EFFECTS OF LAND USE AND LAND COVER CHANGE ON SEDIMENT YIELD FOR UPPER SEBAKWE AND UPPER NYAZVIDZI SUB-CATCHMENTS IN CHIKOMBA DISTRICT

By: Blessing Chiwera – R0122577

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ABSTRACT

The study of the response of sediment yield to land use and land cover changes is quite critical for watershed management and policy formulation. This research investigated the effect of land use and land cover changes to sediment yield from upper Sebakwe and upper Nyazvidzi sub-catchments. Changes in land use and land cover were determined by the use of Landsat Thematic Mapper ™ imagery for years 1984, 1994, 2004 and 2010 using ArcMap^{TM} 10 tool. Sediment yield resulting from the land use and land cover changes was calculated using the Regional Small Catchment Sediment Yield Prediction Model for years 1984, 1994, 2004 and 2010. The effects of changes in land use and land cover to sediment yield were evaluated based on the correlation tested between the parameters.

In upper Nyazvidzi sub-catchment, 31.2% of forest area was lost while in upper Sebakwe sub-catchment, there was a loss of 31.3%. Cultivated land increased by 10.9% for upper Nyazvidzi while a slight 0.1% was increased in upper Sebakwe. Pasture land increased by 38.2% and 31% for upper Nyazvidzi and Sebakwe sub-catchments respectively. There was a significant loss of water bodies in upper Nyazvidzi with a reduction by 16.8% while Sebakwe gained by 0.1%. These changes in land use and land cover resulted in significant changes in sediment yield for both sub-catchments. This study proved that land use and land cover changes are usefully correlated to sediment yield in both sub-catchments.

These findings are relevant to sub-catchments which are experiencing dynamic land use and land cover changes which often lack measurement. The resultant effects of these changes are of great concern relative to sediment yield which causes siltation of water bodies and loss of watershed integrity in many sub-catchments.

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CHAPTER 1: INTRODUCTION

Land is one of three major factors of production in classical economics, along with labour and capital. It is an essential input for housing and food production. Land is also the backbone of agricultural economies and it provides substantial and social benefits. However, any form of economic development will necessitate land use changes, in line with social progress (United States Environmental Protection Agency (USEPA), 2000). The scientific definition of land use implies the syndromes of human activities that alter the processes of land surfaces. These may include such activities as building construction, forestry and cultivation.

Land cover can be defined as the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. Direct observation in the field or remotes sensing are some of the methods that can be used to assess land cover dynamics. Land cover changes generally require an integration of natural and social scientific methods that include expert knowledge of the areas under observation to be able to determine the human activities that occur in different parts of a landscape. Scientific investigation into the causes and consequences of land use and land cover change require an approach that integrates both the natural and social scientific methods.

The analysis of land use change revolves around two central and interrelated questions: "what drives/ causes land use" and "what are the environmental and socio-economic impacts of land use change" (Briassoulis, 2006).

The precise meaning of the "drivers" or "determinants" of land use is not always clear. However, there are two main categories widely accepted: biophysical and socio-economic drivers [Briassoulis, 2006). The biophysical drivers include the characteristics and processes of the natural environment such as climate variation, landform, and geomorphic process, plant succession, soil types and process and drainage patterns. The socio-economic drivers comprise demographic, social, economic, technological, market, political and institutional factors and their processes (Briassoulis, 2006)

Land use and land cover changes may be due to, for example, burning of areas to enhance availability of wildlife and deforestation. Industrialisation, coupled with increasing concentrations of human populations has induced intensification of agriculture in the most productive lands. Sometimes changes may be due to the abandonment of marginal lands.

Consequences of land use and land cover may include biodiversity loss, climate change from greenhouse gases and altered hydrology of local catchments. These consequences may be assessed by means of remote sensing, geospatial analysis and modelling.

Land use and land cover changes may induce soil erosion especially in cases of severe deforestation, overgrazing and over-tilling of the land. The increase in soil erosion may result in the increase in sediment yield in a catchment that is not adequately protected. Sediment yield can be defined as the total volume of sediment that passes through a given point.

Sediment yield estimates have been found to have important economic consequences where in South Africa in 1989, offsite damage of erosion was estimated at US$ 37.6 million annually (Braune and Looser, 1989).

Experimental data tend to indicate that changes in land use have a greater effect on sediment yield than on either total runoff or runoff intensity (Leopold and Maddock, 1954). The removal of vegetal cover from a land surface results in the initial increase in the resultant rate of removal of top soil. Both cultivation and grazing have increased sediment yield over that obtaining in the natural or original condition and the amount is variable depending on the local conditions. Variations in sediment yield could be accredited to differences in parameters such as type and condition of plant cover, soil type and slope.

Resettlement is a continuous process that demands change of use of virgin lands, which then become cultivated lands and built-up areas. With this, there is a continuous deterioration of the ecosystem on which we depend for our well-being (Preamble to the United Nations Agenda 21 on sustainable Development). Upper Sebakwe and Upper Nyazvidzi sub-catchments in Chikomba District have experienced resettlement with tenure systems in the form of individual or private, and communal land ownership respectively.

Based on records with Ministry of Lands and Rural Resettlement (2014), Sebakwe sub-catchment had 24 Large Scale Commercial Farms (LSCF) from 1984 to 1998. Of these, 18 farms were put under A1 and A2 resettlement schemes in the years 1999/2000, with a total of 556 self-contained plots. Manyene communal area is part of the sub-catchment. Villages 1 to 12 were established on 7 LSCFs in Nyazvidzi sub-catchment in 1984 with a total of 276 households. One (1) farm is under 108 A1 self-contained plots and nine are under the Lancashire (SSCF). Parts of Madamombe and Nharira communal areas are also included in the sub-catchment.

These establishments have seen land use changes and modifications occurring where these LSCF, mainly cattle ranches, have been converted to small scale intensive, mixed cropping farming units (SSCF, A1 self-contained and Villagised Schemes).

The aim of this research was to detect sub-catchment land use and land cover changes and relate the changes to sediment yield over a 26-year period, from 1984 to 2010. There is need to integrate protection of the environment and development concerns so as to achieve better-protected and better-managed ecosystems (Preamble to the United Nations Agenda 21 on Sustainable Development)

An understanding of the complex interaction of these changes in their temporal and spatial patterns and processes is the baseline to formulate focused and targeted policy interventions in rural development and environmental management.

1.2 Statement of the Problem

Chikomba District has a watershed divide for Munyati, Save, Ngezi, Sebakwe, Nyazvidzi, Nyamatsanga and Mwerahari catchments. The resettlement exercises were done without paying particular attention to the land classes inherent in the sub-catchments. As a result, people were settled on the upper sub-catchments, starting from the sources of Sebakwe and Nyazvidzi rivers. The exercise has resulted in recorded instances of deforestation (Forestry Commission Chikomba District Annual Reports, 2014), riverbank cultivation (Environmental Management Agency Chikomba District Annual Reports, 2014). Siltation of the river systems has been observed beginning at the upper river catchments due to sedimentation.

1.3 Justification of the Study

Sustainable land management is one of the major challenges in watershed management programs. Demand for food security for growing human populations usually comes with the need to link the procurement of land resources with potentially negative consequences. Acquisition of land for resettlement also carries with it the need to evaluate the pros and cons of such developments with the aim of attaining sustainability in land management. In the area of study, there is no record of measurement nor documentation on the rate of land use and land cover changes and the levels of sedimentation that is occurring to Sebakwe and Nyazvidzi sub-catchments since resettlement was instituted. Moreover, there is no record of a similar project that has been done in the study area, which implies a gap in knowledge of the processes that are happening between human activities and the watershed environment. There is therefore need to quantify the changes that are taking place in these areas and equate the instantaneous benefits of land use and land cover change against future sustainability of water resources.

There is need for comprehensive research into the possible contribution that land use and land cover change may have on sedimentation levels and the overall condition and status of the watershed. Home grown solutions to managing the natural resources in the resettlement areas cannot be underscored. This is an invaluable resource in informing policy.

1.4 Main Objective

The main objective of this study is to quantify changes in land use and land cover over a 26-year period from 1984 to 2010 and estimate sediment yield resulting from the land use and land cover changes for upper Sebakwe and upper Nyazvidzi sub-catchments in Chikomba District.

1.4.1 Specific Objectives

The specific objectives are to:

1. Quantify the land use and land cover changes that have occurred to upper Sebakwe and upper Nyazvidzi sub-catchments for 1984, 1994, 2004 and 2010.
2. Estimate sediment yield resulting from land use and land cover changes from the two sub-catchments

1.6 Hypotheses

Null Hypothesis: There is no significant changes in land use and land cover in the two sub-catchments from 1984 to 2010 at 95%Confidence Interval

Alternate Hypothesis: There is significant changes in land use and land cover in the two sub-catchments from 1984 to 2010 at 95% Confidence Interval.

Null Hypothesis: There are no significant changes in sediment yield resulting from land use and land cover changes from the two sub-catchments

Alternate Hypothesis: There are significant changes in sediment yield resulting from land use and land cover changes from the two sub-catchments

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Land use and land cover changes are a result of human intervention in the natural ecosystem. The effects of changing land use and land cover to sediment yield need to be quantified so that an understanding of the processes and linkages existing may be used to formulate timely interventions and policies that enhance the protection of watershed integrity.

According to Turner *et al*., (1993), about 40% of the earth's surface has already been modified, save for those areas that are of peripheral location or those that are inaccessible. Most of the land cover changes of the present and the recent past are due to human actions, that is, to using of the land for production or settlement (Briassoulis, 2006; Turner II, Skole, Sanderson, Fischer, Fresco and Leemans, 1995). Similarly, land use change involves conversion from one type of use to another.

Modification of a particular land use may involve change in the intensity of this use as well as alteration of its characteristics qualities/attributes. In the case of agricultural land use, Jones and Clark (1997) provide a qualitative typology of land use change: intensification, extensification, marginalization and abandonment. Intensification results in the loss of permanent grassland, due to arable conversion or reseeding of permanent grassland or abandonment of agriculture. The Institute of European Environmental Policy (2010) projected that intensification of conventional agricultural systems will contribute to further losses of soil carbon, and reductions in soil water retention and water quality.

Lambin *et al.,* (1999) and Turner *et al.*, (1995) indicated that land use change is a common phenomenon associated with population growth, market development, constitutional factors and policy action. The entire ecological infrastructure such as change of vegetation cover, a change in soil characteristics, plant and animal population and hydrological cycle have been strongly influenced by the conversion of land and forest resources.

Watersheds and their associated services have an important role to play in land use and land cover change studies. A watershed may be defined as the area or ridge of land that separates waters flowing to different rivers, basins or seas (USEPA, 2000). Alternatively, a watershed can also be defined as the surface area drained by a part or the totality of one or several given water sources and can be taken as a basic erosional landscape where land and water resources interact in a perceptible manner (Abrahams, 1984).

The main functions of watersheds are to provide an adequate and regular quantity of water, to reduce the amount of soil movement and to provide a good supply of high quality drinking water (Preamble to the UN Agenda 21 on Sustainable Development). The introduction of roads, livestock and agricultural activities into a watershed all lead to deforestation, rill erosion and sedimentation downstream in a river catchment (Lu, Brondi'Zio and Moran, 2004a). One of the major direct environmental impacts of development is the degradation of water resources and water quality (USEPA, 2000). Conversion of agricultural, forest, grass, and wetlands to urban areas usually comes with a vast increase in impervious surface, which can alter the natural hydrologic condition within a watershed.

Land use and land cover changes have been found to have a link to the amount of sediment that a can be output from a catchment. A study by Wallingford (1999) concluded that soil erosion is highly sensitive to land use change and human activities. However, the study emphasized that investigations into the impact of land use and human activities should also take into account overall sediment budgets of a catchment rather than just the sediment output.

Different types of vegetation cover also have significant and important differences in run-off generation and production of sediment, (Mohammad and Adam, 2010). In a study carried out in Bathurst Area of New South Wales, surveys conducted for granite catchments demonstrated that land use is the dominant factor determining soil loss rates and sediment yield, (Mahmoudzadeh, Erskine and Myers, 2002). The results showed dam sediments having a higher clay content compared to catchment top soil. Cultivated lands and grazing areas had higher sediment yield being compared with forest.

2.2 Methods for studying land use and land cover changes

Several methods exist that are used to study changes in land cover and land use. Topographical maps, aerial photographs and empirical models can be used to detect changes in land use and land cover. Remote sensed data provides the capability to monitor a wide range of landscape biophysical properties important to management and policy, where information on these variables is needed in the past, present and future (McVicar, Briggs, King and Raupach, 2003). The GIS and Remote Sensing technique is highly relevant for this study.

2.21 Remote Sensing

Remote sensed data provide the capability to monitor a wide range of biophysical properties important to management and policy, where information on these variables is needed in the past, present and future (McVicar *et al.*, 2003). Cameras, Multi-Spectral Scanners, RADAR and LIDAR sensors mounted on spacecraft platforms are used to capture geo-spatial data to produce satellite imagery. There are several imagery satellites which vary in imaging characteristics, for example Landsat series, Spot, Aster, Ikonos, Quick Bird and Geoeye. Landsat series of satellites has provided a continuous coverage since 1972, for environmental data through its Multi-spectral scanner (MSS), Thematic Mapper (TM) and enhanced TM sensor (ETM) (Guindon & Zhang 2002).

Regional datasets of high resolution like Landsat and SPOT are efficient for land use and land cover change studies as data is provided at regular time intervals.

2.3 Land Use and Land Cover Change Detection

According to Lu *et al.*, (2004a), change detection involves identification of differences in the state of an object or phenomenon by observing and quantifying it at different times. The enhancement of better management and use of natural resources comes from an understanding of the relationships and interactions between humans and the environment, as part of change detection (McVicar *et al*, 2003).

Change detection approaches can be placed into two main groups; bi-temporal change detection (direct comparison, post-analysis comparison and uniform modeling) and temporal trajectory analysis (time series analysis) (Jianya, Haigang, Guorui and Qining, 2008). The former measures changes based on a simple ‘two-epoch’ timescale comparison. The latter, which has been adopted for this study, analyses the changes based on a ‘continuous’ timescale, focusing both changes between dates and the progress of the change over the period.

For image classification for the purposes of change detection, Deer (1995) puts the classification approaches into three categories: pixel-based, feature-based and object-based change detection methods. Lu *et al* (2004a) classify the methods into seven groups, that is, direct comparison, classification comparison, object-oriented methods, model-based methods, time-series analyses, visual analyses, and hybrid methods.

2.4 Methods for Estimating Sediment Yield from catchments

Several methods also exist that can be used to estimate soil loss from catchments. Soil erosion is the loss of topsoil from a catchment per unit area. Sediment yield refers to the amount of sediment exported by a basin over a period of time, which is also the amount which will enter a reservoir or pond located at the downstream limit of the basin (Morris and Fan, 1998).

Empirical models like the Universal Soil Loss Equation (USLE), Soil Loss Estimation Model for Southern Africa (SLEMSA) and Revised USLE can be used to predict soil erosion rates. The USLE was developed by Wischmeier and Smith in 1965 for the prediction of average soil losses in run-off over a long time from specific fields in specific cropping and management systems (Wischmeier and Smith, 1978). 11 000 plot years of research data from 47 locations in 24 states of the United States of America were analysed. The basic equation takes into account rainfall and runoff erosivity index, soil erodibility factor, slope and length of slope factor, cropping management factor and erosion control factor. The factors are used for the estimation of mean annual soil loss in tonnes per hectare per year.

The SLEMSA model is also used for estimation of soil erosion which is measured in tonnes of soil lost per hectare per year. The model was developed in Zimbabwe to estimate the long term mean annual soil loss from sheet erosion on arable land. The model was developed as a way of adapting the USLE to African environments (Elwell and Stocking, 1977). Four physical systems are defined in the model; climate, soil, crop and topography. Estimations of soil loss are done by use of the erodibility factor, the crop factor as well as the topographic factor.

However, the correlation of sediment yields to erosion is complicated. The determination of sediment delivery ratio makes it difficult to estimate the sediment load entering a reservoir/pond on the basis of erosion rate within the catchment (Morris and Fan, 1998). Other methods exist that can be used to accurately predict sediment yield from catchments.

2.5 Grab Sampling

The normal method for sediment sampling in Zimbabwe's river systems is the grab sampling technique (Karlson and Rahmberg, 1999). A sampling bottle is placed at the most turbulent point in the flow, usually taken from the riverbank. Depth integrated sampling is used for more accurate measurement of sediment transport in a river.

2.6 Empirical Models

The Regional Small Catchment Sediment Yield Prediction Model has been used to estimate sediment yield for several catchments in Zimbabwe and Tanzania. This model was developed by Wallingford (2004) for estimation of sediment yield from small catchments. The catchment factors selected for inclusion in the predictive relationship, on the basis of correlation with the measured sediment yields, are; Signs of active soil erosion (SASE), Soil type and drainage (STD), Vegetation conditions over the whole catchment (VC) and Catchment slope (Slope) (Wallingford, 2004). The catchment factors are derived using the guidelines outlined on Table 2.

From this information the sediment yield can be predicted, using an empirical predictive equation which is as follows:

$$\mathbf{SY = 0.0194.\ Area^{-0.2}\ .MAP^{0.7}\ .Slope^{0.3}\ .SASE^{1.2}\ .STD^{0.7}\ .VC^{0.5}}$$

$r^2 = 0.95$ SE = 198

Where: SY = Sediment yield ($t/km^2/year$)

Area = Catchment area (km^2)

MAP = Mean annual precipitation (mm)

Slope = River slope from the catchment boundary to the outlet

SASE = Signs of active soil erosion (Score from catchment characterisation)

STD = Soil type and drainage (Score from catchment characterisation)

VC = Vegetation condition (Score from catchment characterisation)

Sediment yield from the sub-catchment is determined by rates of soil erosion as well as the sediment transport and deposition processes that control the delivery of eroded sediment via the fluvial system to the catchment outlet (Wallingford, 2004). Catchment characteristics such as soil types, rainfall intensity and distribution, land use and conservation activities all affect sediment yields. These parameters tend to vary widely in semi-arid regions from year to year.

1:50 000 topographic maps covering the catchment area and a compass are essential tools for catchment characterisation. As it can be very difficult to locate positions in relatively flat featureless catchments, particularly under scrub or woodland, a hand held global positioning satellite equipment (GPS) is very useful, as are up-to-date aerial photographs of the catchment, preferably at a scale of about 1:25 000.

The proposed outlet for the sub-catchments and the physical catchment boundary should be marked accurately on the 1:50 000 topographic maps. Where the topography is very flat it can sometimes be difficult to define the catchment boundaries from maps, and it may be necessary to confirm the location of the catchment boundaries during the field visit. If the catchment is larger than about 30 km2 it should be subdivided into two or three sub-catchments, which should be characterised separately. Where there is a wide range in relief, soil type and/or land use, it may also be useful to subdivide smaller catchments.

Ideally a local officer or farmer who knows the location and direction of the footpaths should accompany the persons making the assessment. Characterisation is based on information collected partly from interviewing local residents who are familiar with the catchment, and partly on observations made while walking a number of randomly chosen transects across the catchment. The siting of transects can be chosen by careful study of the 1:50 000 topographic map. Transects may follow footpaths and tracks where they cross the catchment (running down from the upper slopes down to the watercourses and up the other side). At times, where there are no suitable footpaths, it will be necessary to walk on a bearing. It is also important to walk along random sections of the main watercourses to examine the condition of the riverbanks and riverbeds.

Table 1 Guidelines for catchment characterisation (Wallingford, 2004)

Factor	Extreme	Score	High	Score	Normal	Score	Low	Score
Soil Type & Drainage	No effective soil cover; either rock or thin shallow soils	40	Poorly drained compacted soils; much ponding on soil surface after heavy rains	30	Moderately well Drained medium-textured soils; some ponding on soil surface after heavy Rain	20	Well drained coarse-textured soils; little ponding on soil surface after heavy rain	5
Vegetation Condition over whole Catchment	Little effective plant Cover: ground bare or very sparse cover over 80% of catchment	40	Fair cover: >50% of catchment is cultivated with annual crops	15	Good cover: 20-50% of catchment is cultivated with annual crops	10	Excellent cover: <20% of catchment is cultivated with annual crops	5
			<30% of catchment is under good grass cover or protected forest cover	15	30-60% of catchment is under good grassland or protected forest cover	10	>60% of catchment is under well-maintained grassland and/or protected forest cover	5
Signs of Active Soil Erosion	Many actively eroding gullies (dongas) draining directly into dam and/or watercourses; active undercutting of riverbanks along main watercourses	40	Some actively eroding gullies (dongas) draining directly into dam and/or watercourses; moderate undercutting of riverbanks along main watercourses	20	Few actively eroding gullies (dongas) draining directly into dam and/or watercourses; little undercutting of riverbanks along main watercourses	10	No actively eroding gullies (dongas) draining directly into dam and/or watercourses; no undercutting of riverbanks along main watercourses	5

Soil Type and Drainage assessments should be carried out at the driest time of the year or soil drainage can be gauged by noting soil surface texture (coarse, medium or fine) together with information from local farmers as to whether there is extensive ponding on the soil surface after heavy rains.

The extent of annual cropping and the nature and quality of the grassland and any woodland/forests in the catchment should be assessed separately. For example, although less than 20% of a catchment may be cultivated with annual crops, at the same time less than 30% may be under good grass or protected forest cover giving only fair cover. There are thus two rows for carrying out this assessment on the guidelines.

Obvious signs of active erosion should be recorded, particularly the presence or absence of actively eroding gullies draining directly into the watercourses, or active undercutting of riverbanks along the main watercourses. Factors may be averaged between two columns where more than one description applies to significant proportions of the area being characterised. If the catchment has been subdivided into sub-catchments, the individual factors are averaged after weighting each factor by the proportion of the catchment that it represents.

2.7 Previous studies

Research has been conducted on a large scale relative to land use and land cover change as well as sediment yield from catchments.

2.71 Land Use and Land Cover Change

Land use and land cover raster datasets were spatially analysed by Bare (2011), using the raster calculator which was accessed through the ArcGIS Spatial Analyst Extension. This enabled the evaluation of cell values between selected raster layers using map algebra statements. The study concluded that land use and land cover changes that took place in Dane County, WI from 1970's to 2001, could be a result of several factors which mainly include legislative regulations or land values.

Worku (2014) investigated land use and land cover change in South Ethiopia from 1986 to 2006. Landsat TM, ETM+ and SPOT images were used to produce land use and land cover maps of the selected watersheds. The Maximum Likelihood Classification method was used in ERDAS Imagine 8.6 environment and the results indicated that cropland and mixed cover were on the increase.

New and pervasive spatial patterns were created through land use and land cover changes, especially deforestation (Sun, Southworth and Qiu, 2013). The results also indicated that fragmentation only occurred insignificantly for the study area but cleared areas had strong influences beyond the study areas.

A study carried out in Zanzibar which investigated the link between forest transitions and land use and land cover changes, found that there is a direct link between these parameters (Kayhko, Fagerholm and Mzee, 2013). Analyses of the dynamics of forest cover were done over a 50-year period.

In another study, it was shown that there is general underestimation of the impact of intensive land uses in land change dynamics (Souter, Barret, Moran and Soares-Filho, 2013). This is based on the notion that overall, small scale land uses receive less attention in land use and land cover change studies. It therefore becomes important to look at land use and land cover studies for all possible scales, from small to large scale.

The image processing can broadly be categorized into: pre-processing, image classification or segmentation, post processing and evaluation (Jensen, 2004). Satellite image classification into land cover categories is based on the fact that land cover types have unique spectral response patterns; hence, spectral pattern recognition can be more important (Eastman 2006b).

2.72 Sediment Yield Estimation

According to Mavima *et al.,* (2011), sediment yield from Chesa Causeway Dam in the Upper Ruya sub-catchment was at 774t/km^2/year using grab sampling and 503t/km^2/year using hydrographic surveys. The major sources of sediment were cited as gold panning. The study concluded that the lifespan of reservoirs is strongly linked to upstream land use.

In similar studies by Kamtukule (2008), sediment concentrations below 3000mg/l indicate a well conserved catchment while ranges of 3000 to 10 000mg/l indicate a catchment prone to erosion through mainly poor conservation and steeper slopes. Concentrations above 10 000mg/l indicate catchments highly susceptible to erosion.

The study by Sahaar (2013) in the Kabul River Basin in Afghanistan showed high estimations of sediment yield ranging up to 4748t/km^2/yr. In this case, rangelands produced 57% of the total annual average loss and thus the main contributor to the basin. The study also predicted that if forest region of the Kunar watershed is completely reduced to barren lands, the watershed will produce five times more sediment than the estimated soil loss rate from 1993's UN-FAO land cover map. The annual average loss rate in this watershed was about 29tons/acre/year but it would rise to 149tons/acre/year as deforestation continued to take place in the watershed.

Studies carried out by Merten and Minella (2006) measured changes in soil use in a catchment in Southern Brazil during 2003. There was an increase in cultivated area by 37.7%, decrease by 19.9% in forests and a reduction by 10% of riparian vegetation. All of these changes resulted in increased sediment transfer from hill slopes due to loss of retaining force of the catchment. Cultivation of lowlands adjacent to Lajeado Ferreira stream led to increased runoff and the creation of new sources of sediment. According to the research, cultivated wetland drainage leads to large quantities of sediment in the stream channel.

Dons (1987) compared sediment regimes of three small catchments in the pumice terrain on Central North Island. The sizes of the catchments were 0.1km^2 in pasture, 0.34km^2 in pines and 0.28km^2 in native forest. The pasture area yielded 22t/km^2/year while the pines yielded 4t/km^2/year. The study showed suspended sediment yields normally higher than those from comparable areas with an exotic forest canopy.

Jain and Kothyari (2006) estimated soil erosion and sediment yield using GIS. ILWIS was used to identify sources of sediment and prediction of storm sediment from catchments. The Earth Resources Data Analysis System (ERDAS) Imagine image processor was also used for digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments.

A study by Hicks (1988) also showed that pasture catchments yielded six times more sediment per unit area than forested counterparts. This was inclusive of storm sediments which yielded 6-8 times higher yield than in forested areas. In the steep soft rock terrains of Coastal Hawke's Bay, any given storm may generate up to 2.5 times amount of suspended sediment from pasture compared to those with exotic forest (Fahey and Marden, 2000).

CHAPTER 3: METHODOLOGY

3.1 Study Area Description

The study areas are situated in Chikomba District of Mashonaland East Province in Zimbabwe. Chikomba District has coordinates ranging between 30^o 30' to 31^o 45'E, and 18^o 30' to 19^o 15'S. The District has a total land area measuring 630 744.5044 hectares. On the basis of land use, the District is divided into the categories/sectors shown on Table 1.

Table 2 Chikomba District farming sectors

Farming Sector	Area (Ha)
Communal Area	199 610.0000
Small Scale Area	161 495.7000
White Commercial Area	4 168.0100
Indigenous Commercial Area	41 081.0892
Old Resettlement Area	29 512.0000
A2	62 772.6400
A1	125 637.8252
Peri-urban	3 304.7400
Urban	3 162.5000
Total	**630 744.5044**

The total population is approximately 120 747. It has two agro-ecological regions; II (1.2%) and III (98.8%). Average rainfall is 700mm in a normal season. The main farming activities in the District are extensive livestock production supported by cropping.

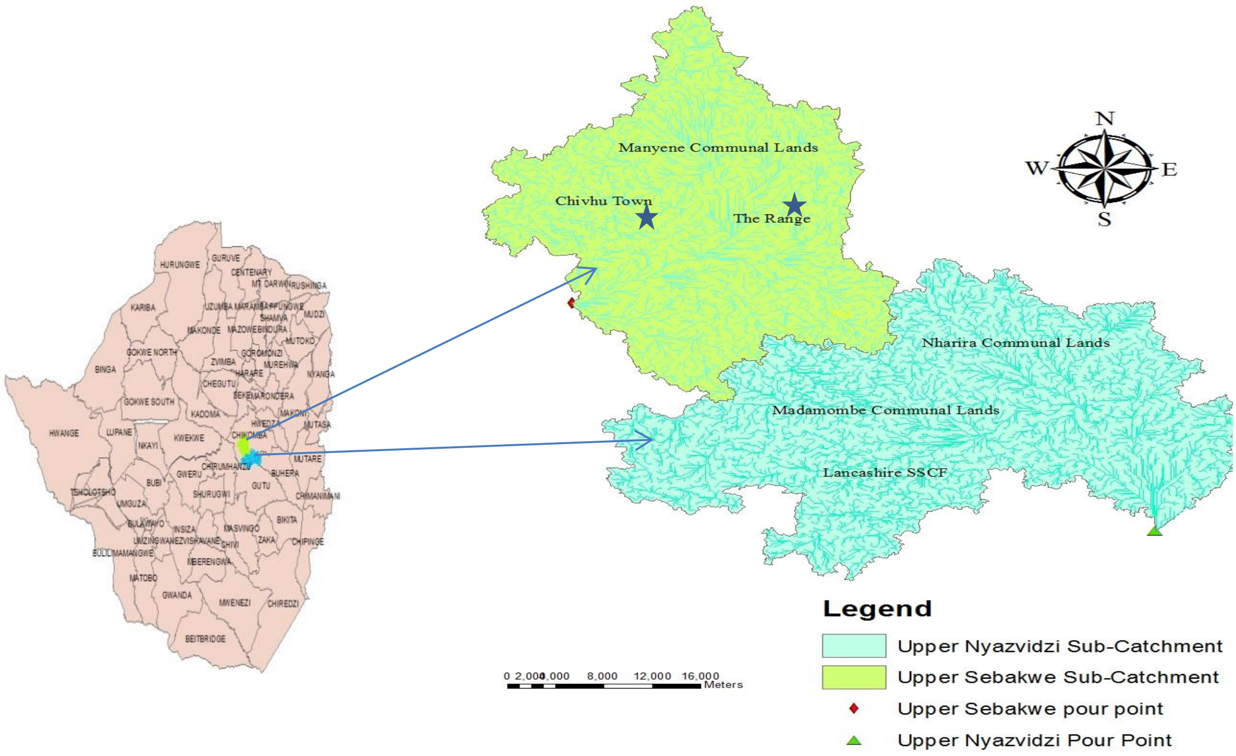

Figure 1 Location of Study Areas

The selection of the two upper sub-catchments was based on noticing that they each have different types of resettlement models that were used, namely communal, SSCFs, A1 and A2 self-contained plots, which are representative of the overall resettlement types in the District.

Upper Sebakwe upper sub-catchment measures approximately 80 972.19 hectares while upper Nyazvidzi upper sub-catchment measures approximately 99 920.92 hectares. They both have moderately drained medium textured soils which show some ponding on the soil surface especially after heavy rains.

The two sub-catchments occur back-to-back in geographical location in Natural Region III. They have gently undulating topography with rocky outcrops and a few kopjes. Open grasslands mainly consist *Hyperrhenia species*, *Loudehaa simplex* and some sedges. The veld mainly consist Msasa (*Brachystegia speciformis*) and Munhondo (*Julbernadia globiflora*) and some Acacia. Land use plans indicate a scattered distribution of Land Classes from I-VIII.

Upper Nyazvidzi sub-catchment was cited to have some problems with summer grazing in the land use plan of 1984 (Chivhu Department of Rural Development, 1984), because the vleis were waterlogged. The ten former units were used as ranches with very small hectarage, if any, were cropped by the workers for subsistence. The most suitable farming practice could have been cattle ranching given the extent of soils and vleis. Cropping under irrigation was not recommended. Willing Buyer-Willing Seller policy for acquisition of farms affected upper Nyazvidzi sub-catchment which was put under communal resettlement scheme.

Upper Sebakwe sub-catchment was under extensive beef cattle production supported by cropping. Small stock such as sheep and piggery were also practiced before the land re-distribution exercise of 1999/2000. There were few irrigation schemes.

3.2 Data Acquired and Source

Landsat TM images have been used for this study. Four images, that is, for 1984, 1994, 2004 and 2010 were acquired online from USGS Landsat archives. The images correspond to path 169 and row 73. The image spatial resolution or pixel size is 30m by 30m, with cloud cover of less than 10% for the area that corresponds to the two selected sub-catchments. These images show data that are collected by the Landsat spacecraft at nominal altitude of 705km, in near-polar, near-circular, sun-synchronous orbit at an inclination of 98.2^0 (United States Geological Survey (USGS), 1999). Return time for the spacecraft is 16 days and the swath is 183km. Data is framed into 170km increments (scenes) along track. Landsat Level 1 images which have been corrected for radiometric and geometric errors were ordered for this study.

Radiometric corrections deal with detector variations within the sensor. The brightness measured by each sensor must be uniform across the scene, an important aspect if classifications are to be done on the imagery. Geometric corrections deal with the correction of distortions in the imagery such as mis-aligned scan lines and non-uniform pixel sizes (USGS, 1999). Level 1images have been ordered online for free from USGS Landsat archives, for this study. 1:50 000 Topographical maps which model geographic features on the earth using points, lines and areas have also been adopted for use as reference or base maps.

The specifications of satellite datasets used for this study are listed in Table 1. For accurate image classification, all the images acquired were geo-referenced to the Universal Transverse Mercator Zone 36 south projections based on the WGS84 datum (Gumindoga, Rientjes, Shekede, Rwasoka, Nhapi and Haile, 2014).

Geo-referencing refers to the process of correcting raster or vector data to overlay a ground measurement coordinate system. This enables the assignment of ground coordinates to the different features in the datasets.

Table 3 Satellites datasets used

Year	Satellite/Sensor	Spatial resolution (m)	Path/row	Date of acquisition	Cloud Cover
1984	Landsat, TM	30	P 169, R 73	22/06/84	0%
1994	Landsat, TM	30	P 169, R 73	14/08/94	0%
2004	Landsat, TM	30	P 169, R 73	25/08/04	0%
2010	Landsat, TM	30	P 169, R 73	06/05/10	0%

3.3 Watershed Delineation

Delineation of the two sub-catchments was done to create the basis for the study area. ArcMap™ 10.0 was used for the delineation of both upper Nyazvidzi and upper Sebakwe sub-catchments.

Using Landsat images, watershed delineation followed a series of steps. The first was to use the Spatial Analyst Tool in the ArcToolbox to identify and remove sinks from the images or Digital Elevation Models (DEM).

The Fill-extension was used for that purpose and the output was a filled DEM. This was followed by computing the flow direction for the DEM using the Flow Direction extension. The output was a flow direction DEM that showed the direction of flow on the image. The Flow Accumulation extension computes the areas in which the flow is accumulated and the output is a flow accumulation DEM. After computing the flow accumulation, the pour point is designated which marks the outlet point of the desired sub-catchment.

The Watershed extension was then used to calculate the total area draining through the pour point. The input raster for watershed delineation was that of flow direction, the input pour point layer was the pour point pixel and the pour point field was left at default. The output from the process was a delineated watershed. These steps were followed for both upper Nyazvidzi and upper Sebakwe sub-catchments.

The watershed boundary polygons were created by converting watershed raster to watershed-bounding polygons. The ArcToolbox Conversions extension was used and the input was the watershed, whose field was left at default. The output was a watershed boundary.

3.4 Image Classification

Satellite image processing and analysis in this study is referred to as the act of examining images for the purpose of detecting, identifying, classifying, measuring and evaluating the significance of physical and cultural objects, their patterns and spatial relationship (Pouncey, Swanson and Hart, 1999)

The USGS classification system was used as a reference for land use categories used in image classification. Residential areas are those with sparse residential land use such as farm homesteads, and were included in categories to which they are related. Land used primarily for production of food and fibre is agricultural land. On high altitude imagery, the chief indications of agricultural activity will be distinctive geometric fields and road patterns on the landscape and the traces produced by livestock or mechanized equipment.

The resolution of the Landsat images used was 30metres by 30 metres, which made it very difficult to classify objects smaller than $900m^2$. Because of this reason, it was difficult to classify built up areas independently as most of the homesteads in the study area do not have coverage of the size of a pixel or cell. Zooming into the image will result in loss of meaningful data as images tend to lose texture. There has been a merger of classes, so that all built-up areas are classified as Cultivated Land.

Four classes were primarily used for the purposes of classification in this research, that is,

- Forest – land that is primarily covered by forest
- Cultivated Land – a combination of land that is used for cultivation and built-up area
- Pasture Land – land that is primarily grassland reserved for grazing purposes
- Water Body – land cover that is primarily a water surface

In ArcMap™ 10 geo-processing tools, the Image Classification extension was used to create training areas. Cells whose spectral patterns are close together in spectral space have similar spectral characteristics. They also have high likelihood of representing the same surface materials. Supervised classification was done based on the Maximum Likelihood Classifier where sets of training areas were designated in the image. Each training area was a known surface material that represented the desired spectral classes.

The training areas were then used to create signature files in ArcMap based on the spectral reflectance of the different classes. Using the Maximum Likelihood Classifier algorithm, the average spectral patterns for each training area were computed and the remaining image cells were then assigned to the most similar class.

After image classification, the DEMs were then clipped to the sub-catchment shapefiles or polygons to remain with the desired areas of study. This was done using the Data Management Tool extension in the Arc Toolbox. The input was the classified digital elevation model or image and the output extent was specified as the watershed boundary shapefile with input features used for clipping geometry.

An error matrix was produced, Table 4, as an accuracy check for the land use and land cover classifications that were done. This compares the number of predicted class pixels against the ground reference pixels. A total of 140 ground control points were randomly selected, 70 points from each sub-catchment, with coordinates recorded during field surveys using a Garmin 72H GPS component. These coordinates were input into the working domain using the Go-To X: Y tool in ArcMap^{TM} 10 software, Fig 3.

The coordinates were superimposed onto the classified map. Of the observed data, the total number of correctly classified pixels was recorded for each class. For example, forest classified as forest, pasture classified as pasture. The total number of incorrectly classified pixels was also recorded including the group to which they were assigned, for example, forest classified as pasture, or pasture classified as water.

The Producer's Accuracy was calculated, for example for Forest Land, using the formula:

$$\frac{\textbf{No. of pixels correctly classified as forest}}{\textbf{No. of ground reference pixels in forest}}$$

User’s accuracy was also computed using the formula:

$$\frac{\textbf{No. of pixels correctly classified as forest}}{\textbf{No. of image pixels in forest}}$$

Area calculations for each class were done using the formula:

Area (Hectares) = [Pv * $900m^2$ / 10000]

Where; Pv is the total number of pixels/cells for each class

$900m^2$ is the square area for each pixel at a resolution of 30m by 30m

The division by 10 000 is meant for the conversion of the area values to hectares

Change was characterized in three ways: **Net change** is change at an aggregate level for each stratum [23]. The difference in the area of Forest between 1984 and 2010 is an example of net change. **Gross change** is change at the individual 30-m pixel scale, for example, the number of pixels changing from Forest Land to Pasture Land.

Table 4: Error Matrix for Upper Sebakwe and Nyazvidzi sub-catchments

	Classified Map						
Ground Reference		**Forest**	**Cultivated Land**	**Pasture Land**	**Water Body**	**Row Total**	**Producer’s Accuracy**
	Forest	20	0	8	0	28	**71.4%**
	Cultivated Land	0	36	12	0	48	**75%**
	Pasture Land	4	4	28	4	40	**70%**
	Water Body	0	0	4	20	24	**83.3%**
	Column Total	24	40	52	24	140	
	User’s Accuracy	**83.3%**	**90%**	**53.8%**	**83.3%**		

3.5 Catchment characterisation

A field survey was conducted to verify the characterisation of each catchment. This was carried out to verify the existence or non-existence of major sub-catchment features such as gullies which significantly affect the scores of susceptibility to soil erosion. A traverse method was used for field surveys on 22 points randomly selected from the two sub-catchments.
The points selected were at namely: Constantia Estates farm, Confluence of Sebakwe river and Constantia tributary, Bosbokhoek of Chigara Farm, Landskroon farm, Vee Plaats farm, Moreson of Rockydale farm, Range 'A' state land farm, Spurwing farm, Seacombe farm, Lancashire Headquarters state land farm, Madamombe Communal Area, Nyazvidzi Communal area, Ruukwa Communal Area, Manyene Communal Area, Welkom of Inkosi farm, Farm 280 Lancashire, Confluence of Nyazvidzi and Nyatsitsi river, Glen Rhoda farm, Allandale farm, Stockdale farm, Kaal Plaats farm and Vegenoeg of Swaartfontein farm.

Catchment characterisation for this study for vegetation condition was carried out using guidelines provided for by Wallingford (2004). Jain and Kothyari (2000) used Landsat imagery in ERDAS Imagine environment for land cover and soil characterisation of the catchment. According to Pait and Roy (1990), there is need for spatial knowledge of vegetation attributes along with land use as a basis for catchment characterisation. Socio-economic and physical parameters are also considered relevant. In their study, space remote sensing data was very useful for obtaining spatial information on vegetation and existing land use through visual interpretation of 1:50 000 scale Landsat TM false colour composites.

Watershed parameters were also derived through remote sensing, GIS and other available data (Sindhu, Sadashipavva, Ravikmar and Shivuhunar, 2015). Thirteen watersheds were delineated based on drainage pattern and topography. Information on land use and land cover was derived from remote sensing data overlaid through ArcGIS software to assign the classes. Soil erosion was then estimated based on the derived classes.

In this study, Landsat imagery was also used in ArcMap environment, in conjunction with the Wallingford guidelines (2004), to characterise the catchments based on the calculated percent values for forest and pasture from the classified images. Soil type and drainage values were scored using land use planning (soil augers) data from Agritex Department. Mean annual precipitation data was also collected from the Agritex Department for 1984, 1994, 2004 and 2010.

The **slope** of the main stem river was obtained from 1:50 000 maps. The elevation difference between the catchment boundary and the river bed at the outlet location is divided by the distance, measured along the main stem river, from the catchment boundary to the outlet (Wallingford, 2004).

The slope was calculated using the following formula:

$$\textbf{Slope} = \frac{\textbf{Elevation difference between the catchment boundary and the river bed}}{\textbf{Distance between catchment boundary and outlet along main river stem}}$$

For Upper Nyazvidzi sub-catchment, the slope was 0.05. Length of main stem river was 30km and the elevation difference at 1500m.

For Upper Sebakwe sub-catchment, the slope was also found to be approximately 0.05. The length of the main stem river was 22.5km and the elevation difference was at 1125m.

The scores used in the Regional Small Catchment Sediment Yield Prediction Model were based on the characterisation (Table 5) done on the catchments. The percent values for forest and pasture were used to characterise the catchment for the scores of vegetation condition. Slope values and image interpretation were used in conjunction with forest and pasture land values to score for the signs of active soil erosion. Soil type and drainage was taken from land use planning records at Agritex, as well as mean annual precipitation values.

3.6 Methods of Analysis

3.61 Land use and Land Cover Change Analysis

This was done using cross tabulation, area gains and losses evaluations of each land use and land cover and net change contribution of each class to sedimentation. Image cross-tabulation is a process in which the categories of one image are compared with those of a second image and tabulation is kept of the number of cells in each combination. The result of this operation is a table that lists the tabulation totals as well as measures of association between the images.

Two variables, X and Y, are said to be associated when the value assumed by one variable affects the distribution of the other variable (Sheskin, 2007). X and Y are said to be independent if changes in one variable do not affect the other variable. Typically, the correlation coefficients reflect a monotone association between the variables. Correspondingly, positive correlation is said to occur when there is an increase in the values of Y as the values of X increase. Negative correlation occurs when the values of Y decrease as the values of X increase (or vice versa) (Sheskin, 2007).

A Chi-Square test was output along with the appropriate degrees of freedom so that the significance of Cramer's V could be tested. If the Chi-Square is significant, so is Cramer's V (Cramer, 1946).

From the statistical analysis done for correlation between the images being compared, Chi-square was significant, and so was Cramer’s V.

3.62 Statistical Analysis of Data

Chi-square test was used to test for significant differences between the land use and land cover data as well as that for sediment yield resulting from land use and land cover change.

Interpretation of the p-value was done according to Chok (2010):

$p < 0.01$: Very strong evidence against H_0

$0.01 \leq p \leq 0.05$: Moderate evidence against H_0

$00.05 \leq p \leq 0.10$: Suggestive evidence against H_0

$0.10 \leq p$: Little or no real evidence against H_0

Pearson's correlation coefficients were used to measure the strength and direction of association or correlation that exists between the land use and land cover change, and sediment yield measured from 1984 to 2010.

CHAPTER FOUR: RESULTS

4.1 Land Use and Land Cover Distribution

The distribution of land uses and land covers are shown on Fig. 4.1 for upper Sebakwe sub-catchment and on Fig. 3 for upper Nyazvidzi sub-catchment.

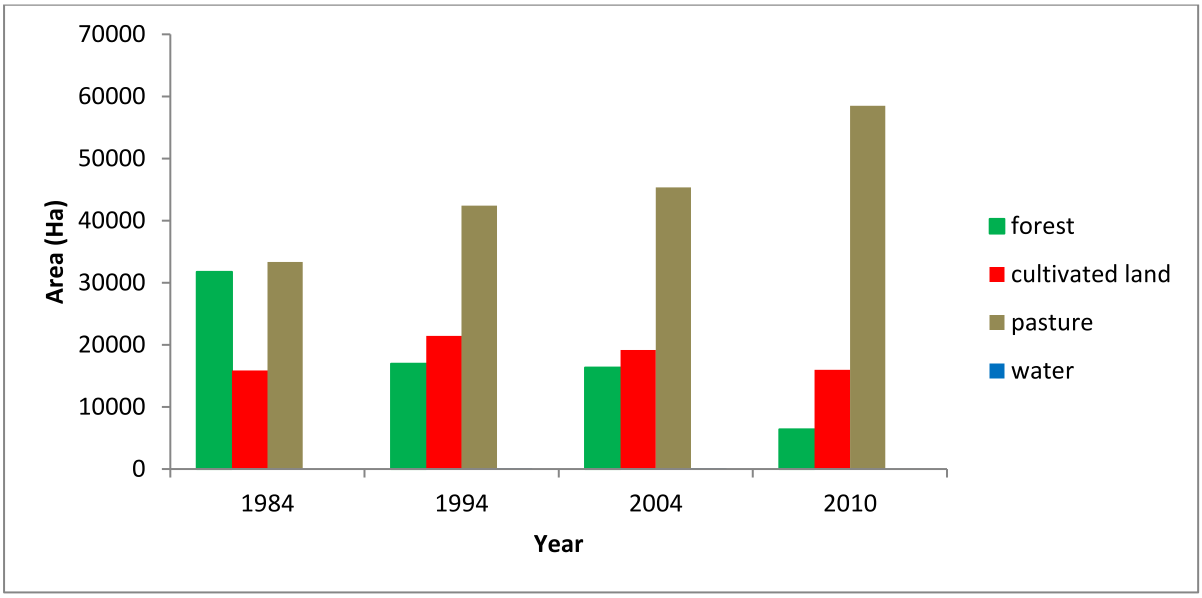

Figure 2: Land use and land cover distribution in upper Sebakwe sub-catchment

The findings for upper Sebakwe sub-catchment show that there was more forest land in 1984 compared to the other years. Between 1994 and 2004, the distribution of the forest in the sub-catchment was almost the same but in 2010, very little forest land remained. The average area covered by cultivation was almost the same. The fluctuations around the mean area for cultivated land were not significantly different for 1984, 1994, 2004 and 2010. Pasture land covered most of the catchment, continuously increasing from 1984 up to 2010. Water bodies covered a very small area in the sub-catchment. The changes in the surface area were not significant throughout the study period.

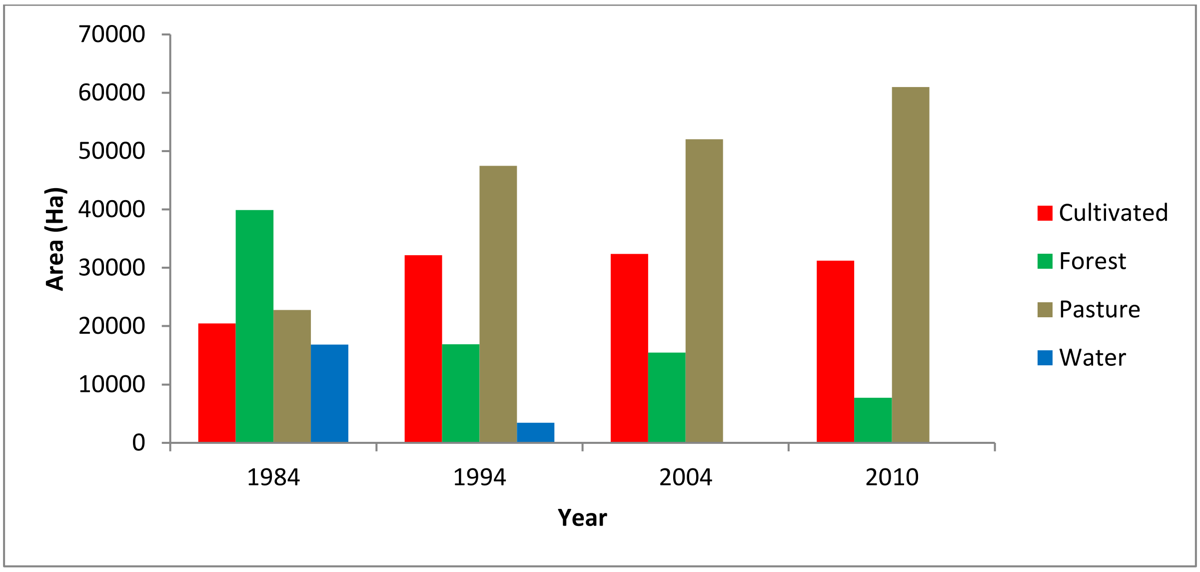

Figure 3: Upper Nyazvidzi sub-catchment land use and land cover distribution

Forest land covered a significant area of upper Nyazvidzi sub-catchment in 1984 but significant changes in distribution were experienced from that year to 1994. Between 1994 and 2004 the extent of the forest land was almost constant though there distribution greatly changed from 2004 to 2010.

Land classified as cultivated area increased notably between 1984 and 1994. The distribution remained almost constant from 1994 to 2010. Pasture land continuously increased in coverage over the catchment to become notably the dominant land cover type in the period 1994 to 2010. Significant changes in area covered by water bodies were noted in the sub-catchment. Between1984 and 1994, there was a huge decrease in water body area as compared to the other years. Continuous decrease in total area covered by water was noted from 1994 up to 2010.

4.2 Land use and land cover change trends

Forest Land area for both catchments shows a continuous downward trend which signifies a decrease in total area covered by forests. There is a continuous upward trend for pastures for both sub-catchments, which signifies an increase in total area. Cultivated land area for upper Nyazvidzi sub-catchment increased up to 2004, but a decrease was recorded in 2010. Upper Sebakwe sub-catchment shows an increase in total cultivated area from 1984 to 1994, a slight increase in 2004 and a decrease in 2010. Upper Nyazvidzi sub-catchment shows a similar trend of increase between 1984 and 1994, but there is a continuous decrease in total area from 1994 up to 2010.

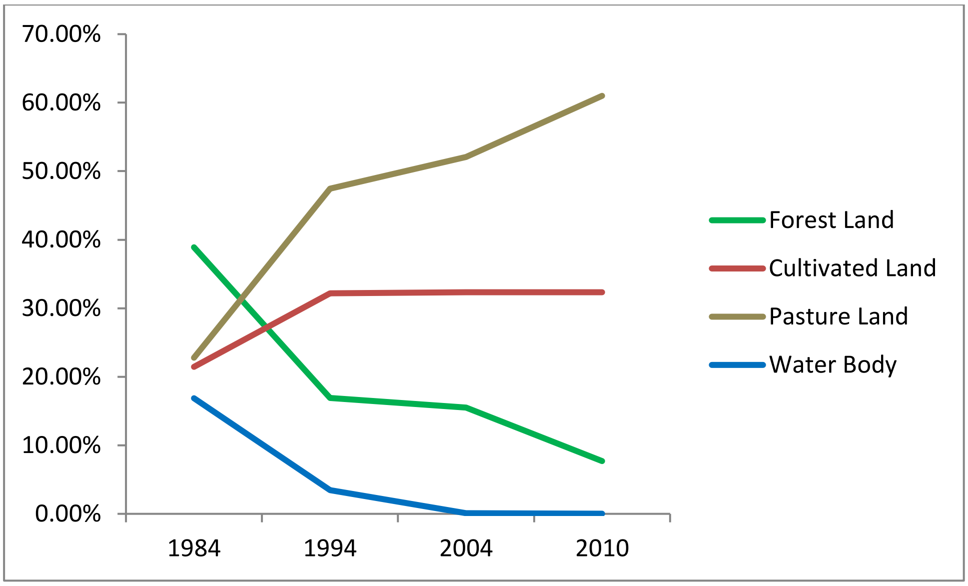

Figure 4: Land use and land cover trends in upper Nyazvidzi sub-catchment

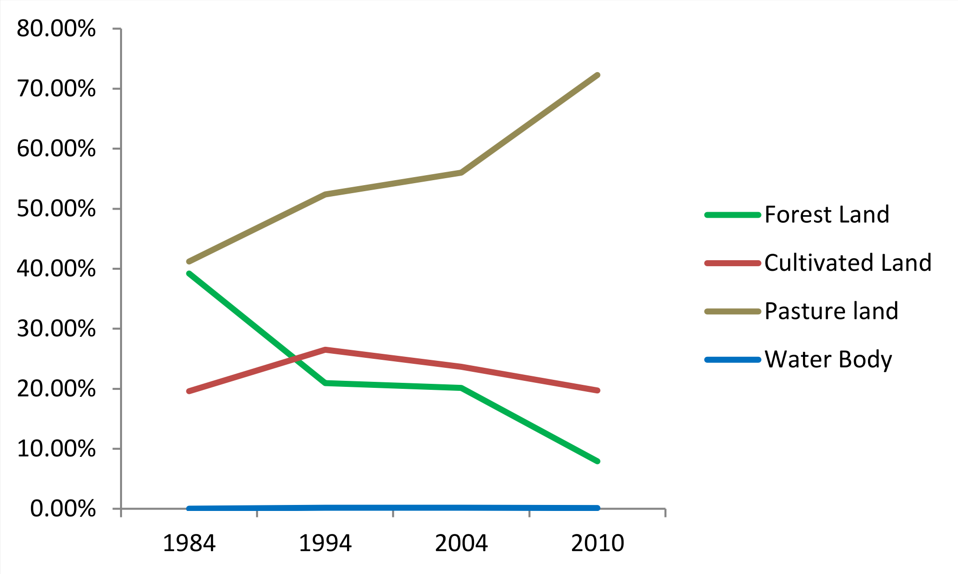

Figure 5: Land use and land cover trends in upper Sebakwe sub-catchment

A similar downward trend which signifies a decrease in total area for water bodies has been witnessed in both sub-catchments though the slope of the curve for Nyazvidzi is quite steep between 1984 and 2004.

4.3 Rates of land cover and land use change

The percentage change rates were calculated on the basis of the difference between the class values against the starting year.

For example:

$$\textbf{\% Change} = \frac{\textbf{Forest Value (Ha) in 1994 - Forest Value (Ha) in 1984}}{\textbf{Forest Value (Ha) in 1984}} \; \textbf{* 100}$$

There was a significant loss of about 46.6% of forest land from 1984 to 1994 for upper Sebakwe sub-catchment. Between 1994 and 2004, a loss of about 3.8% of forest was recorded. About 60.7%

was lost from 2004 to 2010. The total net change for forest land from 1984 to 2010 was a loss of about 31.3% for the sub-catchment.

Cultivated Land increased by 35.1% between 1984 and 1994 but a decrease in total area was recorded between 1994 and 2004. Cultivated land between these periods decreased by 10.6%. A further decrease was realised between 2004 and 2010 where about 16.7% of the cultivated land was lost. The total net change for cultivated land was an additional 0.1% from 1984 to 2010.

Pasture land increased by about 27.3% between 1984 and 1994, again increasing by about 6.9% between 1994 and 2004. The hectarage significantly increased by about 29% between 2004 and 2010. The total net change contribution was an addition of about 31% of pasture land from 1984 to 2010.

The area for water bodies increased significantly by 1162% for the sub-catchment between 1984 and 1994. From 1994 to 2004, there was a loss of 0.9%. Between 2004 and 2010, 33.4% was lost in the sub-catchment. Regardless of these losses, the total net change contribution was an additional 0.096% of water bodies for Upper Sebakwe sub-catchment from 1984 to 2010.

Table 5: Upper Sebakwe sub-catchment land use and land cover percent change

Land Use/Cover Type	**% Change**		
	1984-1994	1994-2004	2004-2010
Forest Land	**- 46.6**	**- 3.8**	**- 60.7**
Cultivated Land	**+ 35.1**	**-10.6**	**- 16.7**
Pasture Land	**+ 27.3**	**+ 6.9**	**+ 29**
Water Body	**+ 1 162**	**- 0.9**	**- 33.4**

Upper Nyazvidzi sub-catchment significantly lost about 57.6% of forest land from 1984 to 1994, 67.8% from 1994 to 2004 and about 50% from 2004 to 2010. The total net change contribution from 1984 to 2010 was a significant loss of about 31.2% of forest land in the sub-catchment.

Cultivated land increased by about 57.2% from 1984 to 1994. A slight increase of about 0.7% was realised from 1994 to 2004. There was a decrease in total cultivated land from 2004 to 2010 of about 3.6%. The total net change from 1984 to 2010 was an additional 10.78% of cultivated land.

Pastures increased by about 108.4% between 1984 and 1994. An additional 9.7% was realised between 1994 and 2004 as well as a further increase in total area by about 17.2% between 2004 and 2010. The total net change contribution between 1984 and 2010 was a significant addition of about 38.22% of pasture land for the sub-catchment

Table 5: Upper Nyazvidzi sub-catchment land use and land cover percent change

Land Use/Cover Type	**% Change**		
	1984-1994	1994-2004	2004-2010
Forest Land	**- 57.6**	**- 67.8**	**- 50**
Cultivated Land	**+ 57.2**	**+ 0.7**	**-3.6**
Pasture Land	**+ 108**	**+ 9.7**	**+ 17.2**
Water Body	**- 79.6**	**- 97.5**	**- 73.8**

About 79.6% of water body area was lost in Upper Nyazvidzi sub-catchment between 1984 and 1994. A further decrease by 97.5% was recorded from 1994 to 2004. About 73.8% of water body area was lost between 2004 and 2010. The total net change contribution was a significant loss of water bodies by about 16.8% for the sub-catchment.

Table 6: Change Detection Matrix for upper Nyazvidzi Sub-catchment

Type Of Change	1984-1994	1994-2004	2004-2010
	Percent Value		
Cultivated Land to Pasture Land	7.6	0.75	131
Forest Land to Pasture Land	11.7	1.9	3.16
Pasture Land to Cultivated Land	0.04	5.5	7.58
Water Body to Forest	0.09	50	0
Pasture land to Forest Land	0.05	0	0
Forest to Cultivated Land	1	0	1.48
Forest Land to Water Body	0.04	0	0
Water Body to Pasture Land	1.2	0	0
Water Body to Cultivated Land	0	0	0

The percent value of land use and land cover conversion was calculated using the formula:

$$\%\mathbf{Change} = \frac{\textbf{Land Use/Land Cover Converted Area (Ha)}}{\textbf{Total Land Use/Land Cover Area changed (Ha)}} * 100$$

The dominant conversion type for upper Nyazvidzi sub-catchment was Forest Land to Pasture Land at about 11.7% followed by Cultivated Land to Pasture Land at % between 1984 and 2004. About 1.2% of the total water area was converted to pasture land for the same period.

Between 1994 and 2004, about 50% of the water area was converted to forest land whereas more pastures were converted to cultivated land at a rate of about 5.5%. About 1.9% of forest land was converted to pasture land for the same period.

In the period 2004 to 2010, 3.16% and 1.48% of forest land was converted to pastures and cultivated area respectively. The greatest conversion was that of cultivated land to pasture at about 131%.

Table 7: Change Detection Matrix for upper Sebakwe sub-catchment

Type Of Change	1984-1994	1994-2004	2004-2010
	Percent Change		
Cultivated Land to Pasture Land	2.7	1.2	4.9
Forest Land to Pasture Land	3.6	6.9	4.14
Pasture Land to Cultivated Land	1	0.13	0.24
Water Body to Forest	0.05	0	0
Pasture land to Forest Land	0.01	0	0.55
Forest to Cultivated Land	0.36	2.1	0
Forest Land to Water Body	0.45	0	0
Water Body to Pasture Land	0	0	0
Water Body to Cultivated Land	0	0	0

The dominant conversion type for upper Sebakwe sub-catchment was from forest land to pasture land for the three periods 1984-2994, 1994-2004 and 2004-2010.

Statistical Analysis of land cover and land use changes was done using the Chi-square statistic. The results are shown on Table 7

Table 8: Chi-square test results for land use and land cover changes

		p-value	*Sig*	*Cramer V*
Upper Nyazvidzi sub-catchment	Pearson's	0	Yes	0.269951
	Max likelihood	0	Yes	0.268996
Upper Sebakwe Sub-catchment	Pearson's	0	Yes	0.16641
	Max likelihood	0	Yes	0.167459

According to the interpretation of p-values, a p-value of less than 0.05 implies that there is a significant difference in the data being tested. For objective 1, a p-value of 0 implies that there are significant changes to land use and land cover in Upper Nyazvidzi and Upper Sebakwe sub-catchments.

For Objective 2, the results of the test show that there are significant changes in sediment yield resulting from land use and land cover changes.

4.4 Sediment Yield Estimations

Sediment yield for each sub-catchment was calculated using Small Catchment Sediment Yield Prediction Model. The calculations were based on the catchment characterisation scores shown on Table 4.4 and Table 4.5.

Table 9: Catchment characterisation results for upper Sebakwe sub-catchment

Parameter	1984	1994	2004	2010
	Score			
Area (Ha)	80 972.19	80 972.19	80 972.19	80 972.19
MAP (mm)	861	385	707	647.7
STD	20	20	20	20
VC	5	5	5	10
SASE	5	5	10	10
SLOPE	0.05	0.05	0.05	0.05

The calculation example is shown as follows:

For Sebakwe Sub-catchment in 1984;

Sediment yield $= [[0.0194*[80972.19^{-0.2}]] * [861^{0.7}] * [0.05^{0.3}] * [5^{1.2}] * [20^{0.7}] * [5^{0.5}]$

$= 11.73$ tonnes/km^2/year

The scores for soil type and drainage did not change throughout the study period because it takes major events like a volcano to change these inherent properties of the soil. According to Jenny

(1941) the soil forming process takes place in conditions where all the five soil forming factors, climate, time, soil organisms, parent material and topography are at a constant in a conducive environment. If any one of them changes, the process will take longer than expected. If the parent material from which the particular soil is derived does not change, the soil type and its physical and chemical properties will remain the same. The major soils in the sub-catchments are primarily derived from granite parent material, are mainly loamy sands with few areas covered by vertic soils which normally show some ponding during heavy storms.

Susceptibility to soil erosion values changed significantly due to the recorded loss in forest land which usually aids in reducing incidences of soil erosion through interception of raindrops and as roots bind the soil. Mean annual precipitation depends on the season and cannot be controlled so the figures were taken as they were for each year.

Table 10: Catchment characterisation results for Upper Nyazvidzi sub-catchment

Parameter	**1984**	**1994**	**2004**	**2010**
	Score			
Area (Ha)	99 920.92	99 920.92	99 920.92	99 920.92
MAP (mm)	861	385	707	647.7
STD	20	20	20	20
VC	5	10	10	15
SASE	5	10	10	20
SLOPE	0.05	0.05	0.05	0.05

The same was done for the slope factor which does not significantly change unless there are major landscape shifts of high magnitude to cause such changes.

Vegetation conditions vary due to several factors. Type of land use in the sub-catchment, prevalence of droughts and rate of agriculture expansion are all contributing factors to changes in vegetation conditions. Therefore, the scores for vegetation condition also varied depending on the levels of stress exerted on the sub-catchment.

Table 11: Sediment yield estimations for upper Sebakwe sub-catchment

Year	Sediment Yield [tonnes/km2/year]	Total sub-catchment Yield in tonnes/Year
1984	11.73	9498.03
1994	15.34	12421.95
2004	33.22	26896.20
2010	71.68	58043.21

Sediment yield significantly increased from about 9498 tonnes for upper Sebakwe sub-catchment to about 58043 tonnes per year 2010. Nyazvidzi sub-catchment also experienced a notably high increment of sediment yield from about 11238 to 85160 tonnes per year.

Table 4.7 Sediment Yield Estimations for upper Nyazvidzi sub-catchment

Table 12: Sediment yield estimations for upper Nyazvidzi sub-catchment

Year	Sediment Yield [tonnes/km^2/year]	Yield in tonnes/sub-catchment/Year
1984	11.25	11238.02
1994	20.80	20785.53
2004	31.84	31812.37
2010	85.23	85160.21

4.5 Correlation between land use and land cover change and sediment yield

Pearson's Correlation test was conducted to ascertain if there are significant interactions between land use and land cover change and sediment yield. With a positive r value of 0.4528, changes in cultivated land area resulted in moderate increase in sediment yield in upper Nyazvidzi sub-catchment. There is therefore moderate correlation between changes in the cultivated area and sediment yield.

There is a strong negative correlation of -0.75 between changes in forest land area and sediment yield. A decrease in forest land area will result in an increase in sediment yield for the sub-catchment and vice-versa. A change in forest land area will result in a change in sediment yield.

An increase in pasture land area results in an increase in sediment yield for the sub-catchment, with a positive correlation coefficient of 0.7811. There is a significant correlation between changes in pasture land area and sediment yield.

For the sub-catchment, there is a moderate negative correlation of -0.624, between changes in water body area and sediment yield. An increase in water body area would yield less sediment yield for the sub-catchment. This also means that there is a significant correlation between changes in water body area and sediment yield.

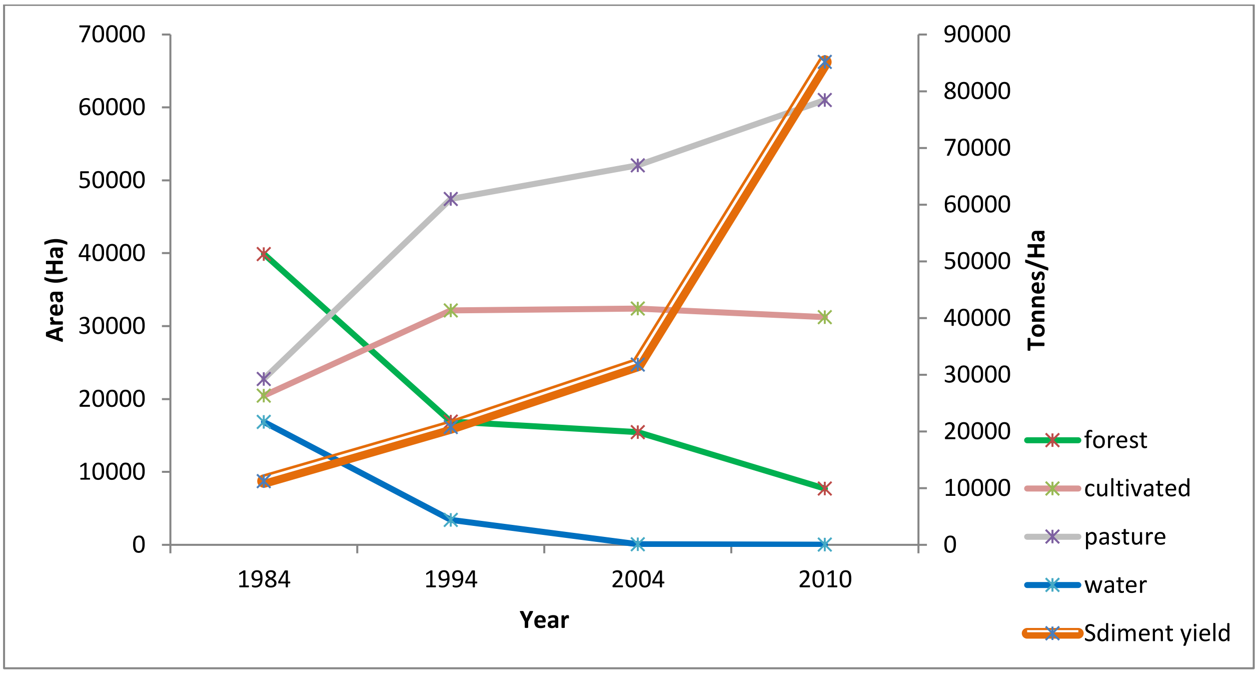

Figure 6: Land use land cover and sediment yield in Upper Nyazvidzi sub-catchment

For Sebakwe sub-catchment, there is a strong negative correlation of -0.84 between changes in forest land area and sediment yield between 1984 and 2010. This means that as Forest Land increases, sediment yield for the sub-catchment decreases and vice-versa. Any change in Forest Land area results in changes to Sediment Yield.

There is a strong positive correlation of 0.9517, between changes in Pasture Land and Sediment Yield. This signifies that the more there is pasture land, the more the sediment yield from the catchment.

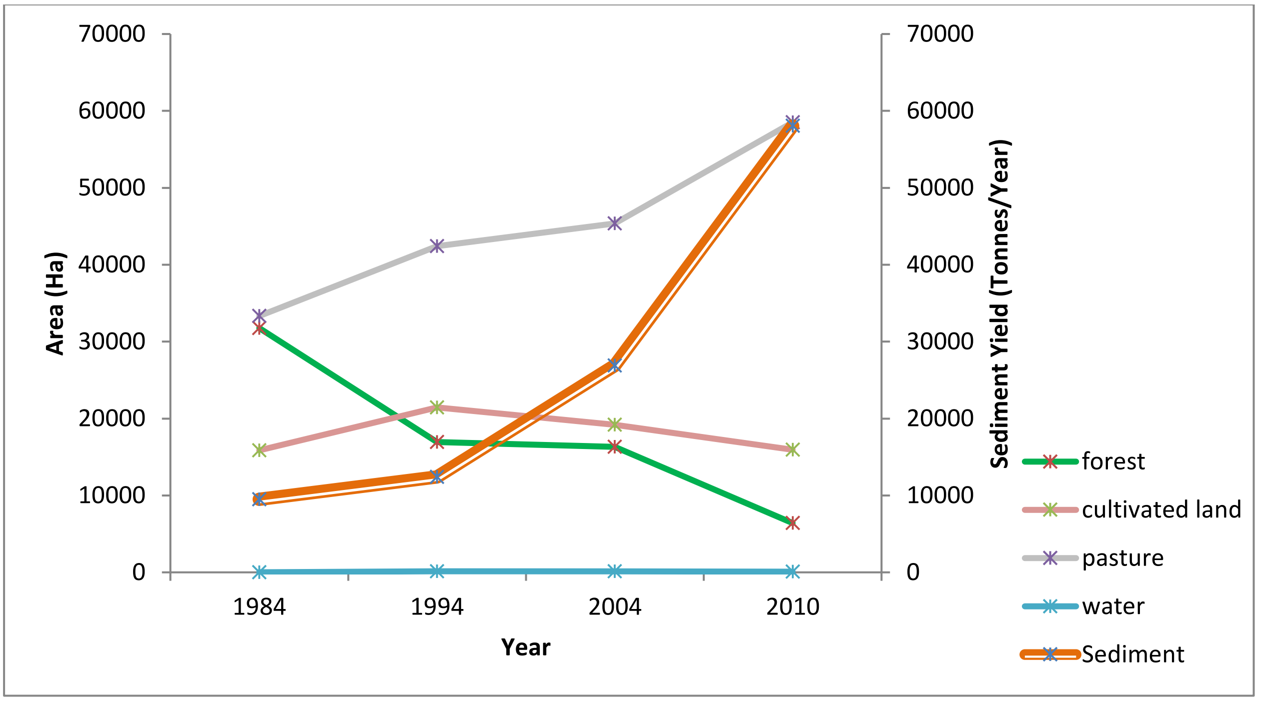

Figure 7: Land use land cover and sediment yield in upper Sebakwe sub-catchment

There is a moderate negative correlation between Cultivated Land and Sediment Yield, suggesting that an increase in cultivation results in a decrease in sediment yield. Changes in area cultivated will result in changes in sediment yield within the sub-catchment.

An increase in water bodies results in slight increase in sediment yield, with a weak positive correlation of 0.1808. There is therefore correlation between a change in water body area and changes in sediment yield.

CHAPTER FIVE: DISCUSSION OF RESULTS

5.1 Effects of Land Use and Land Cover Changes to Sediment Yield

Looking at upper Nyazvidzi sub-catchment, communal resettlement was implemented in the area. Despite warnings from the land use planners in 1984 that there would be negative impacts on the environment if the sub-catchment was subjected to other uses besides extensive cattle ranching, communal settlement meant people coming into the environment which is waterlogged to practice cultivation and intensive cattle ranching.

There has been a notable increase of cultivated area between 1984 and 1994 for the sub catchment and a constant average of total cultivated area between 1994 and 2010. The result of the increase in cultivated area was an increase in sediment yield. This may be accredited to the effect that cultivation has to the soils within the sub-catchment. Cultivation, which involves mechanical manipulation of the soil, loosens it up and promotes aeration, porosity and water holding capacity. However, over-tilling will decrease aggregation, causing the soil to be compacted easily. Compacted soils have dominant few, small pores and hence reduced infiltration and water holding capacity. This then leads to increased run-off which promotes erosion and sedimentation (Cooperative Extension Garden and Yard, 2015).

However, the changes in cultivated area for Sebakwe sub-catchment resulted in a different scenario. An increase in cultivated area resulted in decreasing sediment yield as shown by the correlation coefficient of -0.42

The correlation coefficients indicate that a decrease in forest area will result in increase in sediment yield. This can be explained by looking at the role trees or forests play in the watershed environment. Tree roots improve soil structure in different ways (Weinblutt, 2015). Probing root growth breaks up soil and creates space for storage of air and water, hence improving aeration and drainage. Roots act as underground water channels to help water penetrate the soil. Deep, strong roots also tend to bind the soil and prevent soil erosion.

According to Zinke (1967), natural forests' canopy interception ranges from 15-40% of annual precipitation in conifer stands and from 10-20% in hardwood stands. Interception exceeds 59% for old growth forests (Baldwin, 1938). Therefore, the continuous loss of forests, as the results of this study show, has led to a continuous increase in sediment yield for both sub-catchments due to loss of interceptive ability of trees and loss of soil binding properties.

The United Nations Development Program (UNDP) (1997) indicated that deforestation is one of the major problems facing Zimbabwe with forest losses estimated at between 70 000 to 100 000 hectares every year. The estimated decline was projected at 1.5% per year. These losses were accredited to increasing demand for wood fuel and demand for agricultural development. The resultant effects of deforestation include degradation of river systems, that is, pollution through sediments, and siltation of water bodies.

The results have shown that an increase in pasture land results in increased sediment yield for upper Nyazvidzi sub-catchment. This might be credited to the effect of animal hooves on the soil in terms of compaction, loosening of soil particles and removal of plant cover when grazing. 30-60% of total soil volume is filled with water and air. A well- structured soil has both macro and micro-pores that provide a balance of air and water both of which plants need. Macro-pores provide for good drainage and micro-pores hold water that plants need. The introduction of livestock within a sub-catchment will result in the soil being trampled upon, causing loss of both macro and micro-pores and loosening up of soil particles by cattle hooves.

The result is an increase in runoff and the subsequent carrying away of soil particles or sediments from the sub-catchment.

As the results of the research show, the sub-catchment has been turned from a waterlogged area into a dry one, from a moderately vegetated to a near forest-less area with cultivation on the increase. The resultant effects are increased sedimentation in the sub-catchment, from 11 to about 85 tonnes per square kilometre per year between 1984 and 2010.

Most of upper Sebakwe sub-catchment was primarily used for extensive beef cattle ranching supported by cropping. The main communal area is the Manyene Tribal Trust Land which, since 1984, was already under intensive use. The inception of the Land Redistribution Exercise in the District in the years 1999/2000, led to most of the changes in land use and land cover in the sub-catchment. The introduction of cultivation and other agricultural activities has resulted in marked reduction in forest land and slightly decreasing water resources from 2004. Sediment yield has therefore risen from 11 to about 71 tonnes per square kilometre per year for the sub-catchment. The major contribution to water loss may be due to deforestation which leads to increased soil erosion and sediment yield in the sub-catchment.

From the research findings, there have been significant changes to land use and land cover in the study area. About 31.2% of forest was lost in upper Nyazvidzi sub-catchment between 1984 and 2010, while in Upper Sebakwe sub-catchment; there was a loss of 31.3%. Upper Nyazvidzi sub-catchment has more area under communal resettlement. The initial rise in demand for building materials in the form of wooden poles as well as demand for firewood fuel at the inception of the resettlement could have caused the subsequent loss of forest cover. Continuous loss of the forests in the later years coupled with the reduction in cultivated areas could be attributed to the economic hardships faced by the country from 2000 up to 2010 as people sought for alternative ways of survival in the form of selling firewood.

Cultivated land increased by 10.9% and 0.1% respectively for upper Nyazvidzi and upper Sebakwe sub -catchments respectively. Pasture land increased by 38.2% and 31% for upper Nyazvidzi and upper Sebakwe sub-catchments respectively. There was a significant loss of water bodies in Nyazvidzi with a reduction by 16.8% while Sebakwe gained by 0.1%.

As can be deduced from the Pearson's T-test, reduction of forest cover results in increased sediment levels. Increase in cultivation and pasture land also causes the same increase in sediment yield. This increase in sediment yield levels may be the major cause as to why there is a high loss of water resources in upper Nyazvidzi sub-catchment between 1984 and 2010 due to siltation. Otherwise the trampling of the waterlogged areas by cattle has led to that significant loss in water bodies.

The decrease in cultivated land for upper Sebakwe sub-catchment from 2004 up to2010 could be accredited to social and economic hardships in that period that could have probably stifled agricultural activities.

In a similar study that was carried out in Inle Lake, the results showed the expansion of pastures by 34% between 1989 and 2009 (Htwe, Kywe, Buerket and Brinkmann, 2014). Forest loss was at -49% while water bodies decreased by 16%. The main drivers to these changes were defined as rapid population growth, industrial activities, and government policies. Widespread rural poverty as affected by prices and access to markets also contributed to the changes.

Most of Upper Sebakwe sub-catchment was primarily used for extensive beef cattle ranching supported by cropping. The main communal area is the Manyene Tribal Trust Land which, since 1984, was already under intensive use. There was a lot of forest land in 1984 as compared to 2010. Chivhu town and the Manyene Communal Land are the most likely developments to have yielded deforestation as people look for firewood. The inception of the Land Redistribution Exercise in the District in the years 1999/2000, led to most of the changes in land use and land cover in the sub-catchment. The introduction of cultivation and other agricultural activities has resulted in marked reduction in forest land and slightly decreasing water resources from 2004. Sediment yield has therefore risen from 11 to about 71 tonnes per square kilometre per year for the sub-catchment. The major contribution to water loss may be due to deforestation which leads to increased soil erosion and sediment yield in the sub-catchment.

5.2 Recommendations

Zimbabwe is a signatory to the Earth Charter, Agenda 21 of the UN Convention to Combat Desertification and the Ad Hoc Inter-governmental Panel on Forests. Continuous increase in deforestation might imply a slackened enforcement of these agreements on a micro-scale.

There is very strong need to control deforestation, which is the major factor affecting the ecological integrity of both sub-catchments. Stringent measures will need to be in place to curb this environmental vice that is crippling the ecological excellence of the sub-catchments.

Afforestation programmes in the District are at a much slower rate than deforestation and the capacity of the Forestry Commission to monitor changes in vegetation cover is far too low. In the District, the last forest resources inventory was carried out in 1996. The Kyoto Protocol is an international effort aimed at reducing climate changes induced by greenhouse gas emissions from land use and land cover changes. The proposed measures are aimed promoting tree planting and no-till agriculture. This could also be brought to the attention of local people in the sub-catchments so that lost forests can be replaced over time.

Studies by Mensah (2014) indicated that threats to economic livelihoods are driven by lack of adequate investment for land conservation. Therefore, if cultivation has to be done, there is great need to enforce conservation works which help reduce runoff, erosion and ultimately sediment yield from the sub-catchments. It has already been observed that there are no contour works especially in the Sebakwe sub-catchment resettlement schemes incepted in 1999/2000.

Security of tenure will also need to be greatly improved in the resettlement so that communities can seriously take the conservation of their land seriously enough so as to protect watershed integrity in their areas.

Further studies could also be undertaken that will focus on the effects of the individual land use and land cover classes to sediment yield. That is, the individual effects of forest changes, cultivated land changes, pasture land changes and changes in water body area to sediment yield.

5.3 Conclusion

Statistical analyses on the data indicated that changes in land cover and land use induce corresponding changes to sediment yield. The effects of land use and land cover changes to sediment yield in Nyazvidzi and Sebakwe sub-catchments are quite significant. From 1984 to 1994, sediment yield increased by 30% in Sebakwe. The yield further increased for the sub-catchment by 116.5% and 115.8% from 1994 to 2004 and 2004 to 2010 respectively. Sediment yield increased by 85% from 1984 to 1994 in Upper Nyazvidzi sub-catchment. There was a lesser increase from1994 to 2004 when compared to the preceding years. Between 2004 and 2010, the greatest increase in sediment yield for the sub-catchment was realised at 167.7%.

The findings provide an insight into the interactions between land use and land cover changes and sediment yield. An understanding of these interactions and the strength of their association helps in targeted policy formulation for integrated watershed management.

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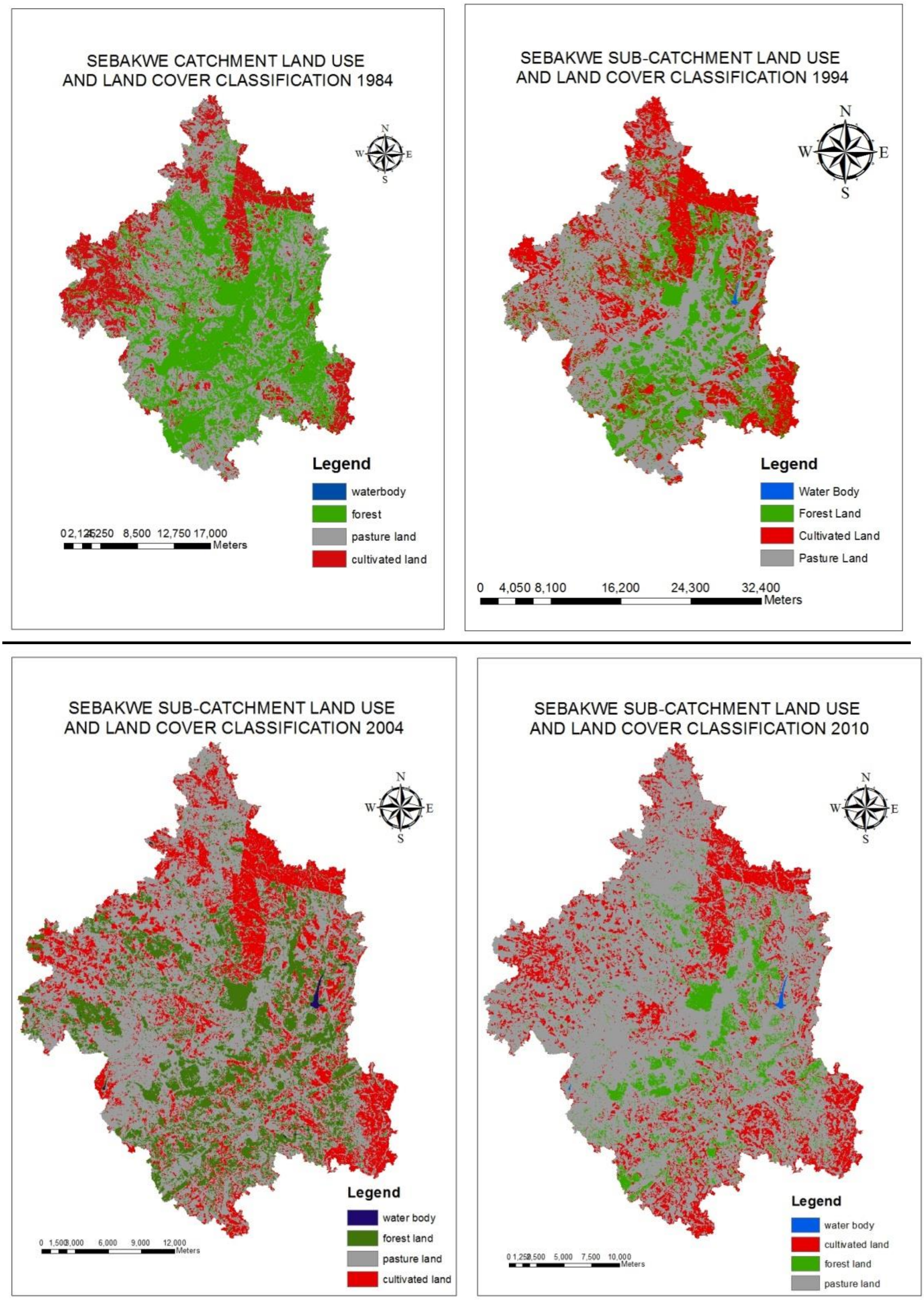
Appendices

Appendix 1Sebakwe sub-catchment image classification results



Appendix 2 Nyazvidzi sub-catchment image classification results