ANALYSIS OF LAND USE AND LAND COVER CHANGES AND THEIR EFFECTS ON THE WATER BALANCE OF INSIZA DAM CATCHMENT

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE OF BACHELOR OF SCIENCE HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT AND AGRICULTURE

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DECLARATION

I, **Lionel Siziba (R10671t)** hereby declare that this submission is my own work towards Bsc. Hons in Land and Water Resources Management and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This project is dedicated to my family Mr and Mrs Siziba, Lucia, Linda, Michelle, and Keith for their sacrifices and encouragement in everything I do.

ABSTRACT

Land-use and land-cover changes have an effect on the water balance as well as water yield of catchments in Zimbabwe. Most of these changes can be attributed to economic activities undertaken by communities within the catchments in an effort to improve their standards of living. The research was carried out in Insiza dam-catchment to investigate the effects of temporal land-use and land-cover changes on Insiza dam-catchment water balance. GIS and Remote sensing techniques were used in ENVI 4.2 and ArcGIS 10 to compute and analyse LULC changes in the study area. Three Landsat images for 1989, 1998 and 2008 (path and row of 170 and 74) were downloaded from the USGS website and classified through maximum likelihood to create thematic maps. Change detection techniques were used to compute class statistics as well as accuracy assessment. The LULC changes were then related to the water balance by computing water use and runoff for each land-cover class. The results showed that there were notable changes in LULC in the Insiza dam-catchment from 1989 to 2008 where cropland and grassland had the greatest increase and decrease respectively. Cropland increased by 81.30% following the FTLRP whilst grassland decreased by 154.48%. Although the annual runoff generated increased from 1989 to 2008 by 48.30%, the increase was not significant because of a suspected increase in sediment load due to the increase in bare soil by 56.56%. There is therefore a need for regulation of LULC activities in dam catchments as changes in land-use have an effect on the water balance.

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ACRONYMS

BCC	Bulawayo City Council
EFR	Environmental Flow Requirements
EMA	Environmental Management Agency
ETa	Actual Evapotranspiration
FTLRP	Fast Track Land Reform Program
GHG	Green House Gases
GIS	Geographic Information System
IWRM	Integrated Water Resources Management
LHWP	Lesotho Highlands Water Project
LULC	Land Use and Land Cover
MAR	Mean Annual Runoff
ROI	Region of Interest
TM	Thematic Mapper
UTM	Universal Transverse Mercator
USGS	United States Geological Survey
WGS	World Geodetic System
ZACPLAN	Zambezi River Action Plan
ZINWA	Zimbabwe National Water Authority

1.0 INTRODUCTION

Water is the basis and foundation of life as it is a component of everyday activities for both biotic and abiotic organisms. Its importance to human health and development resulted in the inclusion of a water related target in the Millennium Development Goals (MDG's). Millennium development goal number seven which is 'ensuring environmental sustainability' has an objective of halving the percentage of the global population that does not have sustainable access to safe drinking water by the year 2015 (UN, 2011). In 2010 the United Nations (UN) General Assembly documented the right of all human beings to have access to adequate water which must be safe, adequate, affordable and physically accessible. Despite its necessity and importance, water availability still remains a dream for many communities as 20% of the world's population or more than one billion people are without access to safe and clean drinking water (Lazlad, 2007)

Water scarcity is caused by several factors which include rapid population growth, deterioration of water quality, climate change, pollution as well as land-use or land-cover change (Lazlad, 2007). Rapid population growth has an effect on the availability of water as it leads to an increase in the demand for water resources (Alam, 2010). Deterioration of water quality as a result of pollution from industries, agriculture and waste dumping causes economic water scarcity where water treatment is limited (Abbaspour, 2011). Agriculture and industrialization cause pollution of water bodies as fertilizers and or pesticides and effluent or industrial waste are carried by runoff and deposited into rivers respectively. Climate change causes water scarcity as a result of reduced rainfall quantities, erratic rainfall as well as droughts which result in the reduction in catchment water yields. Land-use or land-cover change also causes water scarcity as a result of such effects as land clearing for cropping increases siltation of reservoirs and ultimately reduce water yield by altering the water balance (Koomen *et al.*, 2007).

The water problem that is being experienced by Zimbabwean cities is part of a much broader and global trajectory (Musemwa, 2008). The city of Bulawayo is one of the affected cities which have over the years experienced profound water shortages. Geographically it is on a watershed with water flowing away from it towards the North (Zambezi) and South (Limpopo) (Cross, 2007). Alternatives such as the Matabeleland-Zambezi water project has proven to be too expensive to finance and as a result responsible authorities are still debating on it. The

Mzingwane catchment's water supply is sometimes supplemented by the Nyamandlovu aquifer whose pipeline was commissioned in 1992 (Moyo *et al.*, 2005). The Insiza dam is one of the most important dams which supply water to the city of Bulawayo therefore it is of paramount importance to monitor the land use and land cover changes that will be taking place in the dam catchment in relation to the water balance. This will help in making informed decisions to help alleviate water shortages in the city or to halt possible critical water shortages in the future. The research therefore seeks to assess the land use and land cover changes from 1989 to 2008 and the associated water balance of the Insiza catchment.

1.1 Background and Justification

Despite being located in the Gwayi catchment the city of Bulawayo acquires the bulk of its water supply from the Mzingwane catchment as part of a trans-catchment arrangement. The Gwayi catchment alone failed to provide water to the city's increasingly growing population which led to an increase in the demand for water. To complement the increasing population growth the infrastructural development policy from 1928-1976 saw a dam being commissioned every 10-15 years (Mabiza, 2008). The water Act of 1976 took away the responsibility to provide water from local authorities and gave it to the central government and as such the construction of dams has not been forthcoming. The last dam to be constructed before independence was the Insiza dam in 1973 after which the Mtshabezi dam was constructed in 1994, 21 years later (Mabiza, 2008).

There are six storage reservoirs currently supplying the City of Bulawayo with water and these are namely Insiza, Inyankuni, Mzingwane, Lower Ncema and Upper Ncema and recently Mtshabezi dam. In addition to these reservoirs the City's water supply has also been supplemented with underground water sources such as that of Nyamandlovu aquifer. Water reservoirs are operated on an integrated basis where water is first extracted from the dams with less favorable evaporation features first before those with better characteristics in an effort to diminish evaporation losses (Sibanda, 2002). The main function of storage reservoirs or dams is to provide consumers with water for use whilst balancing the variation between demand and supply (Moyo *et al.,* 2005). The catchment water yield from the good years with high dam inflows can be stored for use in the occurrence of droughts. In this study catchment water yield is used to describe the volume of water leaving a catchment in a period of time (Lacombe and

Pierrot, 2011). The above mentioned storage dams are however unable to cater for the current water demand from legal water connections as well as other water needs such as industry and parks. The City of Bulawayo continues to experience water shortages which have since become a perennial issue. Water restrictions have been imposed in Bulawayo in the following years; 1938-1943, 1947, 1951, 1953, 1968, 1971-1973, 1983 and 1990 whilst stringent water rationing has been imposed in the following years; 1949, 1984, 1987, 1991 and 2005 (Moyo *et al.*, 2005). The years 2012 and 2013 have also witnessed stringent water rationing regimes that saw residents going for 48- 72hours without water. The reservoirs supplying Bulawayo have also failed to provide adequate water during the drought years such as 1982, 1992, and 2002 which have been found to have a recurrence of 10 years (Mangore and Taigbenu, 2003). Although land-use change and climate have an interdependent relationship, water shortages have been largely attributed to climate change neglecting the impacts of land-use change (Koomen *et al., 2007)*. Climate change has and continues to be the cause of water shortages in Southern Africa as evidenced by an increase of 1.7ºC in mean temperature and an expected 19% decrease in precipitation in Zimbabwe (Moyo *et al.,* 2005). Although the influence of human activities in the Insiza River have been studied by Onema *et al*., (2005) the impacts of these effects on the water yield was projected to only have an effect on a larger scale and not at dam-catchment level.

Land-use changes were noted between 1991 and 2000 in the Insiza river-catchment where an estimated 14% of the total area (3401km²) was converted into crop fields from housing and grazing land (Onema *et al.*, 2005). Moreover such changes were to be expected after the Fast Track Land Reform Program (FTLRP) as commercial farms once owned by the white people were taken over by locals who also extended their farm sizes (Moyo, 2004). Impacts of land-use have only been studied on the quality of groundwater in Bulawayo by some researchers such as Mangore and Taigbenu (2003) whilst little research has been done on its impacts on the water yield and balance in a dam catchment. Amongst the many impacts of gold panning in the Mzingwane catchment, land degradation and siltation of water bodies occur although ecological disasters such as loss of species diversification and habitat defragmentation were often the main focus of researches done (Phiri, 2011).

The study is an attempt to investigate why the perennial problem of water shortages persist in Bulawayo. The current water supply is unable to cope with the demand resulting in the aforementioned restrictions, penalties and rationing of water in certain months of the year as indicated by Moyo *et al*., (2005). The impacts of the changes in land-cover on the hydrological cycle within Zimbabwean catchments are poorly understood because of lack of data. The knowledge acquired from how land use and land cover change influence watershed hydrology is necessary in order to help policy makers and city planners make suitable response policies that reduce unsolicited effects of future land use and land cover change or alterations (Tadele, 2007).

As population increases within watersheds so do the effects of human activity on hydrology because of the need to increase agricultural and or industrial productivity (Lorup *et al.*, 1998). When Zimbabwe gained independence in 1980, it was faced with the challenge of addressing the land disparities (Mandizadza, 2010). The vast numbers of residents in the communal areas have greatly altered the land-use from grassland to arable land and this has culminated in several undocumented negative impacts on the catchment. These include deforestation, land degradation, loss of biodiversity, soil erosion and siltation of dams and rivers (Mandizadza, 2010).

Owing to such factors as the Fast Track Land Reform Program (FTLRP) and illegal mining, catchments have been left susceptible to soil erosion which may lead to sedimentation of dams thereby reducing reservoir capacities and subsequently reducing their ability to meet demands. Information on land-use and land-cover and its relation to catchment water balance is key to ideal use of land and is important in the selection, scheduling and enactment of land-use schemes as land is increasingly becoming scarce (Opeyemi, 2006).

1.2 Objectives

The main objective of the study is to investigate the effect of land-use and land cover changes on catchment water balance.

Specific objectives

1. To determine the land use and land cover changes in Insiza dam-catchment from 1989 to 2008.
2. To assess the effects of land use and land cover change on the water balance of Insiza dam catchment from 1989-2008.

2.0 LITERATURE REVIEW

2.1 Land-use and land-cover change

Despite being used interchangeably land use and land cover have different meanings. Land cover is the ground cover whilst land-use refers to the purpose served by the land (Levin, 1999). Land-cover refers to the biotic and abiotic gathering of the earth's surface and immediate subsurface for example grasslands (Giri, 2012). Giri (2012) defines land-use as the manner in which the biophysical characteristics of land are used and the purpose for which land is used or occupied by humans. Meyer and Turner (1992) go on to characterize land cover change as either conversion or modification. Land cover conversion is the alteration from one land cover class to another whilst modification is the alteration done within the same land cover category (Meyer and Turner, 1992; Giri, 2012). Land cover change is the alteration of the earth's surface from an original or previous state (Maro, 2011). Land-use change on the contrary is the change in the use or organization of land by people for instance when a recreational area is converted into a game reserve.

2.1.1 Causes and effects of Land use and land cover change on water resources

Land use and land cover change are a result of either anthropogenic intervention (deforestation, afforestation, urbanization, agriculture intensification) or climate variability (Claramonte, 2009). The alteration of land-use and land-cover change is mainly driven by a range of factors and mechanisms of which climate, technology and economics are major. To envisage the forthcoming effects of LULC change in a catchment it is vital to have an appreciation of the effects that past land use and land cover changes have had on the catchments hydrological cycle (Tadele, 2007; Getachew and Melesse, 2013). The determination of the effects of LULC change on the environment is often influenced by the consideration of the historical LULC practices, current land cover patterns as well as the predictions of future land use and cover as influenced by anthropogenic factors (Tom, 2003).

The drivers of land-use and land cover change can be classified as proximate, underlying and or other factors (Maro, 2011). Proximate drivers are the human actions that cause direct disturbances on the environment for instance veld fires or wood extraction for use as fuel or timber which eventually lead to the loss of biodiversity and deforestation respectively. The Fast

Track Land Reform Program (FTLRP) in Zimbabwe is an example of a proximate driver which resulted in the conversion of forestlands into croplands as more than 5 million hectares of land were identified for resettlement. Underlying or indirect drivers are the distresses that predetermine the likelihood and occurrence of proximate causes and as a result they modify and influence human behavior for instance institutional, political and economic factors. Other factors on the other hand include social triggers for instance wars and environmental triggers for instance droughts or floods which have resulted in ecological catastrophes (Maro, 2011). The Tokwe Mukosi flood which was recently experienced in Zimbabwe is an example of an environmental trigger which has resulted in the loss of homes and crops by the former residents.

The Encyclopedia of the Earth (Lambin and Geist, 2007) highlights that the major causes of land-use change are natural inconsistency, economic and technological factors, demographic factors, institutional factors and cultural factors. Economic and technological factors affect LULC by changing prices, taxes and subsidies on inputs and outputs. Providing farmers with better access to credit and markets in addition to improved agricultural technology and better land tenure or subsidies often encourages the conversion of forestland into cropland. Demographic factors such as migration towards urban or rural areas also promotes land-use change to built-up areas (urbanization) and croplands respectively (Lambin and Geist, 2007).

Institutional factors such as political, legal, economic, and traditional institutions have an influence on the land-use. Without legislation resources may be over exploited for instance excessive deforestation is likely to take place leading to a conversion from forestland to bare land (Lambin and Geist, 2007). Before the Environmental Management Act was established and endorsed traditional laws prevailed where chiefs and traditional leaders had the power over the use of resources. The Environmental Management Act [Chapter 20:27] aims to provide sustainable management of natural resources, protection of the environment as well as reduction of pollution and degradation. The Environmental Management Agency (EMA) was established to manage the environment and also take action on those who do not comply with the rules and regulations. Cultural factors such as personal histories, values, attitudes and beliefs of land managers influence land-use decisions because the repercussions of land-use decisions depend on the education, information as well as management skills available to land administrators.

Owing to the fact that the impacts of land use or land cover change are caused by intricate relations between site-specific factors and offsite environments generalized reactions may not be applicable (FAO, 2002). Generalized reports pertaining to land and water connections should be analytically interrogated to decide if they epitomize the best accessible data without bias (FAO, 2002). Land-use change and climate have an interdependent relationship because changes in climate influence land-use change whilst changes in land-use may affect the climate (Koomen *et al.*, 2007). The conversion of forestland into farm land encompasses the clearing of large amounts of land leaving the soil bare and susceptible to erosion. Although the rate of runoff increases as a result of deforestation because vegetation impedes runoff, the rate of dam or reservoir siltation increases as a result of soil erosion. Evapotranspiration rates are also likely to be reduced resulting in the reduction of the amount of moisture that returns back into the atmosphere.

Apart from affecting the regional atmosphere, land features strongly influence local climate. It is also hypothesized that less rainfall is likely to be received in an area as a result of a decrease in evapotranspiration which can eventually decrease the moisture in the atmosphere (Beniston, 2002). Since LULC change indicate diverse environmental and social factors detailed data can be used for effective analysis. Flow variation is affected by the conversion of farmland to forest while a change of agricultural lands to bare ground brings a reduction in evapotranspiration (ET) thereby causing an increase in discharge (Homdee *et al.*, 2010). Eventually such changes can significantly alter the seasonal and annual water balance.

2.2 The concept of catchment water balance

A catchment or a watershed is an area of land forming the drainage system of a stream or river. It captures water from precipitation on land within specific topographic boundaries such as hills, valleys, mountains and other landscapes. Catchment water balance is the equilibrium between the inputs and outputs of water from rainfall and the outflow of water through groundwater recharge, evapotranspiration and or stream-flow (Nugroho *et al*., 2013). In the simplified equation, changes in storage as well as percolation to groundwater are neglected. Catchment water yield is defined as the water volume leaving the catchment during a period of time (Lacombe and Pierrot, 2011). Surface runoff or overland flow is measured as stream-flow and is often referred to as the water yield of a catchment (Wang *et al.,* 2011). The water balance shows the relationship between precipitation, evapotranspiration and surface runoff as follows;

$$\boldsymbol{P + (I) = Ea + R}$$

where: ***P*** = precipitation or water input for a catchment

(I)= water imports (for example irrigation water sources from outside the catchment)

Ea= actual evapotranspiration

R = surface runoff measured as stream-flow often referred to as the catchment water yield

Normally, ***(I)*** = 0 for rain-fed farming areas and natural vegetation (Zambezi IWRM, 2007). The conversion of a grassland or shrub-land into a plantation is likely to affect water yield within a catchment (Farley *et al,* 2005). As a result of changes in vegetation, processes such as evaporation, transpiration and or interception alter the water balance of an area. Trees have a large surface area which means that they lose a lot of moisture to the atmosphere as a result of evapotranspiration (Farley *et al*, 2005).

2.3 Human influences on the water balance

Human activities such as agriculture and mining strongly influence the hydrological cycle because of the alterations in infiltration, overland flow and or evapotranspiration as they cause changes in land-use (Beniston, 2002). These human activities are often driven by demographic factors such as rapid population growth which increases the demand for resources such as water and land for agricultural production. Increases in societal demands such as shelter and food also exacerbate the impacts of human beings on resources as more of them are exploited. Economic growth aspirations also cause changes in human activity in the landscape as most communities will strive to produce more outputs from the resources leading to unsustainable use in an effort to maximize profitability. Moreover in the event that all community members aim to increase productivity from the present resources, the shared resources can be unsustainably deteriorated and consequently destroyed in what called the ‘tragedy of commons’ (Yasamis, 2011).

Illegal gold mining often called ‘gold panning’ has over the years been seen as one of the few coping strategies undertaken by Zimbabweans against economic hardships (Taylor, 1998). A large number of communal people have turned to gold panning following a number of years in which droughts resulted in little or no yields from rain-fed agriculture. Gold panning is defined by Phiri (2011) as an undertaking which involves small, medium and informal mining where undeveloped systems and procedures are used to abstract gold. It is often carried out in river banks as is the case in the Mzingwane catchment where rivers such as Insiza, Umzingwane and Mtshabezi have more pronounced activities. Of late, prospecting for gold has taken a new twist with panners’ embracing technology in the form of mineral detectors. Large tracts of land are cleared by veld fires started by the gold miners in an effort to easily use the gold detecting machines. Land degradation also takes place as a number of trenches and pits are dug on the ground surface leaving the loose soil susceptible to erosion and eventual deposition in the rivers and or dams without any rehabilitation.

The hydrological cycle will always be the central clockwork of the biosphere as long as the sun shines to provide energy for it. The partitioning of precipitation between different pathways is widely distributed because of changes in land-use. The movement of water back to the atmosphere is aided by vegetation through the process of transpiration as water moves from the root zone and through plants to the atmosphere. Therefore the clearing or removal of vegetation and forests as a result of land-use change reduces the amount of transpiration meaning that most of the water remains trapped in the ground. A land-use decision is therefore a water decision because land-use can modify ecosystems and also because most if not all land-use activities depend on water (Fallenmark *et al.*, 1999).

2.4 Use of GIS and remote sensing in land-use and land-cover change

Remote sensing is the measurement of the characteristics of a property of an object through the use of a sensor which is not in physical contact with the entity being studied instance images of the earth’s surface from an aircraft (Levin, 1999). A geographic information system (GIS) is defined as a computerized system that facilitates the entry, analysis and presentation of geographically referenced data (Rolf, 2001). As a result of the variability of resources over time and the number of variables to be studied, GIS can be an important tool in the evaluation of data.

In a GIS attributes (characteristics of data) are attached to the spatial components (location). The properties that are measured using remote sensing procedures relate to land-cover from which land-use can be inferred, principally through ancillary data or prior knowledge (Levin, 1999).

Collection of remote sensing data facilitates the synoptic examination of Earth-system purposes, modeling and modification at different scales over time (Lambin and Strahler, 1994). The application of remote sensing has revolutionized data collection and considerably enhanced the quality and availability of important spatial data for natural resources management and conservation. Satellite images provide valuable spatially dispersed data in order to assess past land-use changes (Wagner *et al.*, 2013). Remote sensing and GIS have been used in several studies to detect and map land-use and land-cover changes worldwide. Muzein (2006) used remote sensing and GIS to detect land-use and land-cover (LULC) change in the Ethiopian Rift valley. In the same year, Opeyemi (2010) also used GIS and remote sensing to detect changes in LULC in Ilorin the capital of Karwa state and the research work demonstrated the importance of GIS and Remote Sensing in depicting variable data.

In a study to analyze LULC changes in the Rize (North East of Turkey), Reis (2008), realized severe land cover changes in agriculture, pasture, urban and forestry areas between 1976 and 2000. Urbanization was identified as the main driver of land cover change in the Mula and Matha river catchment in India by Wagner *et al.,* (2013). Less evapotranspiration and more runoff was expected in the catchment as a result of the ongoing urbanization. In a study conducted by Homdee *et al.*, (2010) on the impacts of land-cover changes on hydrological responses on the Chi River basin, the results indicated that different land-use scenarios contributed to various effects in annual and seasonal water yield and evapotranspiration. As a result changes in land-use are unequivocally connected to water quantity via applicable hydrological processes such as evapotranspiration and or soil erosion. In the long-term the reduction in evapotranspiration and water re-use due to LULC change may cause a negative response mechanism which results in a reduction of rainfall.

In Zimbabwe, Matsa and Muringaniza (2011) used Landsat images from 1991, 2000 and 2009 to study the changes in LULC in Shurugwi district. Their assessment showed that there had been considerable LULC change in the district between 1990 and 2009. Vegetation experienced the largest decrease of 9.4% decrease from 1991 and 2000 and 11.6% from 2000 and 2009. These changes were mainly attributed to the FTLRP which resulted in conversion of land use between 2000 and 2009 (Matsa and Muringaniza, 2011).

2.4.1 Layer stacking and image classification

Layer stacking is the process of combining three bands of a Landsat image which represent the red, green and blue (RGB) wavelengths of the electromagnetic spectrum (ESRI, 2012). ENVI 4.2 software can be used to combine three band layers of the Landsat images from which the land-use or land-cover map are created. A shape-file or thematic layer of the study area can then be used to mask and subset it from the overall Landsat images. Image classification refers to the undertaking of extracting data classes from a multiband (many bands) raster image (ESRI, 2012). The resulting raster image from image classification can be used to create thematic maps. In ssupervised classification spectral signatures that are acquired from training samples are used to classify images. Supervised classification can be used to classify the images according to their digital numbers (DN) as it allows the user to generate the statistical parameters and training data to classify the image and create a thematic Raster map (Reis, 2008). With the aid of the Image Classification toolbar training samples can be created to represent the classes to be extracted. The LULC classes can be derived from the visual interpretation of the color composites achieved from the bands of the Landsat images.

2.4.2 Accuracy assessment

After the classification process the classified maps should be assessed for accuracy in comparison to either a ground truth image (another classified image) or ground truth regions of interest. The Kappa coefficient can be used to assess the accuracy of classified images and to test if a LULC map is perhaps of greater value than a map created from random labels to areas (Frimpong, 2011). It represents the percentage of agreement achieved after the removal of the probability of agreement possibly generated by chance. The Kappa coefficient lies between a scale of 0 and 1 (Frimpong, 2011). A Kappa value that is greater than 0.80 signifies strong agreement, a value between 0.40 and 0.80 represents moderate agreement whilst a value below 0.40 represents poor agreement (Fekele, 2003).

2.4.3 Merits of Using GIS and remote sensing in land-use and land cover change

Remote sensing and GIS are prominent tools which can be used to create accurate and timeous data pertaining to large scale LULC changes (Rogan and Chen, 2003). GIS provides a flexible and automated environment for collecting, storing, displaying and analyzing digital data which is necessary for change detection. Satellite imagery is used for recognition of synoptic data of earth's surface thus remote sensing provides pivotal data for GIS. Satellite data has high spectral resolution and rich archives of information and this makes them important for change detection (Reis, 2008). GIS and remote sensing also provide cost effective and precise alternatives for the appreciation landscape changes (Rimal, 2005).

Ground methods of land-use mapping are mostly labor intensive and time consuming and are as a result unfit for land-use studies (Opeyemi, 2010). The data obtained from remote sensing can address both space and time considerations at a range of spatio-temporal scales. GIS is application oriented and the digitized GIS data can also be revised and the databases can be edited frequently as changes can be monitored. Remote sensing data is useful to many disciplines as it can be used in geology, land-use/land cover, hydrology, forestry and or fisheries and many others.

2.4.4 Demerits of using GIS and remote sensing in land-use and land cover change

Remote sensing images are not direct samples of phenomenon and therefore require calibration and validation against reality. They must be geometrically corrected and geo-referenced in order to be useful maps. Cloud cover, water vapor as well as the sun, affect the accuracy of satellite images as they overshadow the ground surface. Although Landsat images are available for free, greater resolution images such as Quickbird (60cm) are expensive to acquire and often not affordable to many people in need of their uses in industries such as agricultural management and or water resources management.

Change detection techniques involved in post-classification often have significant limitations because the comparison of land-cover classifications performed for different years may not allow the detection of eminent changes within the categories. Quantifiable changes at the sub-pixel level are often left out as homogeneity is assumed in the whole pixel. The most dominant feature within a pixel overshadows the rest of the smaller features leading to a bias towards land-uses and or land-cover in an area.

2.5 Importance of water

Water is an essential component of life as it is part of the physiological processes of nutrition as well as waste removal from cells of all living things. Biodiversity and the distribution of Earth's varied ecosystems both biotic and abiotic as well as their interrelated physical and chemical environments are all controlled by water (Vandas *et al.*, 2002). All ecosystems both terrestrial and marine depend on water for their existence. Water is important in everyday life of human beings as it is essential in all activities. It is required for domestic, industrial, agricultural and municipal as well as sanitation purposes. Of late the environment has also been recognized as a legitimate user of water hence the application of environmental flow requirements (EFR) and reserves in rivers, dams and even ground water systems. Water is also vital in shaping the land surface of the Earth such as canyons, flood plains, terraces and watersheds.

2.5.1 The catchment system and Integrated Water Resources Management

As a remedy for water problems world-wide, the global trend has been the preference for Integrated Water Resources Management (IWRM). IWRM is a process which encourages coordinated improvement and regulation of water, land and other relevant resources, in an effort to increase both economic and social well-being in an equitable way whilst maintaining environmental sustainability (Global Water Partnership, 2000). It aims at ensuring equitable, efficient, economic and sustainable utilisation and management of water resources. Several strategies are essential for IWRM which include the development of water management master plans to ensure that water resources are efficiently used. Regional and international co-operation on trans-boundary rivers and international water resources is also required for easier water abstraction especially when shortages arise. Other techniques such as water harvesting, recycling, legislation, awareness campaigns and educational programs can also be implemented to aid in water resources management and conservation (Rajora, 1998).

Following the International Conference on Water and Environment (ICWE) and the United Nations Conference on Environment and Development (UNCED) in 1992, four principles of IWRM were made and these are;

I. Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
II. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
III. Women play a central part in the provision, management and safeguarding of water.
IV. Water has an economic value in all its competing uses and should be recognised as an economic good. (GWP, 2000)

Integrated Water Resources Management (IWRM) principles have been actively promoted in Southern Africa due to the efforts by proponents like the global, regional and country water partnerships. As a result, the level of awareness on the significance of an IWRM approach among decision-makers in the region has been raised. There is greater recognition now that IWRM needs to be mainstreamed in all development planning activities of all countries and or regions. Through its trans-boundary waters program, the United Nations Development Programme (UNDP) is supporting over 100 countries in the preparation of shared waters governance frameworks in some of the world's most important shared water bodies. These programs include the Danube, Dnipro, Tisza and Kura rivers in Europe; Lake Baikal, Lake Peipsi and Lake Prespa in Europe; the Artibonito River basin in the Caribbean; the Nile, Okavango, Orange/Senqu, Senegal and Niger river basins in Africa; Lake Chad and Lake Tanganyika in Africa (UNDP, 2014). UNDP supports joint 'fact finding' by countries to identify and agree upon priority issues and their causes, and helps countries to prepare and implement joint action programs of governance reforms to address priority challenges.

In China IWRM projects were implemented in areas such as Liao river basin which was experiencing water shortages and severe water pollution (UN-Water, 2008). Ecosystem production functions were lost as urban wastewater discharge was discharged into streams and infiltrating into the groundwater sources. An institutional framework was established comprising of the Liaoning Cleaner Water project and Liao River Basin Coordination Commission under which an IWRM planning project was developed to eradicate the water problems. As a result of the implementation of IWRM water prices were adjusted to ensure equitable water supply, a monitoring network was established and water pollution levels were reduced by 60%. The quality of the river was improved as drinking water was safeguarded and the ecosystems were restored (UN-Water, 2008).

The Senqu (Orange) River originates in Lesotho, and forms the boundary between South Africa and Namibia before it enters the Atlantic Ocean. The Lesotho Highlands Water Project (LHWP) was first conceived in 1954 and diverts about 40% of the water in the Senqu river basin to South Africa's Vaal river system in Gauteng Province for industrial purposes (GWP, 2000). In the project five dams were to be constructed although to date only two of them have been completed namely Katse and Mohale (UN-Water, 2008). Regardless of the fact that Lesotho itself experiences moderate water problems it continues to supply water to South Africa because the sales form the country's largest source of foreign currency. As a result of the project large numbers of people moved into the highlands resulting in a number of environmental and social impacts such as disease outbreaks like HIV and AIDS. Large tracts of grazing and arable land would also be lost upon completion of the project as well. Other environmental impacts of the project include the reduction of water downstream for people, wildlife and fisheries, loss of habitats for endangered species such as the bearded vulture and rock catfish (UN-Water, 2008). The project was conceived in the Apartheid era when South Africa was under international sanctions and was therefore a rule breaking venture. It is as a result of the negative effects of the LHWP on Lesotho such as corruption, environmental and social effects that the project is somewhat not in the local peoples favor.

The Pungwe River Project is a trans-boundary water project between Mozambique and Zimbabwe which began in 2002 (UN-Water, 2008). Before the initiation of IWRM, saline water intrusions from the Pungwe River had negative impacts on the sugarcane plantations and domestic water for Beira City in Mozambique. Poverty-driven activities such as gold panning in the river basin have resulted in poor water quality standards. The suspended solids in the water made it unsuitable for irrigation, drinking and other domestic uses and in some instances they also buried plants. The Joint Integrated Water Resources Management Strategy for the Pungwe river basin has been able to materialize the concept of a wide and sustainable social and economic improvement in the absence of environmental repercussion (UN-Water, 2008).

The Zambezi River Action Plan (ZACPLAN) was adopted by SADC in 1987 and its objective was to achieve comprehensive scheduling and organization of water and associated sources in the Zambezi River Basin (SADC/Zambezi River Authority, 2008). The eight beneficiary nations were Angola, Botswana, Namibia, Malawi, Mozambique, Tanzania Zambia and Zimbabwe. These countries were set to acquire a valuable and sustainable socio-economic improvement through equitable and sustainable use of the shared water resources of the Zambezi River Basin.

In Zimbabwe, water reforms were undertaken in 1995 although they came to a climax in 1998 following the endorsement of the Water Act of 1998 (Mazungu, 2004). Stakeholder involvement was made possible through the sub-catchment committees. A catchment area as defined by the Water Act 31/1998 is an area which naturally drains into a dam, lake, river or reservoir and the water originates from rainfall. The country was divided into 7 catchments namely Gwayi, Mzingwane, Save, Manyame, Runde, Mazowe and Sanyati on the basis of major river systems (Manzungu, 2004). The catchment councils are assisted by ZINWA which supervises the administration of water resources. Zimbabwe National Water Authority (ZINWA) is a parastatal which was established by Section 3 of the ZINWA Act, 1998. It acts as an operator and regulator of water resources in Zimbabwe and is responsible for water planning, implementation and the management of public dams as well as the coordination and supervision of the catchment councils. ZINWA also serves to supply bulk water to urban centers as well as the agricultural, industrial and mining sectors in the country.

2.5.2 Water scarcity in cities

Water scarcity is the absence of adequate water resources to cater for the water usage demands in an area. It is defined by UN-Water (2006) as, the situation in which the collective effect of all users disturbs the supply and or quality of water under the existing official setup to an extent where catering for water requirements becomes almost impossible. Many developing nations such as India, South Africa, Brazil, Turkey as well as China experience water scarcity problems (Wong, 2013). Land-use changes can exacerbate water scarcity in areas with limited water availability (Wagner, 2013). India has an estimated population of 1.27 billion people, three quarters of which live in water stressed regions as water demand continues to surge in the country. In Brazil water demand is driven by rapid urbanization and rising industrial use. China has approximately 21% of the World’s population but only has 6% of the earths’ freshwater

(UN-Water, 2008). Its capital city Beijing has a population of 21 million people but possesses a tenth of the World's average water resources (Wong, 2013).

The Semi-arid and Arid environments in Southern Africa accompanied by the low levels of water development have greatly caused water challenges in the region. As a result approximately one third of the population is living in drought susceptible environments where water shortages deter agricultural productivity (SADC Water Sector, 1998). Zimbabwe, Namibia, Malawi and South Africa are the current water stressed countries in the region whilst Botswana experiences chronic water scarcity (Wallinford, undated). The water stressed countries experience frequent seasonal water supply and quality problems which are exacerbated by occasional droughts. The chronic water scarcity in Botswana is evidenced by continued water supply problems which are heightened by annual dry seasons and frequent severe droughts.

Zimbabwean cities such as Harare, Gweru and Bulawayo have had their share of experiences in terms of water scarcity and as a result water restrictions and rationing regimes have often been imposed in an effort to reduce the deficit (Musemwa, 2008). These water scarcity has resulted in the outbreaks of water borne diseases such as cholera as residents were forced to drink contaminated water which led to the death of approximately 4 000 people between 2008 and 2009. In Bulawayo stringent water rationing was also imposed in 1992, 2005, 2012 and 2013 which saw residents going for 48- 72hours without water. In response to the scarcity of water boreholes were drilled in the Nyamandlovhu aquifer and the pipeline for moving water to the city was commissioned in 1992 (Moyo *et al.*, 2005).

2.5.3 Climate change and water resources

Climate change is the long-term shift in the statistics of weather as a result of natural and or anthropogenic causes. Anthropogenic causes of climate change result in the increase in the concentration of greenhouse gases (GHGs) such as carbon dioxide, nitrous oxide and methane (Rosegrant *et al.*, 2008). Naturally climate change is as a result of alterations in the distribution of solar radiation caused by the in the earth's orbital geometry.

Climate change is anticipated to substantially reduce available water in most water-scarce regions world-wide as reflected by projected runoff (Arnell, 2003). Future prediction shows that

Southern Africa will get drier and the region will find it difficult to cope with impacts of climate change such as a reduction of rainfall given the present level of preparedness (Moyo *et al.*, 2005). The region's precipitation is expected to reduction by 5-20% in all catchments following a projected increase of 1.7ºC in mean temperature. The predicted changes in precipitation, potential evaporation and runoff in the major river basins in Southern Africa show that there is an expected shortfall of 19% of precipitation in Zimbabwe by Chenje *et al.*, (1996). In addition to the droughts and the Semi-Arid climate in Zimbabwe the country's water storage dams are also affected by evaporation as a result of the high temperatures which greatly reduce the quantities of water (Brown *et al*., 2012).

As humans we often compare recent drought years to previous wet periods and as a result perceptions about the increasing severity of droughts are often subjective (Mazvimavi, 2010). The validity of the general assumption and conclusion by most studies that rainfall is declining in Zimbabwe was investigated by Mazvimavi in 2008 (Chikodzi and Mutowo, 2013). The results of his study showed that there was no confirmation of alterations in the rainfall season, and for the whole year. Available water resources have been adversely affected by anthropogenic changes of land-use and land-cover and accelerated soil erosion (Mazvimavi, 2010).

2.5.4 The population dimension in water resources

Being a finite natural resource, water cannot be created and as a result a growing population poses a threat to global water supply (Population Institute, 2010). An increase in population directly increases the water demand for household, agricultural, industrial, and municipal as well as sanitation services (FAO, 1994). The population of the World is projected to expand from 6 billion to an estimated 9 billion people by 2050. Population growth is a key variable in the evaluation of water demand as it determines the quantity requirements as well as the need for new or expansion of water supplies (Ministry of Rural Resources and Water Development, 1999).

For countries such as China which have a huge population (approximately 21% of the World's population) there is a huge demand for water which has resulted in water scarcity since the country only has access to approximately 6% of the World's freshwater supplies. Only 20% of the world's population has access to running water whilst over 1billion people do not have access to clean water (World Water Organization, 2010). Owing to the lack of clean water almost half of the population in developing countries suffers from water related diseases such as cholera and or malaria.

The Euphrates River originates in Turkey and flows through Iraq and Syria and as such there is a huge demand for water resources in the river by the three countries (UN-Water, 2008). The river is a source of irrigation water as well as power generation for the countries. The demand for water resources has been exacerbated by the population growth in Turkey from 70.6 million in 2007 to 76.7 million in 2013 (8.64% growth rate) which prompted the country to construct dams in the Greater Anatolia Project (GAP). The project has resulted in better water supply for Turkey whilst Iraq and Syria continue to have a deficit in their water supplies (UN-Water, 2008).

The rising population growth in Africa is driving the demand for water resources and also accelerating it (UN-Water, 2008). Sub-Saharan Africa is estimated to have the highest prevalence of poverty and overcrowded urban areas and this is expected to further increase. The sanitation levels in the region are very poor as indicated by just 40% of the region having proper sanitation and water resource in 2010 (UN-Water, 2008). In Southern Africa population growth is also quite rampant as evidenced by an increase from 33 million in 1980 to 60,4 million in 2013 (UN Population, 2012). Within the region Namibia and Botswana are two countries whose population growth has resulted in an increase in water demand leading to disputes over the Okavango River. In a bid to cater for the growing population Namibia extended its pipelines network from the river resulting in an increase in water supply for its nation at the expense of Botswana's tourism as the ecosystem is the main tourist attraction.

The census results of Zimbabwe for 1982, 1992, 2002 and 2012 were 7.5 million, 10.4 million, 11.6 million and 13.1 million (rounded off to one decimal place) respectively (GeoHive, 2014). As a result of the growth of population there has been a huge increase in the demand for portable water for everyday life. The census results of 2012 show that there has been an increase in the population of Harare from 1,2 million in 1982 to 1,4 million in 1992 and then to 1,5 million people in 2012 (CSO, 2012). The population growth can be as a result of the immigration of people from the communal areas to the urban towns in search of employment and better quality standards of living.

3.0 MATERIALS AND METHODS

3.1 Background of the City of Bulawayo

Bulawayo was incorporated into a city in 1943 and is located on a crest between Mzingwane and Gwayi catchments. It is located 20°10′12″S 28°34′48″E and covers an area of 479km^2 (CSO, 2012). It has a current estimated population of 655 675 people according to the 2012 census results (CSO, 2012). Climatic conditions are subtropical with an average rainfall of 588mm per annum normally received between the month of October and March, which is however erratic and variable both spatially and temporally. Although Bulawayo is located within the Gwayi catchment, it relies more on the reservoirs constructed within the neighboring Mzingwane catchment for its water supply through a water transfer system linking the Ncema, Insiza, Inyankuni and Mtshabezi dams.

3.1.1 The study area

The Insiza river is the principal tributary of the Mzingwane river. It rises in the Midlands and crosses the Bulawayo to Harare highway near Fort Rixon, and flows through Filabusi until it reaches the Mzingwane river near West Nicholson. The Insiza river catchment covers an area of 3401km^2 within the semi-arid southern portion of the Zimbabwean side of the Limpopo basin (Onema *et al.*, 2005). According to the Agro-ecological zoning, most of it is located in Natural Region IV which is a semi-extensive farming region (Vincent and Thomas, 1960). The Insiza dam was constructed from 1973-1976 and it has a capacity of 96 million m^3 and derives its runoff from a 1810 km^2 watershed. After its construction the dam had a water depth of 29 meters and a surface area of 1250hectares.

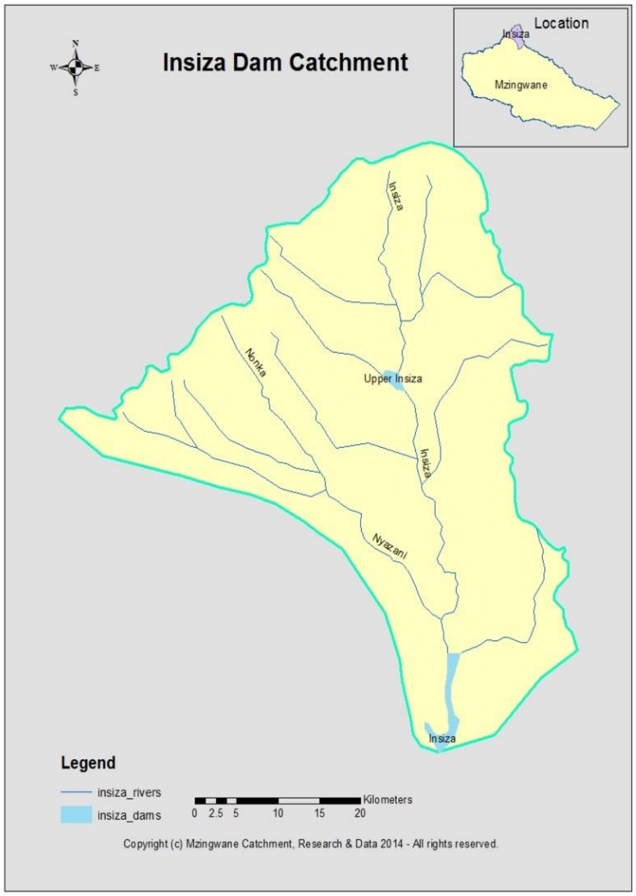


Figure 3.1; Insiza dam catchment, source: ZINWA Data Research Department

3.2 Characterization of the study area

3.2.1 Climate

The climate of Insiza dam-catchment is semi-arid. The study area is located in Natural Region IV and its mean annual rainfall varies from 480mm/year on the southern lower part to 690mm/year on the northern upper part (Onema *et al.*, 2005). This is normally received between November and March and is often accompanied by periodic seasonal droughts and dry spells.

3.2.2 Vegetation

The northern section of the Insiza dam-catchment which often experiences high rainfall has low open woodland of *Combretum-acarcia- terminalia* which is characteristic of granitic sandy soils. However in the southern part the open Mopane woodlands are slowly being replaced by *Terminalia- sericea* (Onema *et al.*, 2005).

3.2.3 Water resources

The major tributaries of the Insiza dam are Nyazani and Insiza rivers which spill into the dam. The study area also consists of the upper Insiza dam located within the Insiza river as shown in Figure 1. Mean annual runoff (MAR) in the study area varies from 50mm in the Upper Insiza portion to 38mm in the Lower Insiza section (Onema *et al*, 2005).

3.2.4 Soils

The catchment area (fig 1) lies beneath gneissic and granite rocks which result in the shallow, coarse grained kaolinitic sands and moderately shallow clay-loams (Onema *et al*., 2005). Insiza dam catchment lies within the kaolinitic soil order within the soil classes of Zimbabwe (Dhliwayo *et al.*, undated). The soils are moderately to strongly leached with appreciable amounts of free sesquioxides (oxide containing three atoms of oxygen with two atoms of another element) of iron and aluminum.

3.2.5 Land-use

Insiza dam-catchment is located in the semi-extensive farming region in the country and land-use is generally comprised of croplands, grassland and forestland (Onema *et al.*, 2005). Between the years 1991 and 2000 there were notable changes in land-use by about 14% of the Insiza dam-catchment where a combination of housing and grazing land were converted into cropping fields (Onema *et al.*, 2005). As a result of the Fast Track Land Reform Program more similar changes were expected because of the increases in farmland and the increase in smallholder farming. Smallholder agriculture is often carried out in the southern portion of the study area and it is mainly rain-fed cropping. Commercial farming on the other hand occurs in the northern portion under irrigation where most of the farmers are resettled. Irrigation schemes are however present in the south and are regulated farming groups. Household level irrigation also occurs in the south and is mostly for vegetable gardens where drip kits are used (Onema *et al*., 2005).

3.4 METHODS

3.4.1 Image acquisition and preprocessing

To determine the land use and land cover changes in Insiza dam-catchment from 1989 to 2008 GIS and remote sensing techniques were used to download and analyze the Landsat images.

Three Landsat images were downloaded for 24 September 1989, 15 July 1998 and 27 August 2008 all of which had a path and row of 170 and 74 respectively from the USGS (United States Geological Survey) Global Visualization website. All three images were captured using the Thematic Mapper (TM) although the first two were taken from Landsat 4 whilst the last image was taken from Landsat 5. These images were downloaded on the above dates in an effort to ensure that they had an anniversary window of equivalent season to eliminate distortions likely to arise from images obtained in different seasons.

Special attention was also given to the amount of cloud cover on the dates that the images were taken by the sensors as it can deter accuracy. The images were downloaded in a compressed *.tar.gz* format, therefore WinZip (Carter, 2010) software was used to decompress and extract data from *.tar.gz* format. The Landsat images were downloaded in tiff picture format therefore there was a need for geometric correction (geo-referencing) through the use of the Universal Transverse Mercator (UTM) projection system (WGS 84).

3.4.2 Creating a shape-file of the study area

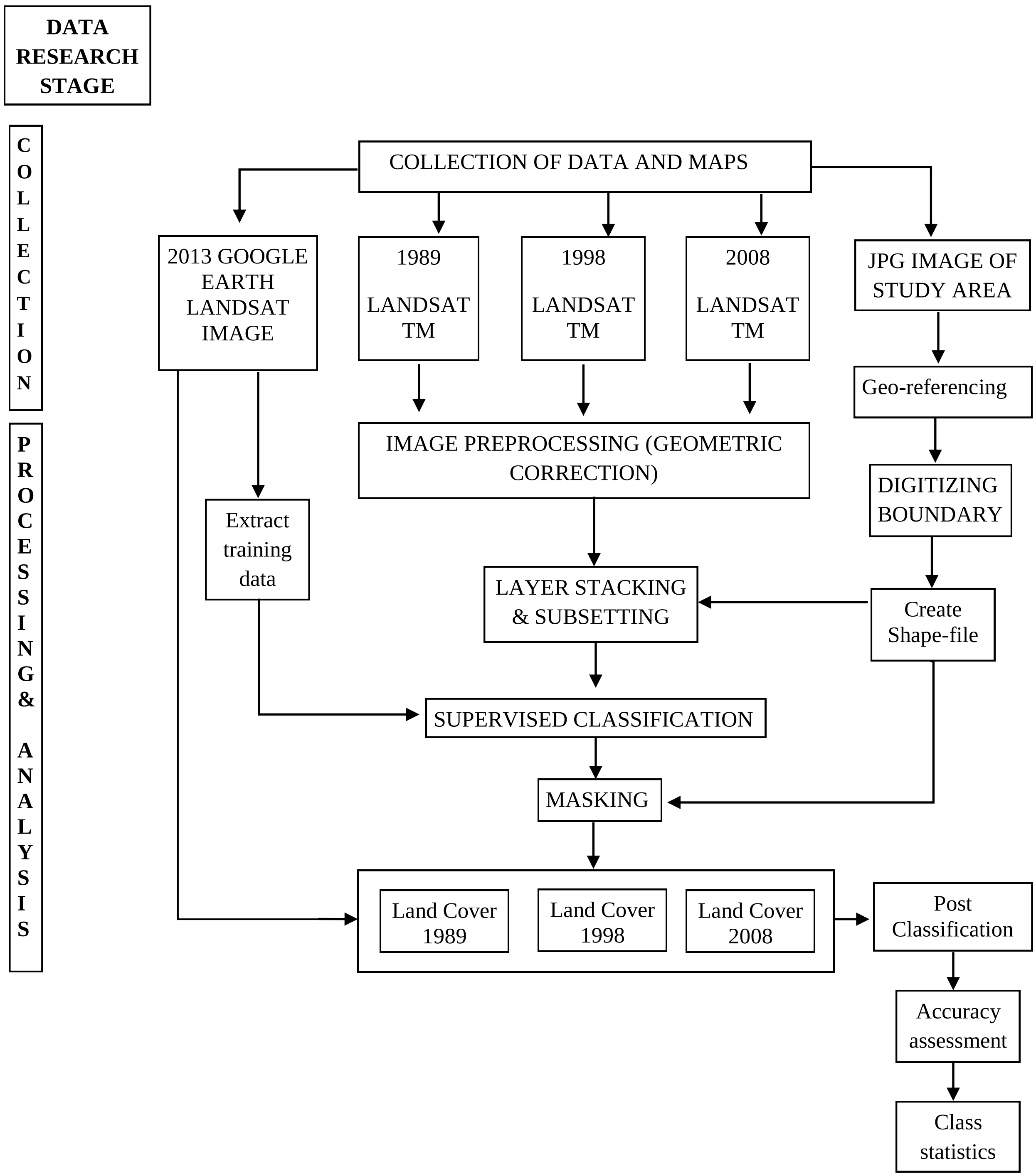
ArcGIS 10.0 software was used to create a shape-file or thematic layer of the study area from the jpg image attained from ZINWA (Data and Research Services Department). A Google Earth Landsat image taken on the 4th of October 2013 was used to geo-reference the jpg image in accordance to the UTM WGS84 projection system. The shape-file was then used to cut out the study area from the Landsat images.

3.4.3 Layer stacking and image classification

Layer stacking was done using ENVI 4.2 software to combine three bands of each of the Landsat images which represent the red, green and blue (RGB) wavelengths of the electromagnetic spectrum. The three bands used were 7, 4 and 2 which were mid infrared (MIR), near infrared (NIR) and Green respectively. The MIR band emphasized vegetation and showed boundaries between land and water, the NIR band was used for water body delineation and the Green band was used to show the green reflectance of healthy vegetation. A shape-file of Insiza dam catchment was then used to subset the study area from the stacked image layers. ENVI 4.2 was also used for supervised classification where land-use classes were extracted from a multiband raster image (ESRI, 2012) by classifying the images according to their digital numbers (DN). User defined land cover classes (training data) derived from the visual interpretation of the color composites achieved from the bands and the spectral signatures obtained from training samples were also used as regions of interests (ROI).

After supervised classification by maximum likelihood the classified images were then masked using the shape-file of the study area to produce raster images. Post classification was done through accuracy assessment and computation of class statistics and changes in ENVI 4.2. Ground truth regions of interest were used to assess the classified maps accuracy. The regions of interest of each classified image were exported and saved as shape-files which were then used to create maps in ArcGIS 10.0. Tables and pie-charts were composed to compare different land use types with respect to area for 1989, 1998 and 2009 so as to determine if there were changes in LULC and to furthermore calculate percentage changes in the area. A bar graph was used to compare the LULC changes from 1989-2008.

Figure 3.2: Flowchart of LULC change analysis methodology



3.6 The effects of LULC change on the water use and water availability

To calculate and assess the water use of each of the land cover classes in the study area the equation below adapted from Zambezi IWRM (2007) was used;

$$\boldsymbol{Eai} = [\frac{\boldsymbol{Ci} * \left(\frac{\boldsymbol{Ai}}{\boldsymbol{A}}\right)}{\boldsymbol{d}}] * \boldsymbol{Ea}$$

Where:

- ***Eai*** is the actual evapotranspiration (annual figure) from water use class no. i,
- ***Ci*** is the average crop factor for water use class no. i,
- ***Ai*** is the area of water use class no. i,
- ***A*** is the area of the total sub-basin,
- ***Ea*** is the total actual evapotranspiration from the entire sub-basin,
- ***d*** = SUM(Ci * Ai/A) (summed up for all the defined water use classes)

In order to estimate the volume and distribution of water in the Insiza dam catchment a simplified form of the water balance equation was used in this study as shown below. In the simplified equation, changes in storage as well as percolation to groundwater are neglected which results in the following equation which was used to estimate the actual evapotranspiration and surface runoff;

$$\boldsymbol{P} + (\boldsymbol{I}) = \boldsymbol{R} + \boldsymbol{Ea}$$

Where; ***P*** = precipitation , ***(I)*** = water imports (e.g. for irrigation from external water sources), ***R*** = runoff, ***Ea*** = actual evapotranspiration

Normally, ***(I)*** = 0 for rain-fed farming areas and natural vegetation. The total actual evapotranspiration for the study area was calculated by subtracting the total annual runoff from the annual precipitation (Zambezi IWRM, 2007).

4.0 RESULTS AND ANALYSIS

4.1 Land use and land cover classes in Insiza dam-catchment

Land cover maps were created from supervised classification from which the following land cover classes (Tab 4.1) were identified. Crop factors were adapted from Zambezi IWRM (2007).

Table 4.1: LULC classes and their descriptions as used in the study

LULC	DESCRIPTION
Bare soil/sand	Area of land that is devoid of vegetation and therefore characterized by soil or gravel
Water	Insiza dam and its rivers and tributaries within the watershed
Forestland	Section of land that is covered forests and composed of trees, shrubs as well as grass
Grassland	Area of land dominated by grasses rather than trees and shrubs
Cropland	Land used for cultivation purposes where crops are grown

4.2 LULC analysis of Insiza dam-catchment

4.2.1 LULC analysis of Insiza dam-catchment in 1989

The spatial extent of the 1989 LULC map after supervised classification yielded land cover classes (Figs. 4.1, 4.2 and 4.3) with grassland (77 670.09 ha, 61.58%) occupying the highest percentage of the study area (126 148.95ha). The concentration of grassland as shown in Fig 4.1 was more pronounced in the Western and Southern parts of the Insiza dam catchment. Forestland (28 463.67 ha, 22.56%) was the second largest LULC class and was mainly concentrated on the Northern part of the map. Bare soil (17 060.13 ha, 13.52%) had the next highest area coverage which was sparsely located in the map with no particular area of greater concentration. Cropland occupied 2 104.38 ha (1.67%) of the map in 1989 and was mainly located close to the Insiza River. Water had the lowest LULC in the map which was 850.68 ha (0.67%) of the total dam catchment area and was located in the Insiza and Upper Insiza dams as shown in Fig.4.2. The proportions of land occupied by each land cover types is shown by the pie-chart in Fig. 4.3

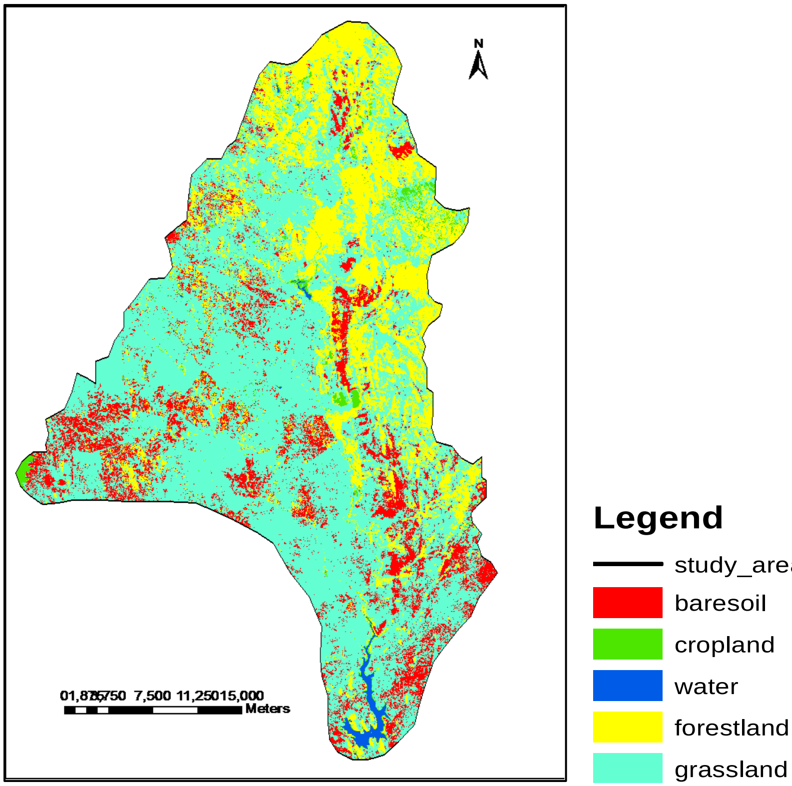


Figure 4.1: Supervised classification map of Insiza dam catchment in 1989

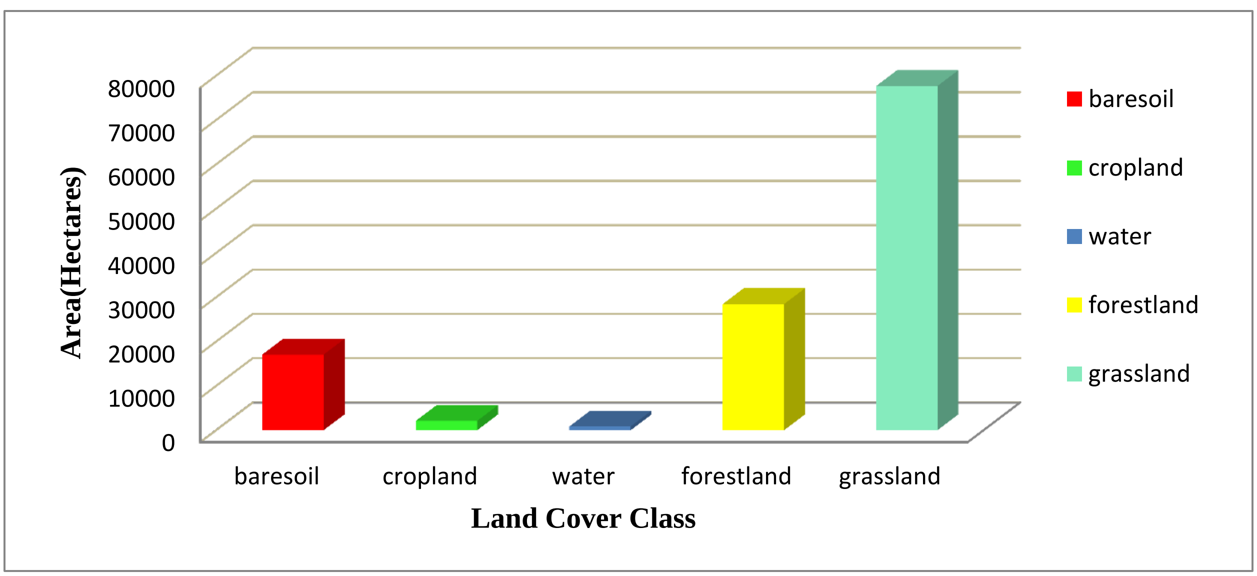


Figure 4.2: Areas (Ha) of LULC classes in 1989

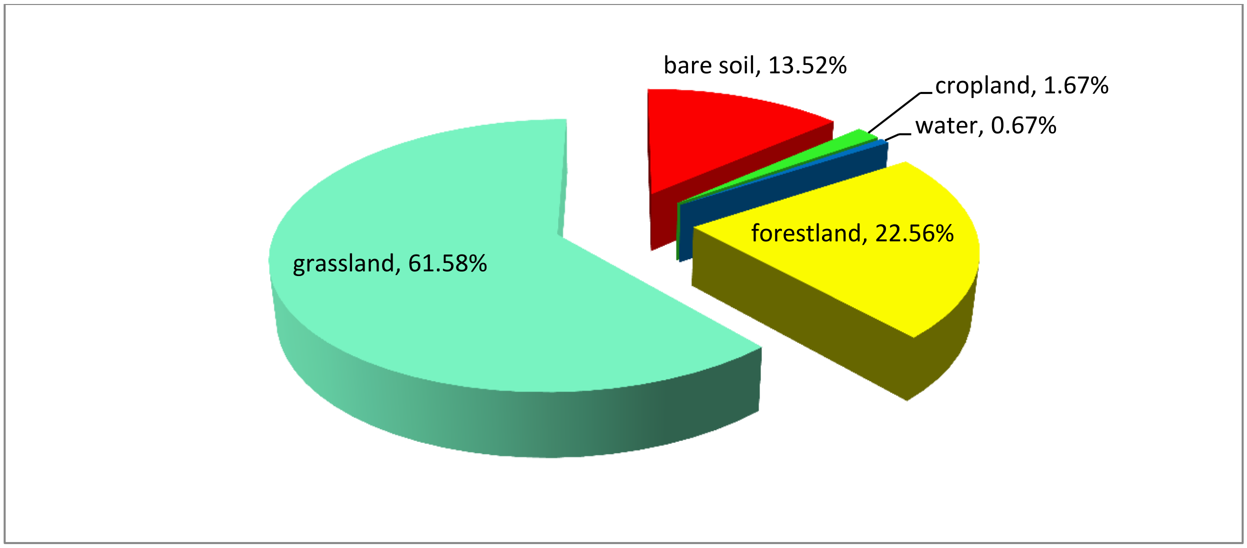


Figure 4.3: Percentages of LULC class areas in 1989

4.2.2 LULC analysis of Insiza dam-catchment in 1998

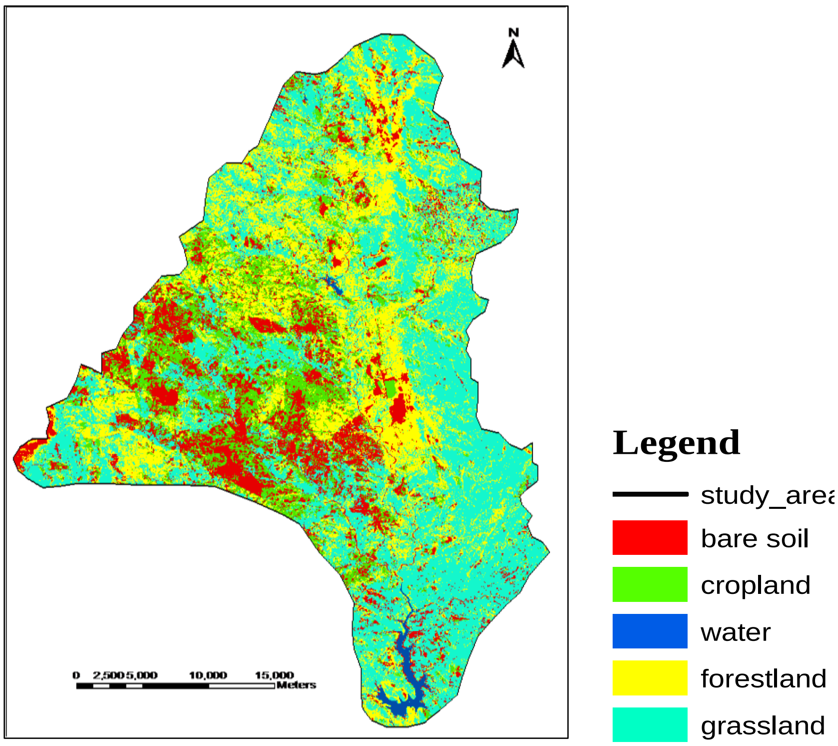


Figure 4.4: Supervised classification map of Insiza dam catchment in 1998

The supervised classification map of the 1998 Landsat stacked layers (Fig 4.4) shows that grassland occupied the largest portion of the map (53 214.57 ha) which was 42.18% of the Insiza dam catchment as shown in Fig. 4.5 and 4.6 and this was mainly concerted on the Eastern and Southern parts of the map. Covering an area of 36 153.54ha, forestland occupied the second largest portion of the Insiza dam catchment which was 28.66% of the total area. Bare soil (18 080.55ha, 14.33%) occupied the next largest area which was almost the same as in 1989. Cropland (17 743.5ha, 14.07%) occupied the second smallest portion of the study area which was a huge increase from 2 104.38ha in 1989. Water occupied almost the same area as in 1989 because it covered a total of 956.79ha or 0.76% of the study area.

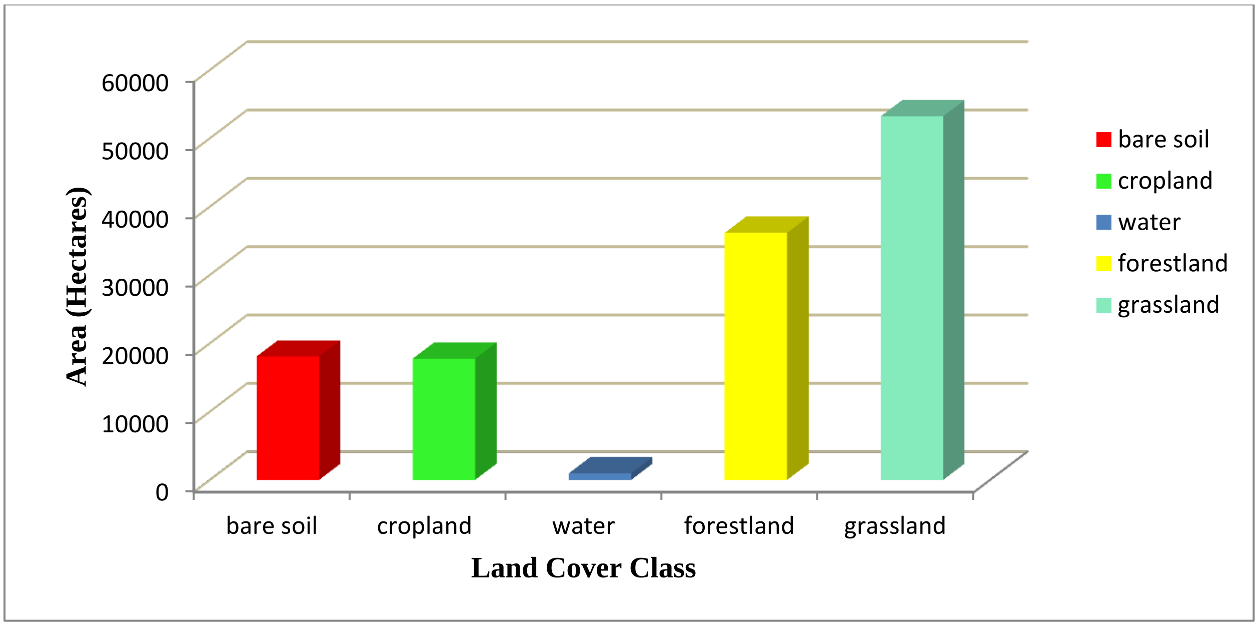


Figure 4.5: Area (Ha) of LULC classes in 1998

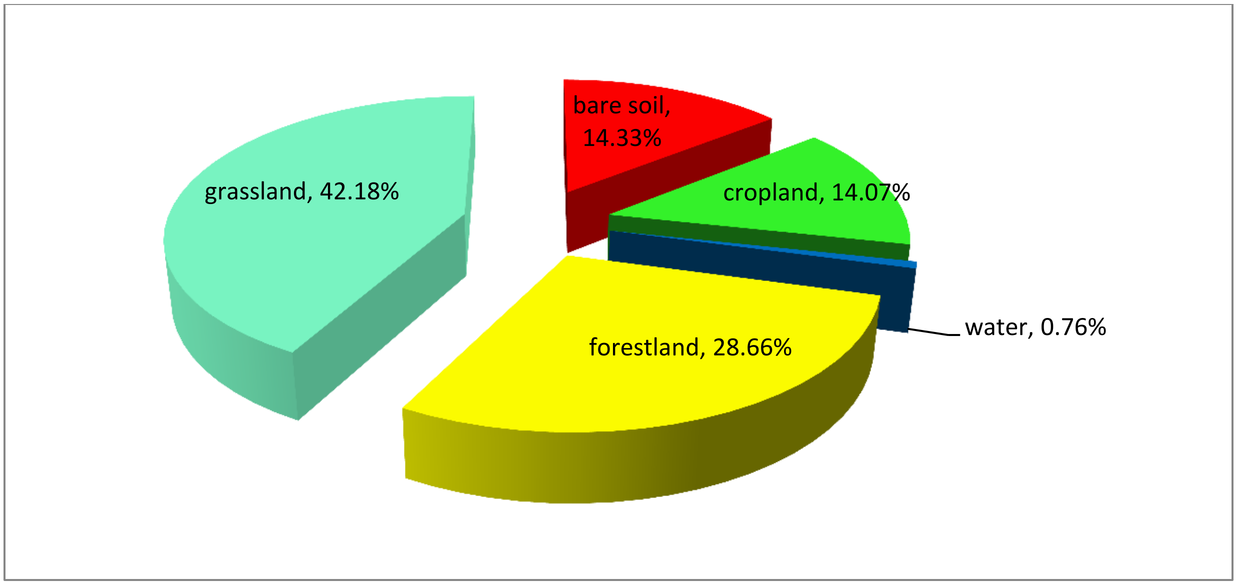


Figure 4.6: Percentages of LULC areas in 1998

4.2.3 LULC analysis of Insiza dam-catchment in 2008

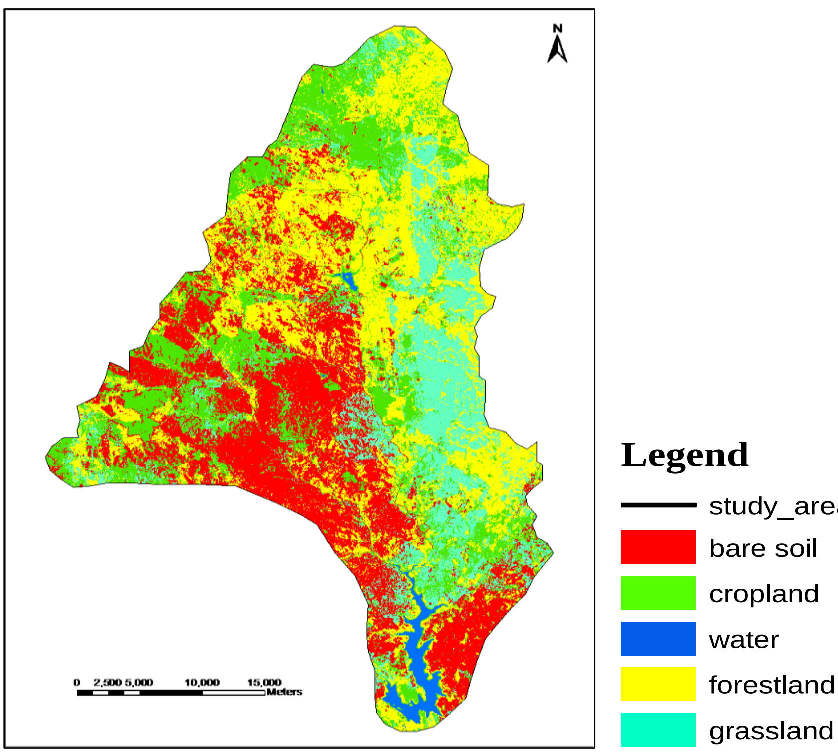


Figure 4.7: Supervised classification map of Insiza dam catchment in 2008

The 2008 supervised classification map (Fig. 4.7) generated that forestland occupied the greatest portion of Insiza dam catchment (34 741.57ha, 27.54%) and this was largely concentrated around the Upper Insiza dam. Cropland occupied the second largest portion of the study area (Fig. 4.8 and 4.9) as it occupied 32 170.69 ha (25.5%) of the study area and this is basically located in the Western and Northern parts of the map and in smaller concentrations in the Eastern part as shown in Fig. 4.7. Grassland (30 521.63 ha, 24.2%) was mostly concentrated in the Southern and Eastern portions of the map. Bare land (26 708.68 ha, 21.17%) was mostly concentrated in the Western part of the map as well as the Eastern side of the Insiza dam and it is also scattered in the Northern section and all over the map in smaller portions. Water covered the smallest area of the map (2 006.38 ha, 1.59%) and this is located in the Upper Insiza and Insiza dams.

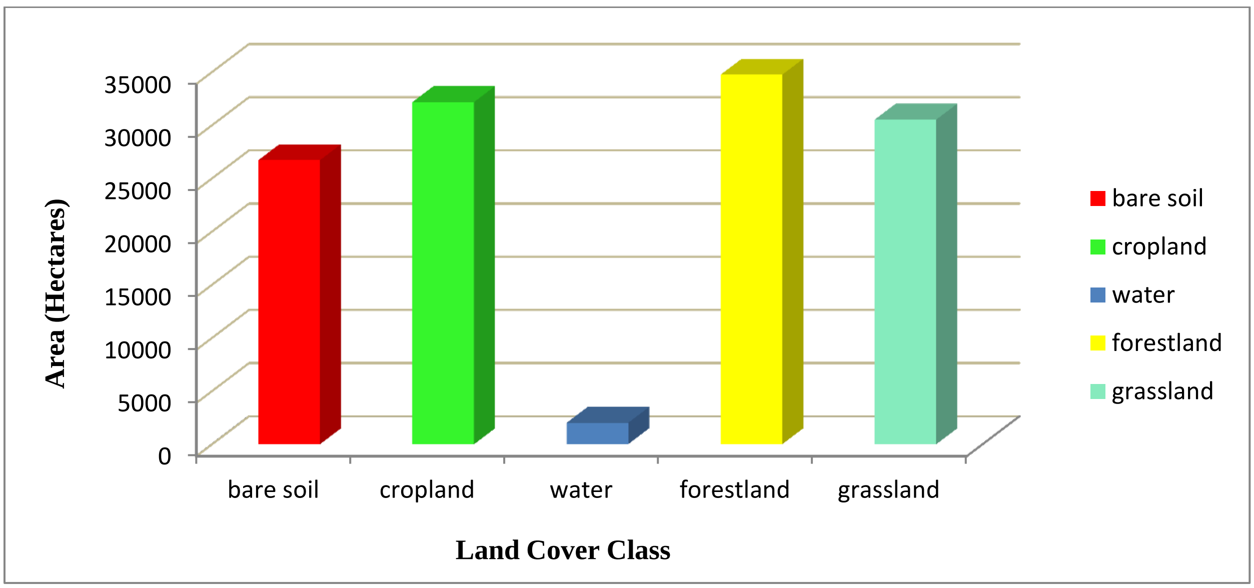


Figure 4.8: Area (ha) of LULC classes in 2008

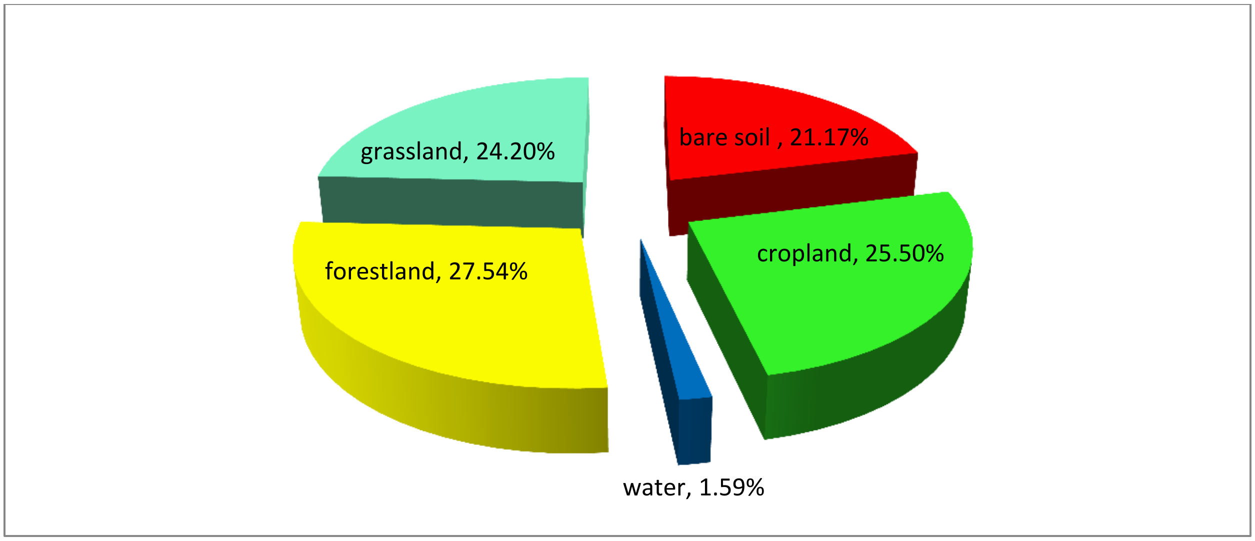
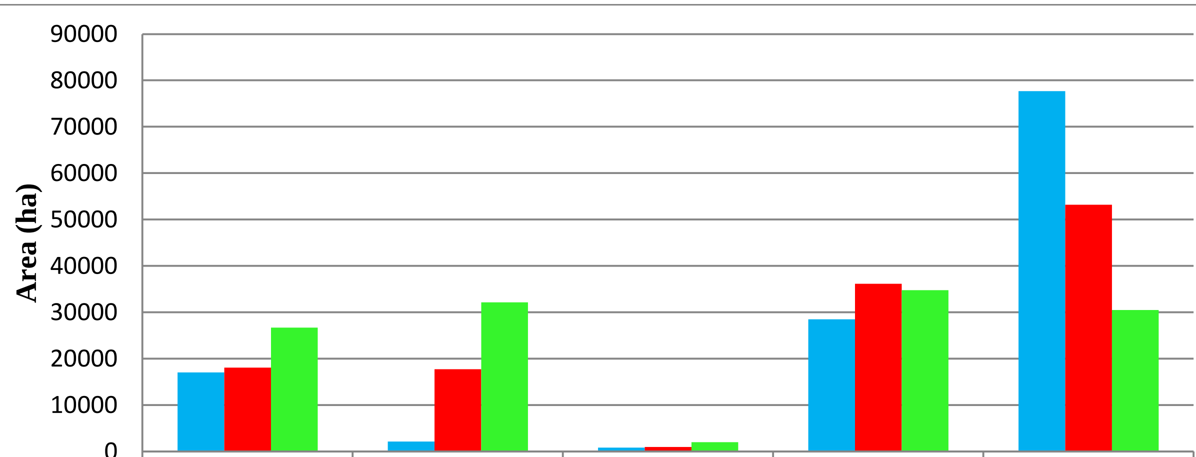


Figure 4.9: Percentages of LULC areas in 2008

There were notable changes in LULC in the Insiza dam-catchment from 1989-2008 (Fig 4.10). Cropland experienced the greatest increase whilst grassland had the highest decrease in land-use. The increase in cropland from 1998-2008 can be attributed to the FTLRP which resulted in increased farm sizes as local farmers took over previously owned white commercial farms. The huge decrease in grassland (Fig 4.10) could have resulted from the increase in farm sizes and or overgrazing because of the arguable surge in livestock as more people inhabit the area.



	bare soil	cropland	water	forestland	grassland
1989	17060.13	2104.38	850.68	28463.67	77670.09
1998	18080.55	17743.5	956.79	36153.54	53214.57
2008	26708.67	32170.86	2006.28	34741.44	30521.97

Figure 4.10: Graphical representation of Land Cover classes in 1989, 1998 and 2008

The population has grown in Insiza district from 78 134 people in 1992 to 85 622 people in 2002 and then to 100 333 people in 2012 (CSO, 2012). The increase in bare soil (Fig. 4.10) from 1998-2008 is greater than that of 1989-1998 and is largely as a result of the increase in human inhabitation accompanied by land clearing for cropping purposes. The land that was previously commercially farmed became bare soil as a result of the lack of resources such as machinery by the resettled farmers in the study area. As a result of population growth, more livestock units are kept by the people and this has an effect on the vegetation as it propagates overgrazing. Gold panning could have also contributed to the increase in bare soil because of the clearing of land for illegal extraction of minerals which is usually carried out using fire.

The surface area occupied by water resources appears to have increased from 956. 79 Ha in 1998 to 2006.38 Ha in 2008 (Fig 4.10). This can be attributed to the siltation of the rivers and reservoirs which can increase the surface area of water whilst decreasing the volume of the water bodies. Surface runoff is likely to decrease as a result of the increase in forest areas because of the interception and percolation facilitated by trees. An increase in land clearing for agricultural use increases runoff but however also increases soil erosion and ultimately causes the sedimentation of the dam and its tributaries.

4.2.4 LULC Accuracy Assessment

Classification accuracy assessment was performed on the 1989, 1998 and 2008 LULC maps for Insiza dam-catchment and the results are shown in Appendix 1, 2 and 3 respectively. The accuracy report included the Kappa coefficient, accuracy totals as well as the error matrices. A Kappa coefficient of 0.7703 (moderate agreement) was achieved for the 1989 classified map which had an overall accuracy of 82.80%. Water had the highest accuracy which was 97.33% whilst cropland had the lowest producers' accuracy being 67.68%. For the 1998 LULC map an overall accuracy of 86.69% and a Kappa Coefficient of 0.8105 were achieved (Appendix 2). The Kappa coefficient shows that there is a strong agreement between the classified image and the ground truth regions of interest. Water had the highest producer accuracy (99.87%) whilst cropland had the lowest (68.85%). The 2008 LULC map yielded an overall accuracy of 75.20% and a Kappa coefficient of 0.6463 (moderate agreement) as shown in Appendix 3. Water had the highest producer accuracy (100%) whilst grassland had the lowest accuracy (22.07%).

4.3 Water balance of Insiza dam-catchment from 1989-2008

Table 4.2 Water balance in 1989

Water use class	**AREA**		**RAINFALL**		**Evapotranspiration**		**RUNOFF**	
	km²	%	mm	10^3 m³	mm	10^3 m³	mm	10^3 m³
Water	8.51	0.6	382	3 250	781.29	6 648	-399.29	-3 397
Forestland	284.64	22.56	382	108 732	545.87	155 376	-163.87	-46 643
Grassland	776.71	61.56	382.1	296 703	359.26	279 044	22.74	17 659
Bare soil	170.6	13.52	382	65 169	107.04	18 261	274.96	46 077
Cropland	21.04	1.67	381.8	8 033	209.16	4 400	172.64	3 632
Total/ average	1261.49	100	382	481 889	353.13	463 731		18 157

There are notable changes in the water balance from 1989 to 2008 as shown in Table 4.2, 4.3 and 4.4. Runoff increased from 1989-1998, 1989-2008 and 1989-2008 by 20.11%, 23.47% and 48.30% respectively. From 1989 to 2008 the amount of evapotranspiration increased in the study area from 463 731 x 10^3 m³ (Table 4.2) to 678 807 x 10^3 m³ (Table 4.4) as a result of the increase in cropland and forestland. Regardless of the increase in the runoff generated in Insiza dam-catchment, the increase was not significant because the annual volume of water that was abstracted from the dam failed to meet the water demands of the city of Bulawayo. This can be as a result of suspected increase in sediment load of the reservoir that may have been induced by the increase in bare soil by 56.56% from 1989-2008 which ultimately reduced the volume of the reservoir causing water to spill-over into the Filabusi River.

The increase in bare-soil from 1989 to 2008 culminated in an increase in surface runoff by 48.30% although the increase in forestland resulted in the opposite effects. As a result of the increase in cropland from 21.04km² in 1989 (Table 4.2) to 321.70km² in 2008 (Table 4.4) the volume of runoff generated from the land cover class greatly diminished as a result of the increase in infiltration capacity of the soil due of cultivation and cropping which increase the soils hydraulic conductivity.

Table 4.3 Water balance in 1998

Water use class	AREA		RAINFALL		Evapotranspiration		RUNOFF	
	km²	%	mm	10^3 m³	mm	10^3 m³	mm	10^3 m³
Water	9.57	0.79	431.04	4 125	822.60	7 872	-391.56	-3 747
Forestland	361.54	28.66	431.69	156 071	571.42	206 589	-139.73	-50 518
Grassland	532.15	42.18	431.70	229 729	367.82	195 734	63.88	33 995
Bare soil	180.81	14.33	471.73	78 061	107.04	19 354	324.66	58 706
Cropland	177.44	14.07	431.68	76 597	525.40	93 226	-93.72	-16 628
Total/ average	1261.49	100	431.70	544 585	399.07	522 777		21 808

Table 4.4 Water balance in 2008

Water use class	AREA		RAINFALL		Evapotranspiration		RUNOFF	
	km²	%	mm	10^3 m³	mm	10^3 m³	mm	10^3 m³
Water	20.06	1.59	581.69	11 668	1123.5	22 536	-541.76	-10 867
Forestland	347.42	27.54	582.09	202 229	781.54	271 522	-199.45	-69 293
Grassland	305.22	24.2	582.10	177 668	503.07	153 547	79.03	24 121
Bare soil	267.09	21.17	582.12	155 478	107.04	28 578	475.08	126 900
Cropland	321.70	25.5	582.12	187 268	718.69	231 201	-136.57	-43 933
Total/ average	1261.49	100	582.10	734 313	538.10	678 807		26 926

5.0 CONCLUSION AND RECOMMENDATIONS

There were notable changes in LULC in Insiza dam-catchment from 1989-2008 of which cropland and grassland had the greatest increase and decrease respectively. Cropland increased by 81.30% following the FTLRP whilst grassland decreased by 154.48%. Water also appeared to have increased in the Insiza dam-catchment because of the suspected increase in sediment load due to the increase in bare soil by 56.56% from 1989-2008. The increase in silt load is likely to have increased the surface area covered by the water whilst reducing the volume of the dam and other water bodies. An increase in forestland and cropland increased the actual evapotranspiration thereby reducing the amount of runoff within the Insiza dam-catchment. Land use change resulted in an increase in runoff from 1989 to 2008 by 52.41% which was as a result of the increase in bare-soil.

There is therefore a need for regulation of LULC activities in the Insiza dam catchment because the changes in LULC have an effect on the water balance which ultimately has an influence on the water yield. Changes in land-use and land-cover should be monitored in catchments because they reduce the water yield and availability for cities such as Bulawayo. The communities residing in the dam-catchment should also be educated or made aware of the effects of their land-use activities on the water balance and water yield of a catchment. For further research, silt surveys can be conducted in the catchments in Zimbabwe so as to determine how LULC changes influence the sedimentation of dams and rivers. The Soil Water Assessment Tool (SWAT) can also be used to determine the effects of LULC on the water yield as a result of sedimentation. The results can then be used to explain why the storage dams are failing to meet the water demands of the cities and how these shortages can be alleviated.

BIBLIOGRAPHY

Abbaspour, S. (2011) *Water quality in Developing Countries, South Asia, South Africa, Water quality management and activities that cause water pollution*. Singapore. Accessed online on http://www.ipcbee.com/vol15/17-U10016.pdf.on 15-02-13 at 2030hrs

Aspinall, R.J. and Hill, M.J. (2008) **Land use change**: Science, Policy and Management. Taylor & Francis Group, Boca Raton, London, New York. Available online on http://www.scribd.com/doc/57407860/Land-Use-Change.

Alam, S. (2010) *Globalization, Poverty and Environmental Degradation: Sustainable Development in Pakistan*. Journal of Sustainable Development, Vol. 3. Canadian Center of Science and Education. Available on http://www.ccsenet.org/jsd. Accessed on 15-03-14 at 1900hrs.

Baker, J. (2012) *Water supply challenges in Bulawayo, Zimbabwe.* GIS in water resources. Available online on http://www.ce.utexas.edu/prof/maidment/giswr2012/TermPaper/Baker.pdf. Accessed on 10-11-13 at 1300hrs.

Beniston, M. (Ed). (2002) **Climate change: implications for the hydrological cycle and for water management**. Kluwer Academic Publishers, Netherlands. Available online on http://link.springer.com/chapter/10.1007%2F0-306-47983-4_16 .

Brown, D., Rance, Chanakira, R.R., Chatiza, K., Dhliwayo, M., Dodman, D., Masiiwa, M., Muchadenyika, D., Mugabe, P., and Zvigadza, S. (2012) *Climate change impacts, vulnerability and adaptation in Zimbabwe*. Available on http://pubs.iied.org/pdfs/10034IIED.pdf.

Chikodzi, D. and Mutowo, G. (2013) *Drought monitoring for Masvingo province in Zimbabwe: A remote sensing perspective*. Herald Journal of Geography and Regional Planning Vol. 2 (1), pp. 056 – 060. Available online on http://heraldjournals.org/hjgrp/pdf/2013/april/Chikodzi%20and%20%20Mutowo.pdf

Claramonte, M.T., (2009) *Effects of Land use/ land cover change on the Hydrological partitioning.* Department of Hydrology and Water resources, The University of Arizona. Available online on http://arizona.openrepository.com/arizona/bitstream/10150/145730/1/azu etd 10775sip1m.pdf. Accessed 10-11-13 at 1330hrs

Demers, M. N. (2005) **Fundamentals of Geographic Information Systems**. John Wiley and Sons, Inc., New York, USA. Available online on http://books.google.co.zw/books/about/Fundamentals_of_geographic_information_s.html?id=hPJOAAAAMAAJ&redir_esc=y

Fallenmark, M., Anderson, L., Custensson, R., Sundblad, K. (1999). *Water: A reflection of land use options for counteracting land and water miss-management.* Swedish Natural Science Research Council.

FAO (2002) *Synthesis report of the FAO electronic workshop*. Available online on ftp://ftp.fao.org/docrep/fao/004/y3618e/y3618e00.pdf. Accessed 15-12-13

Farley, K. A., Jobbagy, E. G. and Jackson, R.B. (2005) *Effects of afforestation on water yield: a global synthesis with implications for policy*. Blackwell Publishing Limited. USA. Available online on http://biology.duke.edu/jackson/gcb05.pdf

Fekele, A. K. (2003) *Land use and land cover in relation to Chromolaena odorata distribution*. Available online on http://www.itc.nl/library/Papers_2003/msc/nrm/abaye.pdf . Accessed 02-05-14 at 2100hrs

Frimpong, A. (2011) *Application of Remote Sensing and GIS for Forest Cover Change Detection*. (A case study of Owabi Catchment in Kumasi, Ghana). Available online on http://dspace.knust.edu.gh:8080/jspui/bitstream/123456789/465/1/ADUBOFOUR%20FRIMPONG.pdf . Accessed on 12-03-14 at 1700hrs

Getachew, H. E. and Melesse, A. M. (2013) *The Impact of Land Use Change on the Hydrology of the Angereb Watershed, Ethiopia*. Intech. International journal of Water Sciences. Available on http://cdn.intechopen.com/pdfs-wm/43448.pdf . Accessed 10-02-14 at 2000hrs.

Giri, C. P. (2012) *Remote Sensing of Land Use and Land Cover- Principles and Applications*. CRC Press 2012. Accessed online on http://www.crcnetbase.com/doi/abs/10.1201/b11964-3. Accessed on 23-01-14 at 1600hrs.

Global Water Partnership (2000) *Southern Africa*. Available online on http://www.gwp.org/en/gwp-in-action/Southern-Africa/ . Accessed 12-01-14 at 1230hrs.

Homdee, T., Pongput, K., and Kanae, S., (2011) *Impacts of Land-cover changes on hydrological responses: A case study of the Chi river basin, Thailand*. Annual Journal of Hydraulic Engineering, JSCE, Vol.55. Available online on http://www.chikyu.mei.titech.ac.jp/suko/2011/0006.pdf. Accessed on 12-02-14 at 1400hrs

Koomen, E., Stillwell, J., Bakema, A., Scholten, H.J. (eds). (2007) **Modelling Land-Use Change Progress and applications.** Springer Publishing. Netherlands. Available online on http://www.researchgate.net/publication/24053790_Modelling_landuse_change_for_spatial_planning_support/file/79e415011aefd0160c.pdf.

Lacombe, G. and Pierrot, A. (2011) *Land cover change and catchment water yield: from local to regional scales*. International conference on Watershed Management. Chiang Mai, Thailand.

Lambin, E. and Geist, H. (2007) *Causes of land-use and land-cover change*. Retrieved from http://www.eoearth.org/view/article/150964. Date 20 January 2014 at 1600hrs

Lazlad (2007) *An overview of the Global Water problems and solutions.* London. Available online on http://www.goftaman.com/daten/en/articles/An%20Overview%20of%20the%20Global%20 Water%20Problems%20and%20Solutions.pdf Accessed on 12 February 2014 at 1900hrs

Levin, N. (1999) *Fundamentals of Remote Sensing.* [On-line]. Available: http://geography.huji.ac.il/personal/Noam%20Levin/1999-fundamentals-of-remote-sensing.pdf Accessed 24-08- 2013 at 1640hrs

Lorup, J.K., Refsgaard, J.C., and Mazvimavi, D. (1998). *Assessing the effect of land use change on catchment runoff by combined use of statistical test and hydrological modelling: case studies from Zimbabwe*. Journal of Hydrology 205: 147-163. Available online on http://coaps.fsu.edu/pub/williams/AGC_presentation/Grindin_2009/New_papers/Lorup_1997.pdf. Accessed on 22 January 2014 at 1600hrs

Love, D., Uhlenbrook, S., Madamombe, E. Twomlow, S., and Van der Zaag, P. (2006) *An evaluation of climate and runoff variability and associated livelihood risks in the Mzingwane*

Catchment, Limpopo basin, Zimbabwe. Available online on https://cgspace.cgiar.org/bitstream /handle/10568/21271/21 271.pdf?sequence=1. Accessed on 12 December 2013 at 1400hrs

Mabiza, C.C., Van der Zaag, P., Ahlers, R., and Manzungu, E. (2008) *Politics and water: insights from Bulawayo.* Available online on http://www.waternetonline.ihe.nl/challenge program/P54%20Mabiza%20Water%20politics.pdf

Maro, P. (2011) **Environmental changes in Lesotho***: An analysis of the causes and consequences of Land-use change in the Lowland region*. Springer science, New York. Available online http://link.springer.com/chapter/10.1007%2F978-94-007-1881-4_1. Accessed 21-12-13

Matsa, M. and Muringaniza, K. (2011*) An assessment of land use and land cover changes in Shurugwi District, Midlands Province, Zimbabwe*. Ethiopian Journal of Environmental Studies and Management Vol. 4 No.2.Available online on www.ajol.info/index.php/ejesm/article/ download/69155/57202

Mazvimavi, D. (1998). *Water availability and utilization in Zimbabwe*, Geographical Journal of Zimbabwe, Vol. 29, 23-36. Available online on http://www.hydrol-earth-systsci.net/14/2671/ 2010/hess-14-2671-2010.pdf

Moyo, B., Madamombe, E., and Love, D. (2005) *A model of reservoir yield under climate change scenarios for the water stressed City of Bulawayo, Zimbabwe.* Available online on http://www.waternetonline.ihe.nl/challengeprogram/P07%20Moyo%20B%20Reservoir%20yield .pdf. Accessed on 12-11-13 at 1530hrs

Musemwa, M. (2008) *Disciplining a 'dissident' city: Hydropolitics in the City of Bulawayo, Matabeleland, Zimbabwe, 1980 – 1992*. Department of History, University of South Africa.

Nugroho, P., Marsono, D., Sudira, P., and Suryatmojo, H. (2013) *Impacts of land use change on water balance.* Kyoto University, Japan. Published by Elsevier. Available online on : http:// www.sciencedirect.com/science/article/pii/S1878029613000388. Accessed 12-02-14 at 1340hrs.

Onema, K.J., Rockstrom, J., Mazvimavi, D., Love, D., Mul, M.L., Van Rooyen, A., and Steve Twomlow, S. (2005) *Influence of human activities on the hydrology of the Insiza river, Limpopo* *basin, Zimbabwe- implications for catchment planning.* Available online on http://www.waternetonline.ihe.nl/documents/2169381603131a7c0b10224fe34db1b8.pdf.Accessed on 11-12-13 at 1800hrs.

Opeyemi, Z.A. (2006*) Change detection in land-use and land-cover using Remote sensing data and GIS.* Available on www.geospatialworld.net/uploads/thesis/opeyemizubair_thesis doc.doc

Phiri, S. (2011) *Impact of artisanal small scale gold mining in uMzingwane District (Zimbabwe)*. Available online on http://natagri.ufs.ac.za/dl/userfiles/Documents/00002/2302_eng.pdf.

Prakasam, C. (2010) *Land use and land cover change detection through Remote sensing approach*. University of Burdwan. Journal of Geomatics and Geosciences Vol 1. Available online -http://www.ipublishing.co.in/jggsvol1no12010/EIJGGS1015.pdf. Accessed 10-11-2013

Rajora, R. (1998) **Integrated Watershed Management-Principles and Practice**. John Wiley and Sons, London. Available online on http://www.poptel.org.uk/iied/sarl/gatekeepers/gk_back issues/documents/GK113.pdf

Reis, S. (2008) *Analyzing Land-use/ land-cover changes using remote sensing and GIS in Rize North East Turkey*. Aksaray University. Available online on http://www.ncbi.nlm.nih .gov/pmc /articles/PMC3707445/pdf/sensors-08-06188.pdf . Accessed 02-03-14 at 2100hrs

Rogan, J. and Chen, D. (2003) *Remote sensing technology for mapping and monitoring land-cover and land- use change*. Progress in Planning, 61, 301–325. Elservier. Available on http://www.clarku.edu/departments/geography/pdfs/Rogan%20&%20Chen%202004.pdf

SADC/Zambezi River Authority (2008) *Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin.* Available online on http://bscw-app1.let.ethz.ch/pub/bscw.cgi/d11576619/ZRB_water_balance.doc.

Sibanda, P.N. (2002) *Water supply and Sanitation: How have African cities managed the sector? What are the possible options?* Available online on http://info.worldbank.org/etools/docs/library

/110868/kampala/docs/Water%20Supply%20and%20Sanitation-%20word-%20P%20Sibanda.pdf. Accessed on 14-11-13 at 1400hrs

UNDP (2013) *Water and ocean governance*. Available online on http://www.undp.org/content/undp/en/home/ourwork/environmentandenergy/focus_areas/water_and_ocean_governance.html

UNESCO (2003). *Integrated water respources Management*. Available on http://whycos.org/cms/sites/default/files/pdf/projects/Pacific/Training/Surface_Waters/Integ_WR_Mangmt.pdf
.

UN-Water (2006) *Coping with water scarcity*. A strategic issue and priority for system-wide action. http://www.unwater.org. Online - accessed 19/03/2014 at 2130hrs

Wagner, P.D., Kumar, S. and Schneider, K. (2013) *An assessment of land use change impacts on the water resources of Mula and Mutha River catchment upstream of Pune, India*. Copernicus Publications. Available online on http://www.hydrol-earth-syst-sci-discuss.net/10/1943/2013/hessd-10-1943-2013-print.pdf. Accessed on 16-02-14 at 1900hrs

Wang, S., Fu, B., He, C., Sun, G. and Gao, G. (2011) *A comparative analysis of Forest cover and catchment water yield relationships in Northern China*. Elsevier. Available online on http://www.admin.forestthreats.org/products/publications/A_comparative_analysis_of_forest_cover_and_catchment.pdf

Wong, G. (2013) *China's war on water scarcity: slaking the thirst of a huge nation*. Available online on https://www.pwc.com/gx/en/capital.../chinas-war-on-water-scarcity.pdf. Accessed on 12-01-14 at 1200hrs

Yasamis, F. D. (2011) *Economic instruments of environmental management*. Istanbul Aydin University, Turkey. Accessed- 27/02/2013 at 1600hrs. Available online on http://www.iaees.org/publications/journals/piaees/articles/2011-1(2)/Economic-instruments-environmentalmanagement. pdf. Accessed on 22-01-14 at 1300hrs

Appendices

Appendix 1: Confusion Matrix: C:\project\24 Sep 1989 TM L1T\maskedmaxlike1989

Overall Accuracy = (12437/15021) 82.7974%

Kappa Coefficient = 0.7703

Class	Ground Truth (pixels)				
	Cropland	Water	Forestland	Grassland	Bare soil
Cropland [green]	1250	56	4	1	1
Water [blue]	0	4123	0	0	0
Forestland [yellow]	32	38	1938	1615	25
Grassland [cyan]	527	19	130	4118	61
Bare soil [red]	38	0	0	37	1008
Total	1847	4236	2072	5771	1095

Ground Truth (Pixels)	
Class	Total
Cropland [Green]	1312
Water [Blue]	4123
Forestland [Yellow]	3648
Grassland [Cyan]	4855
Bare soil [Red]	1083
Total	15021

Class	Ground Truth (%)				
	Cropland	Water	Forestland	Grassland	Bare soil
Cropland [Green]	67.68	1.32	0.19	0.02	0.09
Water [Blue]	0.00	97.33	0.00	0.00	0.00
Forestland [Yellow]	1.73	0.90	93.53	27.98	2.28
Grassland [Cyan]	28.53	0.45	6.27	71.36	5.57
Bare soil [Red]	2.06	0.00	0.00	0.64	92.05
Total	100.00	100.00	100.00	100.00	100.00

Ground Truth (percent)	
Class	Total
Cropland [Green]	8.73
Water [Blue]	27.45
Forestland [Yellow]	24.29
Grassland [Cyan]	32.32
Bare soil [Red]	7.21
Total	100

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Cropland [Green]	4.73	32.32	62/1312	597/1847
Water [Blue]	0.00	2.67	0/4123	113/4236
Forestland [Yellow]	46.88	6.47	1710/3648	134/2072
Grassland [Cyan]	15.18	28.64	737/4855	1653/5771
Bare soil [Red]	6.93	7.95	75/1083	87/1095

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Cropland [Green]	67.68	95.27	1250/1847	1250/1312
Water [Blue]	97.33	100.00	4123/4236	4123/4123
Forestland [Yellow]	93.53	53.13	1938/2072	1938/3648
Grassland [Cyan]	71.36	84.82	4118/5771	4118/4855
Bare soil [Red]	92.05	93.07	1008/1095	1008/1083

Appendix 2: Confusion Matrix: C:\project\15 July 1998 TM L1T\maskedmaxlike1998

Overall Accuracy = (8338/9618) 86.6916%

Kappa Coefficient = 0.8105

Class	Ground Truth (pixels)				
	Bare soil	Cropland	Forestland	Grassland	Water
Bare soil [red]	428	401	292	13	0
Cropland [green]	55	935	44	243	0
Forestland [yellow]	10	19	1353	173	3
Grassland [cyan]	0	3	21	1039	3
Water [blue]	0	0	0	0	4583
Total	493	1358	1710	1468	4589

Ground Truth (Pixels)	
Class	Total
Bare soil [Red]	1134
Cropland [Green]	1277
Forestland [Yellow]	1558
Grassland [Cyan]	1066
Water [Blue]	4583
Total	9618

Class	Ground Truth (Percent)				
	Bare soil	Cropland	Forestland	Grassland	Water
Bare soil [red]	86.82	29.53	17.08	0.89	0.00
Cropland [green]	11.16	68.85	2.57	16.55	0.00
Forestland [yellow]	2.03	1.40	79.12	11.78	0.07
Grassland [cyan]	0.00	0.22	1.23	70.78	0.07
Water [blue]	0.00	0.00	0.00	0.00	99.87
Total	100.00	100.00	100.00	100.00	100.00

Ground Truth (Percent)	
Class	Total
Bare soil [Red]	11.79
Cropland [Green]	13.28
Forestland [Yellow]	16.20
Grassland [Cyan]	11.08
Water [Blue]	47.65
Total	100.00

Class	Commission (percent)	Omission (percent)	Commission (pixels)	Omission (pixels)
Bare soil [red]	62.26	13.18	706/1134	65/493
Cropland [green]	26.78	31.15	342/1277	423/1358
Forestland [yellow]	13.16	20.88	205/1558	357/1710
Grassland [cyan]	2.53	29.22	27/1066	429/1468
Water [blue]	0.00	0.13	0/4583	6/4589

Class	Prod. Acc. (percent)	User Acc. (percent)	Prod. Acc. (pixels)	User Acc. (pixels)
Bare soil [red]	86.82	37.74	428/493	428/1134
Cropland [green]	68.85	73.22	935/1358	935/1277
Forestland [yellow]	79.12	86.84	1353/1710	1353/1558
Grassland [cyan]	70.78	97.47	1039/1468	1039/1066
Water [blue]	99.87	100.00	4583/4589	4583/4583

Appendix 3: Confusion Matrix: C:\project\27 August 2008 TM\maskedmaxlike2008

Overall Accuracy = (7233/9618) 75.2027%

Kappa Coefficient = 0.6463

Class	Ground Truth (pixels)				
	Bare soil	Cropland	Water	Forestland	Grassland
Bare soil [red]	68	63	0	2	706
Cropland [green]	170	1149	0	629	93
Water [blue]	0	0	4589	0	0
Forestland [yellow]	45	30	0	1003	345
Grassland [cyan]	110	116	0	76	324
Total	493	1358	4589	1710	1468

Ground Truth (Pixels)	
Class	Total
Bare soil [Red]	939
Cropland [Green]	2041
Water [Blue]]	4589
Forestland [Yellow	1423
Grassland [Cyan]	626
Total	9618

Class	Ground Truth (percent)				
	Bare soil	Cropland	Water	Forestland	Grassland
Bare soil [red]	34.08	4.64	0.00	0.12	48.09
Cropland [green]	34.48	84.61	0.00	36.78	6.34
Water [blue]	0.00	0.00	100.00	0.00	0.00
Forestland [yellow]	9.13	2.21	0.00	58.65	23.50
Grassland [cyan]	22.31	8.54	0.00	4.44	22.07
Total	100.00	100.00	100.00	100.00	100.00

Ground Truth (Percent)	
Class	Total
Bare soil [Red]	9.76
Cropland [Green]	21.22
Water [Blue]]	47.71
Forestland [Yellow	14.80
Grassland [Cyan]	6.51
Total	100.00

Class	Commission (percent)	Omission (percent)	Commission (pixels)	Omission (pixels)
Bare soil [red]	82.11	65.92	771/939	325/493
Cropland [green]	43.70	15.39	892/2041	209/1358
Water [blue]	0.00	0.00	0/4589	0/4589
Forestland [yellow]	29.52	41.35	420/1423	707/1710
Grassland [cyan]	48.24	77.93	302/626	1144/1468

Class	Prod. Acc. (percent)	User Acc. (percent)	Prod. Acc. (pixels)	User Acc. (pixels)
Bare soil [red]	34.08	17.89	168/493	168/939
Cropland [green]	84.61	56.30	1149/1358	1149/2041
Water [blue]	100.00	100.00	4589/4589	4589/4589
Forestland [yellow]	58.65	70.48	1003/1710	1003/1423
Grassland [cyan]	22.07	51.76	324/1468	324/626