Gokwe North District

To analyse the relationship between LULC and flood risk, the researcher statistically tested these two variables after mapping them. Flood risk was quantified to get an estimate of the potential damage a future flood can cause to land features. Risk was quantified by giving LULC classes values with respect to their importance. Built up areas are the most valuable since they provide housing to people and are the location of infrastructure which is likely to be at risk. Cultivated land is second in importance because the crops are a source of livelihood. Vegetation is third as it contains natural forests, natural habitats and grazing lands. Last but not least in terms of importance was area covered by water. The cross tabulation of the two variables, LULC and flood risk, is given in table 4.4.

Table 4.4: LULC and Flood risk cross tabulation

LULC Class	Flood risk			
	Low risk	High risk	Very high risk	Total
Vegetation	1	0	0	1
Cultivated land	0	2	0	2
Built up area	0	0	4	4
Water	1	0	0	1
Total	2	2	4	8

The cross tabulation was made on the basis of interviewee responses and field observations. From these, it was observed that all LULC classes are at risk from flooding. Built-up area in particular is more vulnerable to flood risk than other LULC classes as it houses people and infrastructure. Results from the Chi-Square test (Table 4.5) prove that there is a strong relationship between land use and flood risk. The association had a 0.01 P-value proving that there is a strong relationship between LULC and flood risk.

Table 4.5: Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.000[a]	6	.014
Likelihood Ratio	16.636	6	.011
N of Valid Cases	8		

a. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .25.

From the research findings the researcher was able to prove that the alternate hypothesis was indeed false because there is a relationship between land use and flood risk. During the course of the study, the researcher discovered that there are many possible linkages that exist between LULC and flood risk in Gokwe North District. Flood risk on any given LULC category was observed to have a spatio-temporal dependence. The level of risk imposed on a particular LULC category was determined by the location of the category in the district and occurrence of the flood event. This means that LULC category has different levels of flood risk depending on where it is and the type of flood due to spatio-temporal variations of precipitation.

There is substantial evidence in the district that present day LULC practices have enhanced surface runoff generation at a local scale and this has frequently created impacts through muddy floods. Land use or land cover activities have a direct influence on runoff generation. LULC categories such as vegetation and cultivation restrict runoff generation as they heavily promote infiltration. Built up areas and cultivation to a certain extent promote runoff as they sometimes leave soil surface bare and cause deep compaction of soils hence making it hard for rainwater to infiltrate. Runoff generated from these LULC categories combined with the clay soils in the area results in muddy floods.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study presented an approach to integrate GIS and remote sensing in flood risk prediction to improve flood prediction and warning. The approach mainly focused on detecting changes in LULC and mapping the areas with greater potential of flooding in order to estimate the potential damage a future flood can cause in Gokwe North District. This approach also made it possible to analyse the relationship between LULC and flood risk.

There were notable changes in LULC in Gokwe North District from 2005-2015, of which cultivated land and vegetation had the greatest increase and decrease respectively. Built-up area also increased while water decreased. Population growth in the district caused an increase in built-up areas and cultivated lands as the increasing population sought open spaces to settle and cultivate on. Accordingly massive deforestation took place as land was cleared for farming and infrastructural development.

Flooding in Gokwe North District is strongly related to the occurrence of torrential rainfall which causes the ground to be covered in water. The lowlands of the district are prone to flooding almost every rainy season. The district as a whole is prone to flooding as it is generally low lying. The flood risk map produced from the research findings solidifies this since a larger percentage of the district is bound between the 'very high risk' and high risk categories. Only areas at higher elevations are marginally safe from flooding. All LULC categories in the district, that is, vegetation, cultivated lands, built up areas and water are at greater risk from flooding since they more often than not exist in lowlands.

The research findings also indicated that proximity of an area or a LULC class to a stream determines its flood risk level. The closer an area is to a stream, the higher the probability of flooding and risk. Gokwe North District is continuously experiencing flooding conditions almost every rainy season because major streams in the Sanyati Catchment pass through the district. Major streams like Ume, Sasame, Bvumbvudze, Gunguwe and Sengwa pass through the district supplying tributaries in the district such as Busi, Hwadzi, Kamwa and Magube with water. The flow direction map also shows that a majority of these rivers flow into the district hence the probability of the streams filling up quickly is high. Accordingly, areas such as Zomba, Nenyunka, Chireya, Goredema and Madzivazvido which are close to these major rivers and their tributaries are at greater risk from flooding.

The results also indicated that the most prominent flood risk in Gokwe North District is the loss of accommodation. Flood waters may inundate the ground for days such that houses may collapse or get washed away and the people sheltered by these houses are negatively impacted upon. Loss of accommodation in turn leaves the community vulnerable to other problems such as loss of food, property and lives as people and goods will be sheltered under these destroyed homes. Another danger posed by flooding is the destruction of infrastructure such as roads, bridges, schools and clinics which leave the area remote and unable to access crucial services.

5.2 Recommendations

Basing on the findings and conclusions of this study the following recommendations can be drawn to enhance non-structural measures of reducing flood damage:

- Organizations that deal with flood issues such as ZINWA, Meteorological Department, Civil Protection Unit of Zimbabwe and local Councils should enhance and consolidate GIS and remote sensing in their flood prediction and monitoring measures. Data from GIS and remote sensing has the capacity to provide information for areas of poor accessibility or lacking in ground measurements.
- There is need for Gokwe North RDC in liaison with the Civil Protection Unit to use the flood risk prediction model that was developed in this study in developing a flood action plan for flood warning and mitigation that can be applied at a local scale. The flood risk prediction model estimates the potential damage a flood will cause in the identified areas, thus when a flood occurs it becomes easier to locate areas in need of emergency aid.
- Gokwe North RDC planning department should improve their spatial planning strategies and regulations on land use activities in order to manage land and development in the district so as to reduce the rate of LULC changes.
- The Civil Protection Unit of Zimbabwe should strengthen their emergency response system by adopting evacuation and rescue plans, forecasting and services at a local scale. Adopting these measures at a local scale improves effectiveness of flood monitoring since resources will be budgeted for that area specifically hence there won't be any shortfalls when aid is required.
- ZINWA should desilt water bodies at both catchment and district so that water reservoirs won't easily fill up and flood due to silt accumulation.

- EMA must introduce land reclamation projects such as afforestation and reforestation programs in areas degraded by erosion to limit soil erosion in the district.
- There is need for public education on flooding and LULC, information can be disseminated through communication tools such as flood hazard and risk maps, public presentations and collaborative platforms.

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APPENDIX 1: Research ethics form

Project Title: **Flood risk prediction using remotely sensed data in the Sanyati catchment: a case of Gokwe North district.**

Researcher: Lewis Tapiwa Chiguye

Position: Student

Tick inside box

1. I confirm that I have read and understood the information sheet for the above mentioned study and have had the chance to ask questions for clarity. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving reason. ☐
3. I agree to take part in this study. ☐
4. I agree to the interview being audio recorded. ☐

……………………………………	………………………………..	…………………
Name of Participant	Signature	Date
……………………………………	………………………………..	…………………
Name of Researcher	Signature	Date

APPENDIX 2: Interview guide for key informants.

My name is Lewis T Chiguye and I am final year student at Midlands State University majoring in Geography and Environmental Studies. I am carrying out a study entitled, 'Flood risk prediction using remotely sensed data in the Sanyati Catchment: A case of Gokwe North District'. The questions you are going to be asked are for the sole purpose of obtaining information for this academic research. Results of this study are solely for academic purposes, anonymity and confidentiality will be respected for all the information obtained during this interview. An ethics form is attached to this document which the interviewee will sign first as form of agreement before the interview commences.

***Interviewee* ……..…………………… *Interviewer* ..……..……………………**
***Interview guide No* …… *Date* ……………………………**

1. How best can you describe land use activities in the area?
2. What are the main reasons for the changes in land use activities and land cover in the community?
3. How long do floods occur and how long do they last.
4. Which was the last most high risk (most dangerous) flood that affected the area.
5. How did that flood affect the community?
6. What risks has the community been exposed to in previous flooding incidences
7. What are your perceptions on flood risk?
8. Which measures have been taken to control floods and to reduce flood risk in the community?
9. What, in your own opinion, are the major changes that can be made in the community to reduce flood risk and flood damage?

Thank you very much for your time and information.

APPENDIX 3: Observation checklist for Gokwe North District

In carrying out the research on flood risk prediction in Gokwe North District, the researcher observed a number of aspects that were of fundamental importance. This was used for ground truthing of what had been observed remotely and for accuracy assessment of remotely sensed data.

Aspects to be observed:

1. Land use activities.
2. Land cover features.
3. Water bodies.
4. Damages caused by previous flood incidences