EFFECTS OF SEDIMENTATION ON WATER-LINKED SECTORS IN THE LUSITU RIVER CATCHMENT IN SOUTHERN ZAMBIA

By

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DECLARATION

I, **Nordoft Singubi** do hereby declare that this dissertation represents my own work and has not previously been submitted to the University of Zambia or any other institution for the award of a degree. I have herein dully referenced and acknowledged all cited works and materials from other sources.

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APPROVAL

The dissertation of Nordoft Singubi has been approved as fulfilling the requirement for the award of Master of Science in Geography by the University of Zambia.

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ABSTRACT

The problem of sedimentation and drying-up of rivers is very pronounced globally, continentally, and nationally. In Southern Zambia and, Lusitu River Catchment in particular, sedimentation and eventual drying up of the river during most parts of the year punctuated diverse environmental and socioeconomic problems, which this study investigated to contribute to the ongoing epistemic debates around the problem. Lusitu River supports a large population of over 20,000 Gwembe Tonga People who were relocated into Lusitu Catchment in 1958, following the construction of Kariba Dam. The overall aim of the study was to assess how sedimentation affected water-linked sectors in the Lusitu River Catchment to formulate strategies for mitigation of negative effects. The objectives of the study were to: (i) investigate main drivers of sedimentation in the Lusitu River; (ii) determine the magnitude of sedimentation in the downstream section of the Lusitu River; (iii) to assess how sedimentation of Lusitu River affected water-linked sectors and (iv) to design an integrated restorative framework for the Lusitu River Catchment. The study was informed by analytic eclecticism paradigm and used mixed methodology, particularly concurrent design so that where applicable, both quantitative and qualitative data were collected. Data on objective one was collected using observation and semi-structured interviews and was analysed using descriptive statistics namely, mean, standard deviation, coefficient of variation and thematic analysis. Data on objective two was collected using sediment coring method and was analysed using Inverse Distance Weighted (IDW) in ArcGIS10.4. Data on objective three was collected using semi-structured interviews and was analysed using thematic analysis. Data on objective four was gathered using Focus Group Discussions and was analysed using thematic analysis. The results showed that agricultural activities particularly, dry season crop field preparation prior to the onset of rainfall and intensive soil tillage farming practices were the major drivers of sediment. Sand mining was the least contributor. Geomorphic factors driving sedimentation of Lusitu River were gully erosion, loose soils (Leptosols), unstable riverbanks and weak sedimentary rock formations. There was large-scale siltation in the downstream section which measured 2,863,913.78m^3 with mean sediment depth of 3.13m. Due to heavy sedimentation, the downstream of the Lusitu River was found to have lost 68.34% of its channel storage capacity. The intensity of riverbank gardening varied in relation to Lusitu River flow regime. The drying up of the Lusitu River led to water shortage for crop irrigation and livestock watering, but improved supply of drinking water. Small-scale crop farmers and livestock farmers experienced serious water shortage, with the former being the most hit. Time taken to draw water for domestic use increased in relation to the drying up of the river. The study found that local people adapted to water shortage by digging wells on the dry riverbed which were complimented by small sandy reservoirs dug by the local authority on the same for livestock watering. The study proposed river restoration framework, which constitutes nature-based solutions, engineering, conservation agriculture strategies, indigenous knowledge, and sediment business development model, among others. The study concluded that both soil erosion processes such as gully erosion, and upstream anthropogenic activities such as crop cultivation were the main drivers of sedimentation in the Lusitu River Catchment. Water shortage due to severe river sedimentation reduced income from crop farmers. It also reduced the number of livestock farmers reared thereby, perpetuating rural poverty. The study designed an integrated catchment restoration framework for Lusitu River Catchment to restore the river to perennial status, halt and reverse land degradation. The study recommends piloting of the framework for subsequent full-scale implementation.

Key words: *Sedimentation, Sediment coring, Water-linked sector, Lusitu river, River restoration*

DEDICATION

To St. Noah Taguta Momberume, the late High Priest of the Apostle Church and St. Nimrod Momberume, the current High Priest and to my parents, Mr. Samson Singubi and Mrs. Esnart Siamapande Singubi for cherishing academic endeavours in my life.

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OPERATIONAL DEFINITIONS

Catchment	Space that collects water that feeds into a river.
Livestock	In this study means cattle and goats.
Sediment	In this study refer to soil particles detached from land by erosion.
Sedimentation	In this study means deposition of sediment on the riverbed.
Sediment burden	Total quantity (m^3) of sediment that has accumulated on the riverbed.
Water-liked sectors	Refer to small scale crop farming, livestock farming and domestic water supply.

ACRONYMS AND ABBREVIATIONS

3DSATs	Three-Dimensional Spatial Analyst Tools
AWARE	Accelerate Water and Agriculture Resources Efficiency
AU	African Union
BUA	Build Up Area
CSO	Central Statistics Office (now Zambia Statistics Agency)
ECM	Elevation Change Method
FAST	Farming System and Tillage Experiment (Switzerland)
FDG	Focus Group Discussion
GIS	Geographical Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GRZ	Government of the Republic of Zambia
HEP	Hydro Electric Power
ICRF	Integrated Catchment Restoration Framework (Lusitu River Catchment)
IDW	Inverse Distance Weighted
LDN	Land Degradation Neutrality
IDSP	Irrigation Development Support Project
MSL	Mean Sea Level
MWh	Mega Watts per hour
NGOs	Non-Governmental Organizations
NbS	Nature-based Solutions
NTU	Nephelometric Turbidity Unit

P value	Probability value
PASERA	Pan-European Soil Erosion Risk Assessment
PCA	Principal Component Analysis
pH	Power of Hydrogen (Measure of how acidic or basic water is)
RSHR	Red Soil Hilly Region in China
RUSLE	Revised Universal Soil loss Equation
SDGs	Sustainable Development Goals
SSC	Suspended Sediment Concentration
SWAT	Soil and Water Assessment Tool
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WARMA	Water Resources Management Authority (Zambia)
ZRA	Zambezi River Authority

CHAPTER ONE: INTRODUCTION

1.1 Background

Sediment generation, transportation and deposition is catchment specific, and is influenced by several factors within a catchment such as rate of sediment generation (Ezugwu, 2013). Sediment deposition is reducing the economic importance of rivers and has continued to be one of the major threats to river ecosystems around the world (Walling and Fang, 2003). A study by Walling and Fang (2003) showed that most of the rivers around that world have high sedimentation records and have a steady downward trend of flows and will lose about 50% of their storage capacity by the year 2100. This trend has steadily led to freshwater crisis around the world including in Lusitu River Catchment, which receives low rainfall and hence more prone to the impact of climate change.

A study by UNESCO (2011) indicates that due to removal of ground cover, soil erosion processes have led to high levels of turbidity in water bodies. Silt and clay particles adsorb chemicals such as phosphorus which pollute water in rivers and other water bodies. River sedimentation often has high social and environmental costs involving community relocation due to water shortages and ecosystems destruction. Sediment deposition can cause floods which would otherwise be contained by riverbanks and levees (UNESCO, 2011).

Sustainable management of river sedimentation and construction of reservoirs along rivers bring effective management of sediment in rivers. Some strategies to combat the problem of river sedimentation include land management and soil conservation techniques such as low tillage and terrace farming. Identification of key stakeholders in sediment issues needs to be a primary step in the development of sediment management plans (UNESCO, 2011).

The importance of river management has led to the formulation of laws and regulations governing land and water use in many regions of the world (Zhao *et al.* 2013). Several countries are recognizing the importance of healthy rivers for the health of communities and the environment (Zhao *et al*. 2013). However, according to UNESCO, (2011), regulation of sediment is a relatively new concept in some areas. In Australia for example, laws were only quite recently passed to protect the Great Barrier Reef from excessive sediment runoff from sugar cane farms in adjacent river systems. Relevant regional and local regulations, rules, methods and guidelines on sediment management are necessary. Sustainable Development Goals (SDGs) 6 and 15 urge countries to promote sustainable water resources management as well as protection and restoration of terrestrial ecosystems and, to halt and reverse land degradation and biodiversity loss (UN, 2020).

In Africa and Zambia in particular, studies on sedimentation show that the phenomenon is a major stress to many water managers, and communities that depend on natural water bodies such as rivers (Sichingabula, 1997; Sawunyama *et al*., 2006; Dalu *et al*., 2013; Sichingabula *et al*., 2014; Chitata *et al*., 2014, Chomba and Sichingabula 2016; Hamatuli and Muchanga, 2021; Simweene and Muchanga, 2021). High rates of sediment deposition contribute to disruption of various socioeconomic livelihoods and disturbs ecosystems. Through chemical sediment triggered by anthropogenic activities, rivers get contaminated with various pollutants causing an adverse impact on human health and aquatic life (Lawson, 2011). The quality of water is getting immensely deteriorated due to reprehensible land management and carelessness to the environment.

Lusitu Catchment is mainly occupied by Gwembe Tonga people who were resettled following the construction of the Kariba Dam in 1958 (Zambezi River Authority (ZRA), 1996). This resettlement led to an increase of people in the Lusitu River Catchment, especially the downstream section. The ever, increasing population has led to limited land resource which has resulted in severe degradation. In terms of livestock, the area is stocked beyond its capacity (ZRA, 1996). Local knowledge shows that, the river was perennial up to early 1980s, but currently, the river is non-perennial. Local people have observed that the period of water flow in Lusitu River is increasingly reducing over the past years with an increase in sediment deposits. This has led to a reduction in water available for domestic use, crop irrigation and for livestock (ZRA, 1996), hence, this study, which sought to investigate the effects of sedimentation of the river on the water linked sectors within the catchment so as to devise remedial measure to reverse the scenario.

1.2 Statement of the problem

While the rest of the world including Zambia seek to meet SDG number 6 where every person has access to sufficient and quality water supply, river sedimentation is impeding this progression in Lusitu River Catchment. Gully erosion from natural processes coupled with anthropogenic activities such as deforestation and cultivation along riverbanks have over the years, augmented soil erosion and choked up the river with sediment contrary to SI 1 of 2000 (GRZ, 2019). During heavy storm events such as Ana (African Union, 2022), flush flooding of the Lusitu River due to reduced storage capacity led to large scale erosion and transportation of sediment and damaging of crops. On the other hand, loss of perenniality of the Lusitu River since early 1980s has also subjected over 1,073 households within the study area to water stresses between May and December, which is quite a long water stress period because water is trapped in sand on the riverbed (Kalyocha, 1988; 2000). Chirundu district in which Lusitu area lies has 7,126 cattle and 32,800 goats CSO (2017) mainly concentrated on the downstream section of the Lusitu River which are strained during water stress period and hence susceptible to diverse livestock diseases (Tundu *et al*., 2018). The geomorphic system is also prone to large degradation rendering the entire ecosystem incapable of sustaining riverine ecosystems and water demand for water-linked sectors. Hence, this study which sought to clarify the magnitude of the problem and proposed restorative measures.

1.3 Aim

The overall aim of the study was to assess how sedimentation affected Lusitu River and selected water-linked sectors in the catchment to inform the designing of an Integrated Catchment Restoration Framework (ICRF).

1.4 Objectives

i. To investigate main drivers of sedimentation in the Lusitu River.
ii. To determine the magnitude of sedimentation in the Lusitu River.
iii. To assess how sedimentation of Lusitu River affected water-linked sectors.
iv. To design an Integrated Catchment Restoration Framework for the Lusitu River Catchment.

1.5 Research questions

i. What are the main drivers of sedimentation in the Lusitu River Catchment?
ii. What is the magnitude of Sedimentation of Lusitu River between Lusitu Bridge and its confluence with the Zambezi River?
iii. In what ways is sedimentation of Lusitu River affecting water-linked sectors?
iv. What strategies can be put in place for integrated restoration of the Lusitu River?

1.6 Significance of the study

This study may contribute to the body of knowledge in Geography, particularly, Potamology and Fluvial Geomorphology. It contributed to enhanced understanding of the nature of the sediment problem in Lusitu River which was not initially well documented. Information on sedimentation is essential for management of current and predicted sedimentation problems on water resources (Collins and Walling, 2004). SDGs 1, 2, 3, 13, 14 and 15 are water-dependent (United Nations Development Programme (UNDP), 2018). Therefore, understanding the complex process of sedimentation that affect water quantity is important for the world and Zambia in particular, to successfully implement and domesticate these SDGs by 2030.

Ensuring sustainable supply of water for crop irrigation and livestock watering strengthens rural economies that are dependent on pastoral and crop farming (Muchanga, 2020). This study may contribute to realisation of Zambia's 8th National Development Plan on environmental sustainability. The study developed an ICRF which may inform public and private stakeholders on measures needed to restore degraded ecosystems and water catchments with similar characteristics as those of Lusitu River Catchment.

1.7 Conceptual framework

The physical and anthropogenic drivers of sedimentation interplay in sediment generation. Therefore, reducing sediment generation in a river catchment should begin by identifying these drivers and measures needed to mitigate them. As such, the conceptual model represents concepts seeking an integrated strategy to solve the issues of water shortage due to sedimentation. The overarching concept is that catchment restoration can be achieved when a coordinated interdisciplinary approach is taken (Spray *et al*., 2022). For example, combining engineering technologies, nature-based solutions, and effective implementation of legal frameworks and engagement of local communities, can sustainably lead to river catchment restoration (Muchanga, *et al*., 2023) as depicted in the conceptual framework for this study (Figure 1).

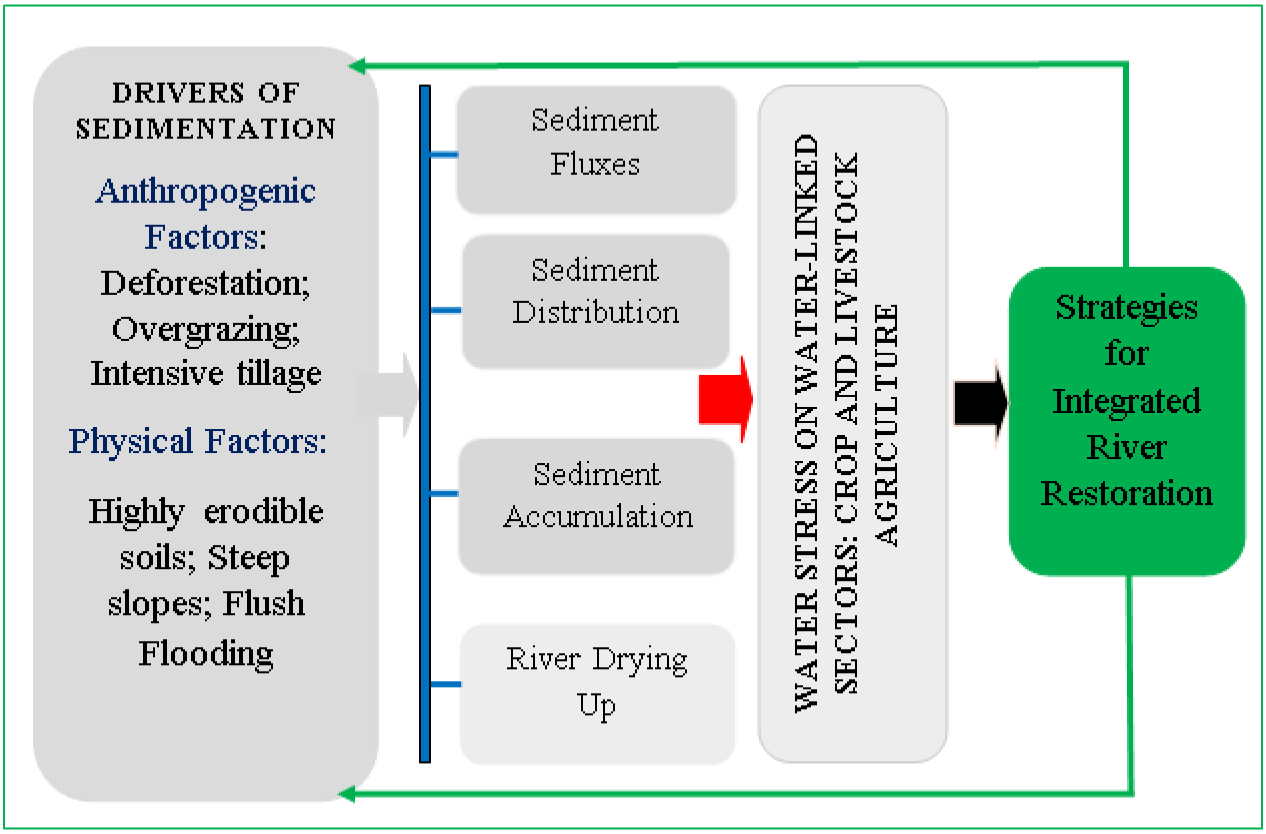


Figure 1: Conceptual Framework of the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Chapter overview

This chapter presents a review of literature related to main drivers of sedimentation, magnitude of sedimentation, and how sedimentation affects water-linked sectors as well as measures that different geographical areas have adopted to address the problem. The gaps observed in the reviewed literature and how this study bridged them up are also highlighted.

2.2 Main drivers of sedimentation in rivers

Sediment, which is sometimes called silt or alluvium comprise of solid particles of mineral and organic material transported by water (Ezugwu, 2013). Factors which influence the quantity of sediment transported in a river are, supply of sediment and flow regime (Lativin *et al.*, 2003). River flow-sediment relation is very complicated. Many river channels have undergone dramatic changes in recent decades due to sedimentation (Ran *et al.*, 2010; Xu, 2013). For example, studies on the Yellow River (Mongolia Reach Region) show that the Yellow River channel reduced following an increase in siltation of the Mongolia Reach Region (Fan *et al*., 2013; Qin *et al*., 2011; Ta *et al*., 2013; Zhang *et al*., 2017). A long-term trend of reduction in precipitation, as well as rainfall intensity, is considered as a factor leading to the changes in runoff and sediment load of the reach (Zhang *et al*., 2005; Xu *et al*., 2007; Fan *et al*., 2013; Wang *et al*., 2015; Wu *et al*., 2014; Shi *et al*., 2017). Studies by Chen *et al*. (2017) and Yao *et al*. (2011) show that sediment deposition at river tributaries, fluctuating river flows and unstable riverbanks impede flood control. Therefore, studies on the changes in the flow-sediment relations and deposition-scour characteristics are very important and have aroused wide concern especially in the Yellow River (Ren *et al*., 2002; Zhang *et al*., 2005; Fang *et al*., 2008; Ran *et al*., 2012; Wang *et al*., 2016; Huang *et al*., 2017; Si *et al*., 2017; Yao and Liu, 2019). Other studies which have documented the influence of rainfall in sediment generation are Leopold (1995), Das and Saikia (2009), Viessman and Lewis (2012), Wohl, (2015) among others.

Poor land management and sheet erosion lead to topsoil being carried into the water bodies (Dai and Liu, 2013). The agricultural sector is primarily responsible for sediment runoff in most areas of the world through unsound farming practices. These include downhill ploughing and deep ploughing (Makwara and Gamira, 2012). This loosens the soil and, is easily eroded by agents such as runoff. Erosion and sedimentation are natural phenomena which can be seriously influenced by human activities (Yao and Liu, 2019). Some of the natural factors such as highly erodible soils and steep unstable slopes, increase rates of erosion and sediment loads (Yao and Liu, 2019). Nonetheless, natural erosion is normally a very slow process. Human-induced or accelerated erosion can result in major increases in sediment generation (Yao and Liu, 2019). A study by Zhao *et al*. (2013) found that some principal factors which influence accelerated erosion rates were area under cultivation, changes of landuse, crop rotation and agricultural practices. A study of seven rivers by UNESCO (2011) found that, the key anthropogenic driver of high sediment loads in rivers were agricultural practices. The study pointed that, clearing of vegetation to promote agricultural expansion, as well as tillage techniques which loosened soil, increased rates of erosion by runoff. This results in highly destructive forms of erosion such as gullies which make farmland useless. The other major human-induced changes, which disturb the natural processes of erosion and sediment transport include construction of dams and other river-control structures, such as locks and weirs among others (Zahar *et al.*, 2008).

Sediment problems faced by different river basins are to a large extent river-specific due to specific combination of controlling factors, which include, but not exclusively topography, surface conditions and landuse patterns and the socio-economic conditions in a river basin (Walling and Fang, 2003). Poesen (2011) also found that local factors which include topography, river control structures, soil and water conservation measures, tree cover, land use or land disturbance such as agriculture and mining influence sediment loads in rivers. A study by Wallling (2009), showed that climate change is influencing sediment loads of rivers around the world. Changes in sediment yields were due to climate change and associated changes in rainfall and runoff. Effects of climate change in sediment yield may also interact with other anthropogenic causes of sedimentation in rivers, such as agricultural production (Ananda *et al.*, 2003; Midgrey and Bond, 2015; Liu *et al.*, 2016).

Martins *et al*. (2022) conducted a study on the most significant factors in the development of the Alva gully in Portugal. Its development was examined for four years, based on a study of the modification of its morphological characteristics. Principal Component Analysis (PCA) was used to estimate the correlation between the quantitative characteristics and other variables such as biophysical variables. The results showed that, the main factors that controlled the spatial variation of soil erosion were soil penetration resistance, slope, slope shape, and vegetation cover. The study found that, a convex bank slope has denudation rates greater than a concave bank slope in respect to gully widening. Soil erosion processes such as gully erosion are localised, thus are dependent upon prevailing factors such as type of soil and rainfall amount. Hence the study could not deduce how gully erosion was influenced by all the factors as the gully was not gauged.

A study by Daramola *et al*. (2022) used Soil and Water Assessment Tool (SWAT) to assess the roles of landuse change, land cover area, and runoff on watershed's sediment yield in the Kaduna Watershed (Nigeria), Western Africa. The SWAT model generated NS, r^2 and *p*-factor of 0.71, 0.80, and 0.86, respectively. Therefore, the model performed well for stream flow and sediment yield predictions. The study suggested that the destruction of evergreen forests and a significant change in landuse from grass cover and forest to agricultural and residential use between 1975 and 2013, increased sediment yield by 68% (Daramola *et al*., 2022). There are many other studies which have documented the interplay of drivers of sedimentation, such as landuse change, landuse area size, runoff, steeper slopes and stream gradients (Ichim, 1990; Milliman and Syvitsk, 1992; Birkinshaw and Bathurst, 2006; Umit, 2022).

In East Africa, a study by Amasi, *et al.* (2021) found that catchment environmental factors driving sedimentation were slope, climate, vegetation cover, soil and geology, and topography. Other factors were landuse changes and climate changes, which were driving accelerated soil erosion in the semi-arid East Africa. This led to increases in reservoir sedimentation and decreased energy production. Similar findings were reported in Ethiopia by Kidane and Alemu (2015).

Dlamini *et al*. (2016) conducted a study on implications of load Shedding and charcoal use in Zambia. The study found that unreliable supply of hydroelectric power in Zambia has resulted in increase in charcoal usage, which is becoming the main energy source among several households. The study highlighted the importance of understanding the impact of load shedding on forest degradation and deforestation. The study found that charcoal production affects the biophysical resources. Charcoal prices had increased by 65% between 2013 and 2015. During the same period, the number of charcoal kilns per person increased from an average of three kilns in 2013 to four kilns in 2015. The study found that charcoal producers lacked the capacity to comply with policies and disregarded traditional forest governance. The results were similar to a study by Mulenga *et al*. (2015) and Samboko *et al*. (2016). Sedano *et al*. (2016) also did a similar study in Tete, Mozambique on the impact of charcoal production and found that, charcoal production for urban energy was a major driver of forest degradation and eventually contributed to river and reservoir siltation.

A study by Mphande and Sichingabula (2019) in Mushibemba catchment found that, sediment which was filling up the small reservoirs originated from cleared commercial agricultural land. Sichingabula (1997) documented that soil erosion was a serious problem in Zambia. Sediment generation was attributed to long history of sedentary agriculture and overgrazing by cattle, especially in the Southern part of Zambia (Sichingabula, 1997). Many studies have shown that crop farming is a key factor in sediment generation (Alemaw *et al.,* 2013; Sichingabula, 2018; Simweene and Muchanga, 2021; Chisanga *et al.,* 2022; Muchanga *et al.*, 2023). The main gap observed in most of the reviewed studies above is that none of them took into consideration how cultural practices may be drivers of sedimentation. This gap was partly bridged up by the current study, which documented a cultural practice that was contributing to sedimentation. While some studies especially outside Africa documented their studies on rivers, majority of them especially in Zambia and Africa in general, seemed to be more focused on reservoirs unlike rivers. Hence, this study partly contributed to the ongoing development of insights around drivers of river siltation.

2.3 Magnitude of sediment burden in river systems

A study by Ferreira *et al*. (2013) in the Amazon River Basin - Brazil, show that Amazon River had in the last 50 years been experiencing negative effects of urban growth, industrial and agricultural development, and had been severely affected by sedimentation. The study found that, mean sedimentation rates at Anadim, Outeiro and Tucunduba were in the range between 0.04 and 1.02cm per year, which was within the range of expected values for systems with human activities (Ferreira *et al*., 2013). The study quantified sedimentation using a high-resolution gamma spectrometry, which is a nuclear technique. This method was also used to determine the magnitude of sedimentation by Akram *et al*. (2006) in the Arabia Sea; Xu *et al.* (2008) at the Aswan Dam in Egypt; Ligero *et al*. (2010) in Southwest of Spain, Santos *et al*. (2008) in Brazil and Jweda *et al*. (2011) in Michigan. All these studies found sedimentation to be within the magnitude like the one observed in the Amazon basin, implying some spatial homogeneity of the magnitude in some instances.

A study by Kats (2016) estimated the sediment trap efficiency of the Nga Moe Yeik reservoir in Myanmar, using empirical equations. The study found that the reservoir had a trap efficiency of 97.65%. Even though it was cost effective to use empirical equations (Kats, 2016) to estimate sedimentation, this method may not produce accurate results needed in determining sedimentation (Muchanga, 2020). Despite this short coming, there are a number of studies which have estimated sedimentation using empirical equations. For example, Morgan (1994) in Malaysia; Mikhahalova *et al*. (1997) in Honduras; Zaw and Intralawan (2014) in Myanmar; Isa *et al*. (2015) in Mosul Dam Reservoir and Yin *et al*. (2015) in China. This simply implies that the contemporary sediment monitoring, and measurement methods could be getting adopted at a slower rate than expected.

In Ethiopia, a study by Kebedew *et al.* (2021) conducted four bathymetric surveys to determine volume change due to sediment depositions on Lake Tana. They found average annual increase in lakebed at 2.8 mm from 1940 to 1987, a period during the beginning of the agricultural growth in the basin. Later, annual increase in lakebed sedimentation doubled, following intensification of agricultural activities in the basin. Further, the study found that population pressure accelerated land degradation in the lake basin. The study recommended immediate catchment management to stop gully formation (Kebedew *et al*., 2021).

A study by Tundu *et al*. (2018) on sedimentation and its effects on river systems and reservoir water quality, in a case study of Mazowe Catchment in Zimbabwe found that, high amount of sediments in rivers lead to reservoir sedimentation which reduces the useful life of the reservoir. The study estimated annual soil loss in the catchment of up to 65 tonnes per hectare annually, while Bathymetric survey at Chimhanda Dam revealed that the storage capacity of the dam had reduced by 39% due to sedimentation.

A study by Chitata *et al*. (2014) in the semi-arid Southern Zimbabwe investigated the capacity loss due to sedimentation and estimated the sediment trap efficiency of Mutangi reservoir in Chivi, which is a semi-arid region. Between 2000 and 2012, the study used hydrographic surveys and water depth-capacity methods to determine the capacity of the dam. They computed dam capacity loss from 2000 to 2012; by comparing dam capacities for 2000 and 2012. The results showed that Mutangi reservoir had an average trap efficiency of over 96%. The sedimentation of the reservoir led to loss of 37% of its water storage capacity. The study pointed out that, capacity loss due to sedimentation was a serious problem because the area is semi-arid and therefore, called for management practices that reduce erosion, in order to prolong the dam lifespan. The study recommended that the local population should be involved in anti-erosion management activities. However, the study did not specify the stakeholders needed to work with the local people.

A remote sensing approach was used by Mupfiga *et al*. (2016) to determine sedimentation process in Mzingwane Catchment, Zimbabwe. The results showed loss in reservoir gross capacity due to silt deposition for a period of 47 years (1966 to 2013). The study determined reservoir gross loss to be 3.371 Million m^3 (40.84 %). The annual rate of sedimentation was calculated to be 0.87 % per annum. The specific sediment yield over Tuli-Makwe Catchment was calculated to be 110.63 tonnes / km^2 / year. If this sedimentation rate continued at the same rate, then Tuli-Makwe reservoir would be filled up by the year 2081. Even though the study was able to assess sedimentation using remote sensing, the attitudes of the local people regarding sediment generation could not be established hence, a need for integrated approach (Spray *et al*, 2022).

Sichingabula (1999) investigated sediment-discharge regimes for rivers in southern Lake Tanganyika Basin. These rivers were Lucheche, Lunzua, Izi, Kalambo and Lufubu. The study found that, changes in bed elevations which had a mean of 0.61m translated into large quantities of sediment being liberated from the bed and thus, accessed by the high flows. The study also found that, in terms of specific sediment yield, the five rivers each contributed between 1.2 and 9.6 tonnes of sediment per km^2 annually, which was being deposited into Lake Tanganyika. The data showed that sediment yield decreased with drainage area. The study pointed that where catchments are not protected from tree clearing for agriculture and settlements, the sediment yield rates could increase radically.

Chomba and Sichingabula (2016) conducted a study on sedimentation of four small reservoirs: Lwiimba, Silverest, Morester and Katondwe. The results of the bathymetric survey showed that, reservoirs had capacity storage losses of 99,044.57 m^3; 379,480.5 m^3; 13,805.68 m^3 and 9,937.12 m^3 respectively. As a result of sedimentation, the reservoirs were at risk of drying up especially in the dry season. A study by Muchanga (2017) to understand sedimentation process in the Makoye Reservoir of Southern Zambia, employed a variety of methods which included sediment coring, onsite measurements using Sedimeter SM3A, Elevation Change Method (ECM). The results showed that Makoye reservoir had silted at a rate of 3,112.97 m^3 per year, leading to average accumulation of 87,163 m^3 of sediment, reducing the storage capacity by 53.5%, leaving the reservoir with only 24 years of useful life from 2017. Another study done by Sichingabula (1999b) shows a heavy sediment transport in the Luangwa and Zambezi River, but the challenge is that the study did not highlight the quantity of sediment that was accumulating on the riverbed. This scenario was notable in the other rivers that were studied within the Kaleya Catchment (Walling *et al*., 2001; Chisola *et al*., 2022a) as well as the Kafue River (Sichingabula *et al.*, 2000). Chisola and Kuraz (2016) also noted that, sediment loads could have been threatening the hydrological regimes of the

Chongwe River. Notwithstanding the significance of all these studies, it was noted that, many of them focussed on reservoir sedimentation and overlooked river channel sedimentation. Studies which investigated river channels were concerned with sediment transportation into reservoirs or nearby lakes and or oceans. This study physically quantified river sediment accumulation using in-situ measurement.

2.4 Sedimentation and Water-driven sectors

Pradhan, (2004) conducted a study to devise solutions to the problem of high sediment loads facing hydropower plants, with respect to sediment handling at headwork. The study found severe sand erosion of turbines which led to loss in energy generation. Further, the study found that one turbine at Jhimruk Power Station, was exposed to a sediment load of 6,900 tonnes during a period of about two months. 80% of the sediment were hard minerals that abrade the runners. This led to efficiency loss of 4% to 25%. Sediment loads in the water subjected the power station to be undergoing annual repair works, which further disrupt power generation. The study further pointed that sediment problem has inhibited hydroelectricity generation in the Himalayan rivers, which have sufficient water flows and steep gradients. Within Nepal, Shrestha and Shrestha (2019) found that at Kulekhani First Hydropower Station, energy generation was decreasing at the rate of 826.46 MWh per year due to high sediment loads in rivers. These results suggest that river sedimentation has negative multiplier effects by limiting generation of electricity. Therefore, more research is needed to improve sediment handling.

Mohammad (2020) conducted a study at Mosul Dam Pumping Station on the Tigris River in Iraq, to find a solution to the problem of sediment deposition in front and inside of the intake, which disrupted the functioning of the pumping station. To ensure the sustainability of the pumping station's efficiency, the study proposed adding a control earth dike upstream from the station and managing the pumping rate. A number of studies have shown that sediment deposition is negatively affecting water supply systems across the world. In the United States of America, at Conesville Power Station, Michell (2006) proposed realignment of riverbanks upstream from the pump house. Moussa (2011) at the Rowd El-Farag pumping station on the Nile River in Egypt, recommended using dredging as a solution to maintain the sustainability of the station. Shahidan and Hasan (2011) at Ijok Intake on the Ijok River in Malaysia, proposed using a dike to solve the problem of accumulation of sediment near the inlet. Charafi (2019) used a 2-D numerical model in Morocco, to predict the shutdown period of a pumping station for any high sediment concentrated flow. The disruption of water pumping stations across the world imply that sedimentation is indeed a serious problem to the water-linked sectors.

Similarly, a study by UNESCO (2011) found that, if there is a lot of sediment in the water body, it can disturb the normal operations of irrigation pump house intakes and can also interrupt irrigation when a lot of sediment being transported is deposited in a canal system. When sediment is deposited in canal systems, it can lead to high costs for those reliant on these systems as a water supply (UNESCO, 2011). A study by Bhatti *et al*. (2021) investigated the problem of soil erosion and how it should be managed for sustainable irrigation in area which receive less rainfall, the Gomal River Catchment in Pakistan and Afghanistan. The study found that managing the sub-catchment in a semi-arid environment and having steep slopes and less vegetation cover cannot reduce a lot of sediment entry into the irrigation system compared to the use of a settling reservoir.

A study by Chen *et al.* (2021) on the effects of muddy water irrigation, on nitrogen transformation in agricultural soil of Yellow River basin indicated that, water management of agricultural soils is important, especially in semi-arid regions. River sedimentation leads to flooding of agricultural fields because the watercourse is unable to convey the quantity of runoff flowing downstream (Munthali *et al*., 2011; Liu *et al*., 2016). Flooding has always occurred naturally and maintains ecosystem composition and processes (Dalu *et al*., 2013). However, it can also be altered by landuse changes resulting to increased sediment accumulation in river systems, raising the level of the riverbed as was observed by Liu *et al*. (2016). Munthali *et al*. (2011) conducted a study to estimate sediment yield of the Songwe which is found in Malawi. Watershed climate, land use, and several physical properties were gathered and used in GIS to determine the hydrological sediment potential of Songwe River watershed, and to quantify reservoir sedimentation. Most of the sediment generation was established to be occurring in the upper sub-basin from built up area and degraded natural land. These trends caused the increased flooding events in the lower sub-basin which affected crop fields in the area.

Yi *et al*. (2011) carried a study on sediment pollution and its effect on fish through food chain in the Yangtze River. The problem of the concentration of heavy metals in water, sediment, and fish were studied in the middle and lower reaches of the Yangtze River. The study found that, the concentrations of heavy metals were 100-10,000 times higher in the sediment than in the water. Benthic invertebrates had relatively high concentrations of heavy metals in their tissues. This was due to their proximity to contaminated sediments. The concentration of heavy metals was lower in the river sediments than in the lake sediments. In the opposite, the concentration of heavy metals was higher in river water compared to lake water (Yi *et al*., 2011). The study pointed out that even if a pollution event into a water body may not take long as it is transitory, the effects may stay longer because the pollutants are adsorbed by the sediments and then released into the food chain.

Tundu *et al*. (2018) conducted a study on sedimentation and its effects on river systems and reservoir water quality in Mazowe Catchment in Zimbabwe at Chimhanda Dam. The study determined a variation in two selected reservoir water quality indicators, turbidity, and pH. A significant difference in turbidity was observed for the years 1988 to 2014 with a *p* value of 0.02. The mean value of turbidity for 1988, 2003 and 2014 were 15.6, 34.4 and 41.7 NTU, respectively. The values showed an increasing trend in turbidity which was attributed to anthropogenic activities occurring upstream of the dam, which increased soil erosion, thereby contributing more sediment into the reservoir. Water high in turbidity can aid the formation of nuclei, to which gastrointestinal disease pathogens can attach. If such water is consumed untreated, it can cause diseases (Tundu *et al*., 2018). High turbidity levels also make the treatment of water expensive. Concerning pH, the results showed that there was no significant change between 1988 and 2014 (p-value > 0.05). This could have been because pH is a chemical parameter determined by the type of sediments that are carried into the river, not the sediment load. Pollutants are adsorbed by the suspended sediment in flowing water in rivers and are deposited onto the bed. As pollutants accumulate in the riverbed, the sediment act as carriers of pollutants which may affect the bio-community through food chain over a period of time (Tundu *et al*., 2018).

Sedimentation of rivers affect different communities in different ways (UNESCO, 2011). During the rainy season, the quality of water is affected due to increase in turbidity which is visible as water change colour (Addo *et al*., 2011; Bhadja and Vaghela, 2013). In agricultural river catchments, sediment may be contaminated with high levels of agricultural phosphorus, which create algal blooms. These cause eutrophication; reduction in dissolved oxygen which threaten the life of aquatic micro-organisms (Castro and Reckendorf, 1995) which are important in the normal functioning of ecosystems (Grobler, 2011). Several studies have documented how sedimentation affect water quality for example, Kapungwe (2013); Chomba and Sichingabula (2016); Song *et al*. (2017); Kandler *et al*. (2017); Lu and Yu (2018) and Cui *et al.* (2018). A study by *Kunz et al.* (2011) on sedimentation of Lake Kariba found that about 70% and 90% of incoming total Nitrogen and Phosphorus were removed from the lake water by sediment adsorption and denitrification. Owing to the large volume of Lake Kariba, it attenuates flow from over 50% of the Zambezi River basin. Removal of Organic Carbon, Nitrogen and Phosphorus resulted in extreme reduction in nutrient loadings to the downstream riparian ecosystems and to the coastal Indian Ocean.

A study which was conducted by Gandiwa and Gandiwa-Zisadza (2015) in Zimbabwe established that, increased sedimentation of major rivers in Gonarezhou impacted the local people through reduced water provision for livestock and economic activities such as gardening and aquaculture. Further, the loss of soil in the adjacent communal areas degraded the land, making it less productive. This increased the vulnerability of local people to extreme weather events such as droughts and floods. The study highlighted the need for enhanced integrated river basin management (similar to the earlier observation by Gandiwa *et al*., 2012a) in order to reduce soil loss and river siltation for the benefit of livelihoods, and wildlife conservation in the region. Rankoana (2020) in South Africa, further found that, supply of water from Mutale River was negatively affected by siltation, drought, and change in the occurrence and distribution of rainfall, and increased temperature. The study established that water levels in the river had declined which led to unsustainable water supply.

Muchanga and Sichingabula (2021) conducted a study at a lacustrine reservoir in the Magoye Catchment, in Southern Zambia and found that, there were differences in the concentration of Total Dissolved Solids, Total Suspended Solids, and turbidity during the rainy season and cool-dry season. The study found that turbidity was high in the rainy season and low in the cool-dry season. This variation was attributed to sediment deposition into the reservoir by runoff in the rainy season, which affected the quality of water for livestock. A similar study by Simweene and Muchanga (2021) found that, sedimentation of Makoye Reservoir in Southern Zambia, affected economic activities which were predominantly, gardening and livestock watering. The study further found that, sedimentation reduced water quality in the reservoir. The other distinctive effect was reservoir overflow, which resulted in the downstream flooding, hence affected the communities downstream. Despite all these challenges, there were no sediment management measures to sustainably address the sediment problem in the Makoye Reservoir. This shows that management of water resources in Zambia require scaling up, and the scenario seem to suggest that small scale farmers who depend on water for cultivation of vegetables in the gardens and for livestock watering are the most hit by the problem of sedimentation (Sichingabula, 1997; Muchanga, 2020; Chisanga *et al*., 2022).

A study by Muchanga *et al.* (2023) on the impacts of sedimentation on priority water-linked sectors in the Zambezi River Basin in Zambia established that, small reservoirs were susceptible to severe water stress for much of the dry season with more than 90% of the local population facing economic water shortages. The study established that, the problem of reservoir sedimentation could be solved by using mechanisms such as provision of alternative livelihoods, among other coping strategies and, proposed water education for behavioural change towards water resources management. Although this study was at Zambezi Catchment scale, its focus was on reservoirs and generally only gave a snapshot overview of the entire catchment rather than giving more specific details on what was happening at sub catchment scale. Moreover, like other earlier studies earlier mentioned, the emphasis was on reservoirs instead of rivers. Hence, the current study, provide areas-specific evidence to validate the earlier study.

The main limitation in most of studies above, is that they only focussed on the technical part of water quality without specifying how local people were being affected. Even though some studies highlighted reduction of water supply to local communities, they were based on reservoir sedimentation. These gaps were addressed by particularizing how river sedimentation affected small scale crop farming, livestock farming and domestic water supply in the downstream section of the Lusitu River.

2.5 Strategies for restoration of rivers from sedimentation

There is growing interest across the world for large-scale restoration of habitats, to some extent, triggered by the designation of 2021–2030 as the United Nations Decade on Ecosystem Restoration (UN, 2020) whose aim is to support and scale up all efforts meant to prevent, bring to halt and reverse the degradation of ecosystems across the world and, further, to raise awareness of the importance of successful ecosystem restoration (Spray *et al*., 2022). River catchments around the world have been transformed by human activity such as deforestation and agriculture intensification (Spray *et al*., 2021). The negative effects of these activities need to be addressed (Spray *et al*., 2022). However, the solutions are not only a matter of reversing their extent, but also a need to apply a combination of interventions (Palmer, 2005; Peskett, 2020; WWF, 2020).

Restoration of rivers has been focusing on Nature-based Solutions (NbS) as means of resolving the problems of biodiversity loss and climate change (Spray *et al.*, 2022). Sedimentation of rivers and their eventual drying up, has severe implications on biodiversity loss, frustrates the efforts to meet SDG 6 and other SDGs which are water dependent (Spray *et al*. 2021). The interdisciplinary approach in river restoration, was a result of the realisation that river catchments function as a unity and cannot be managed from a single lens of water engineering (Spray *et al*., 2021). One notable example where strategies to reduce erosion and sediment delivery has succeeded is in the Loess Plateau, in the Yellow River Basin (UNESCO, 2011), through dam construction, afforestation, terracing, and construction of check dams and conversion of crop land on slopes into grazing land. The project was successful in reducing sediment loads transported by the Yellow River (Zhao *et al*., 2013).

Frankl *et al*. (2017) conducted a study of recent land management efforts to reduce soil erosion in northern France in the loess-dominated Aa River basin of northern France, where cropland accounts for 67% of the cover. They assessed the effect of fascines on gully erosion control, together with rainfall characteristics and cropland management. The study found that even if the presence of fascines had an effect on reducing gully length, the spatial and temporal differences in gully length were mainly driven by cumulative precipitation. Measurement of sediment which was being deposited at 29 fascines in 2016 showed that only 47% of the fascines functioned as sediment sinks, storing on average 1.7 million grams of sediment per winter half-year. The results suggested that fascines positively impacted the landscape's resilience and reduced ephemeral gully erosion rates.

Seitz *et al*. (2019) conducted a study on the impact of different arable farming practices on soil erosion at the FAST experiment of Agroscope, Switzerland. The study showed that organic farming decreased mean sediment delivery compared to conventional farming by 30%. The study established that, reduced tillage in organic farming decreased sediment delivery (0.73 tonnes per hectare per year) compared to organic plots where tillage was intensive (1.87 tonnes per hectare per year). The study established that, soil surface cover and soil organic matter were the best forecasters for reduced sediment supply. Soil erosion rates were significantly lower when soil cover was above 30%. The study concluded that both organic farming and conservation agriculture reduce soil losses through reduced tillage.

According to Xu *et al*. (2014), river basin engineering measures for sediment control have been widely used in the Yellow River. They include the construction of structures to trap sediment on slopes, and within pond, and dam systems in gullies which intercept sediment discharged from the slope. Settling basins are constructed in catchments to limit gully erosion. These small dams trap only the large sediment particles, and the sediment load builds up within a short time in the downstream. This measure has no major impact on the sediment yield (Xu *et al*., 2014). The construction of such debris trap dams in the upper catchment areas as a solution require proper regular maintenance, as such dams will be quickly filled through bed load transport, and in the long term serve no purpose. In addition, upstream sediment trap dams present a challenge of finding a place for the continuing long-term disposal of the incoming sediments, especially that the settling basins are also too small, to significantly affect the sediment yield into the reservoir or river (Zhao *et al*., 2013). These dams also provide sources of water for local residents and agricultural enterprises. (Godwin, 2011).

Liu *et al*. (2019) conducted a study on gully erosion control practices in Northeast China. Practices to manage gully erosion were developed by researchers and farmers over the past 50 years. These were various drop structures and check dams, a shrub plant enclosure, and an arbor plant enclosure (Liu *et al.,* 2019). The study found that the application of these practices depended on topography, gully size and local economy. In the application of the biological and engineering systems for controlling gully erosion, the important procedures were regrading the gully head and banks, placing riprap on the regraded head and banks, planting various plants; shrub on the banks, head and inside gully to enclose relevant area (Liu *et al.,* 2019). The study concluded that, the indigenous people who are responsible in the protection of their land, needed knowledge empowerment on the drivers of sedimentation and how gullies form in order to sustainably manage the gullies (Liu *et al.*, 2019).

Islam *et al*. (2018) conducted an impact analysis of sand dredging from alluvial tidal river Payra in southern Bangladesh. The study was prompted by the plan to make a large build up area (BUA) along the northern bank of Payra River. This sedimentary bar had to be raised by 3.45 meters to keep it free from any extreme events. Accordingly, it was planned to collect the required filling material which was estimated at 57.6 million m^3 of sand/soil by dredging the same riverbed. The analysis revealed that dredging of the sandbars resulted in changes in flow field. Dredging created direct influence on bank erosion because proper method and techniques were not used, and the hydrodynamic changes were not taken into consideration. The study recommended controlled dredging with regular monitoring, and studies related to changes of geological and morphological behaviour of the river due to dredging. Controlled river dredging was documented by scholars such as Shen, (1999) and Karmacharya, (2021). The usefulness of the dredged material was documented in some studies. For example, by the Great Lakes Commission (2013) in the United States of America and Mwiinde (2017) in Zambia.

A study by Xu and Cheng (2002) on the relationship between erosion and sedimentation zones in the Yellow River, found that, soil can be protected from erosion by afforestation or vegetation screens depending on local climatic conditions. Stopping the clearance of native vegetation in erosion-prone areas is a good strategy for areas which are experiencing increasing erosion due to land clearing for agricultural expansion and other reasons. This strategy can have a significant impact on sediment reduction in waterways (Wang and Hu, 2009). Other benefits from afforestation include environmental quality improvement and creation of habitat for different species (Zhao *et al.*, 2013).

Prasetyo *et al.* (2021) investigated the effectiveness of vegetation cover for soil erosion control in the Upper Progo watershed, Java, Indonesia; an agricultural watershed. Soil erosion was calculated using the Revised Universal Soil Loss Equation (RUSLE) model. The result showed that increase of vegetation cover from the existing condition from 4.8% to 30% can significantly reduce about 76% of soil erosion. The study further found that, preservation of about 30% vegetation cover in the upstream area of the watershed can enable farming practices with a low risk of soil erosion to be practiced. Chen *et al.* (2019) indicated that there was a threshold phenomenon between vegetation coverage and soil loss. As a result, the vegetation coverage was divided into three zones. The lower zone (0–40%) was suitable for artificial restoration and the middle zone (40–80%) suitable for a mixture of artificial and natural restoration, and the upper zone (80–100%), suitable for natural recovery.

In East Africa, Mersha *et al.* (2022) did a study in the Blue Nile Highlands, Ethiopia, which has been experiencing serious land degradation, and threatening water security for the people in the region. It hosts over 90% of the country's population (Asfaw *et al.*, 2018), hence present a fragile ecosystem prone to degradation (Hurni *et al.*, 2005; Bewket and Sterk, 2005; Nyssen *et al.*, 2010; Rientjes *et al.*, 2011). The study assessed the benefits of sustainable land management after a 5-year catchment restoration measure and found that implementing sustainable land management reduced runoff and increased soil moisture storage by 15.6% to 800%, which promoted rapid recovery of the hydrologic functionality of the natural landscape (Nyssen *et al*., 2010; Haregeweyn *et al*., 2012; Akale *et al*., 2019; Abera *et al*., 2020; Gumma *et al*., 2021).

A study by Dube *et al*. (2021) in South Africa, proposed an integrated catchment management approach based on numerous variables among them, natural water resource availability patterns, natural environmental conditions, the built environment, societal systems, strategic policies, national and local economics, legislation, water management methods and land use. The study found that integrated catchment management was failing in South Africa because national policies and strategies emphasised integrated water resource management, integrated water quality management and integrated water resources planning which were fragmented in their application (Stosch *et al*., 2017). The study reported that, water management was about control and dominated by technical considerations with little consideration for people and the environment (Schulz, 2007; Schreiner, 2013; Pengelly *et al*., 2017).

A study by Monde *et al*. (2023a) on sustainable ecosystems management in Zambia, found that, ecosystems sustainability was failing partly because the management was reactive and lacked behavioural scientific strategies. The study proposed an Environmental Education Framework for Ecosystem Management (SEFREEM). The challenge posed by lack of environmental and water education for sustainable and effective catchment management tend to have negative feedback on such phenomenon as rivers and reservoirs (Mtonga and Muchanga, 2021; Fonte, 2022; Chisola *et al*., 2022b; Monde *et al*., 2023b). Lack of environmental education may explain the low adoption of conservation farming among small scale farmers in Zambia (Nyanga, 2012). While a number of studies proposed vegetation restocking measures, they did not mention specific tree species and how local communities were being involved in catchment restoration. This study addressed these gaps by being specific on tree species for vegetation restocking and above all, developed an ICRF for Lusitu River Catchment together with the local people for them to have ownership of the tool.

2.6 Synthesised gap analysis in the reviewed literature

With due recognition of various insights reviewed in the literature, none considered the cultural dimension in sediment generation. Focus was on reservoir sedimentation and, to a lesser extent, sediment transportation in rivers. Effects of sedimentation were presented from a more technical aspect of water quality, and generally, on a large geospatial scale, and were not clear on tree species for vegetation restocking and how local people were being involved in catchment restoration. This study bridged these gaps by documenting a cultural practice which is a driver of sedimentation, and physically quantified river channel sediment accumulation using in-situ measurement, and particularised how sedimentation affected small scale crop farming, livestock farming and domestic water supply in the downstream section of the Lusitu River. This study specified tree species for vegetation restocking based on their economic importance and those naturally growing on the riverbanks and developed an ICRF for Lusitu River Catchment together with the local people for them to have ownership of the tool.

CHAPTER THREE: DESCRIPTION OF THE STUDY AREA

3.1 Chapter overview

This section describes the physical characteristics of the study area in terms of geographical location and size, climate, geology, soils, vegetation and hydrology, and the socio-economic characteristics. The chapter ends with a justification for selection of the study area.

3.2 Physical characteristics

This section describes characteristics of the study area in terms of geographical location and size, climate, geology, soils, vegetation, and hydrology.

3.2.1 Location and size

Lusitu River Catchment covers an area of about 1,831 km^2, its geographical location is at16^o 05$'$ 0$''$ S to 16^o 25′ 0″ S and 28^o 10$'$ 0″ E to 28^o 50′ 0″ E. Figure 2 below shows the location of Lusitu River Catchment.

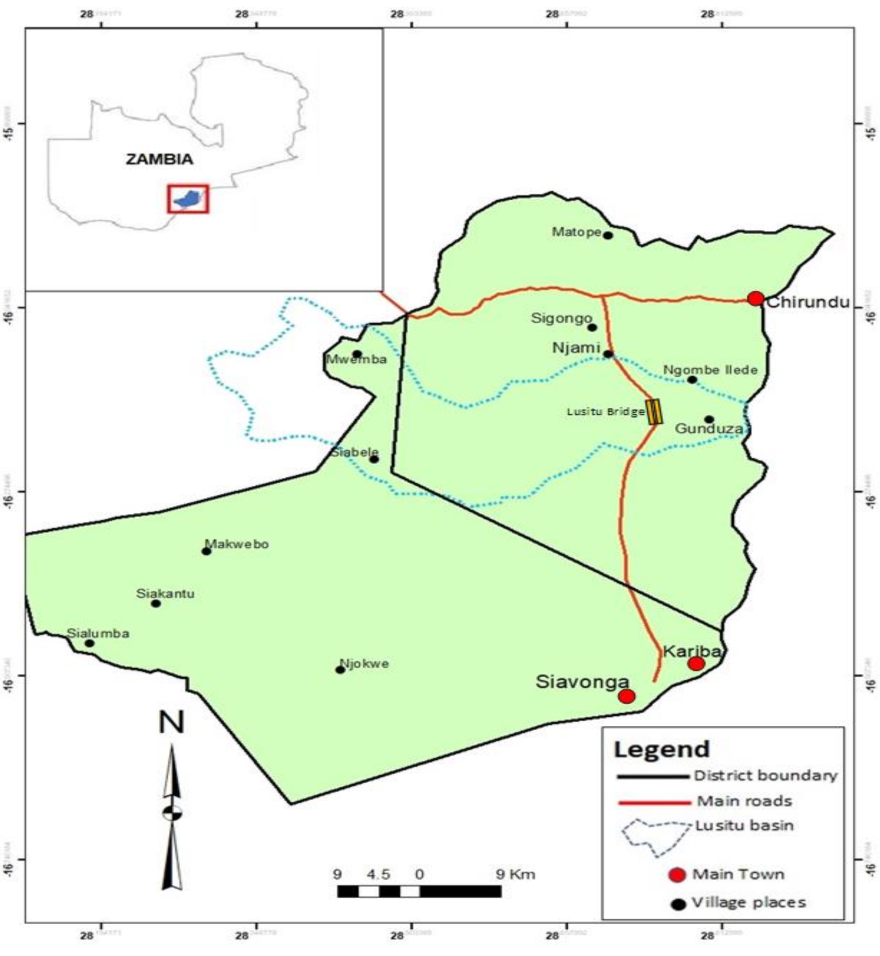


Figure 2: Location map of Lusitu River Catchment

3.2.2 Climate

In terms of climate, the study area experiences a hot, semi-arid climate with higher temperatures and lesser rainfall; class Bhs according to the Koppen-Geiger classification (Baumle *et al.*, 2007). Figures 3 and 4 shows the maximum and minimum temperature fluctuations in the catchment.

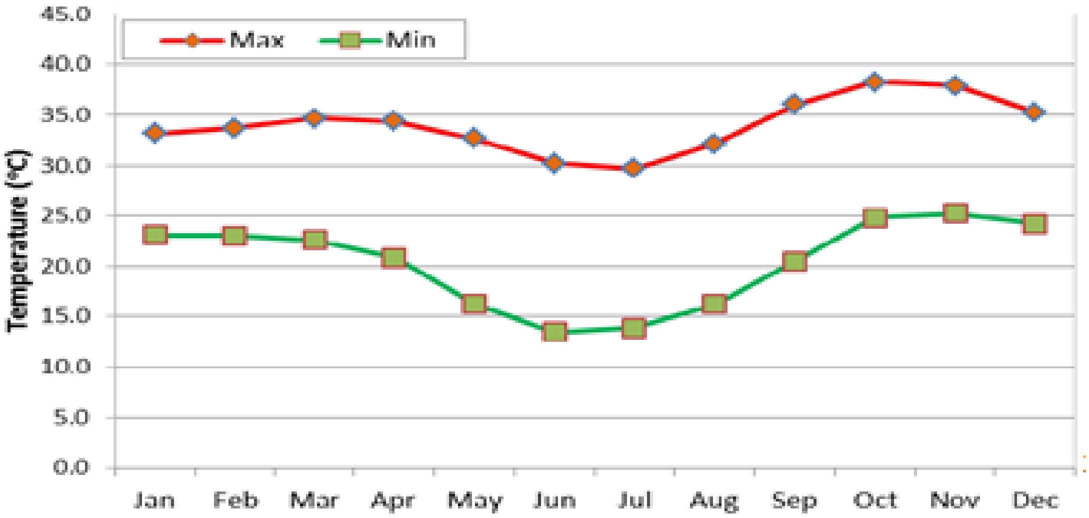


Figure 3: Minimum and maximum temperature in Lusitu (Source: Lusitu Irrigation Development Support Project, 2015).

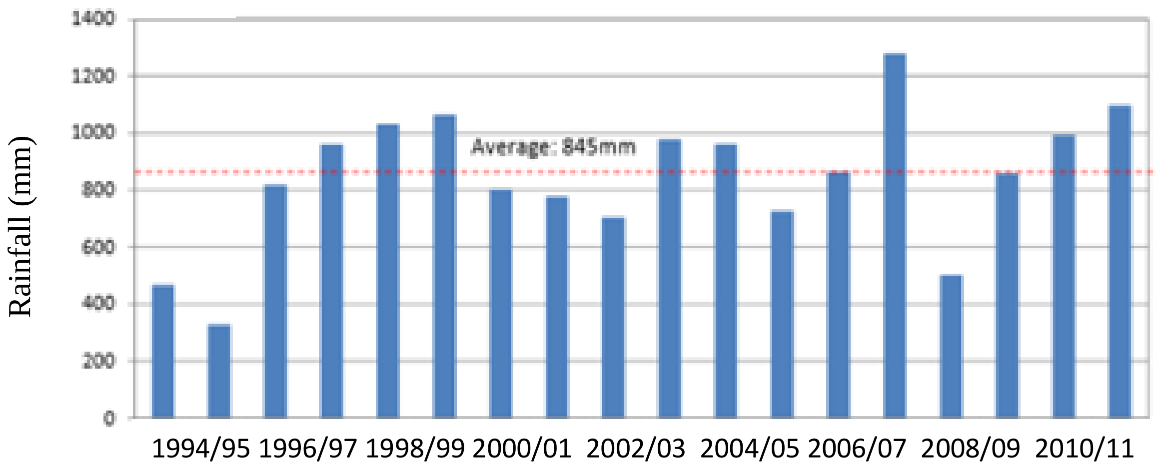


Figure 4: Average annual rainfall for Lusitu area 1994 – 2011 (Source: Lusitu Irrigation Development Support Project, 2015)

3.2.3 Soils

The soil types in the study area are Luvisols, Cambisols and Leptosols (Figure 5). The Luvisols and Cambisols dominate the lower and middle sections of the catchment and are associated with Karoo Supergroup in the Zambezi Valley and adjacent escarpment zone. They are sometimes referred to as Gwembe valley soils. Luvisols are soils that have high clay content in the subsoil than in the topsoil because of pedogenetic processes (especially clay migration).

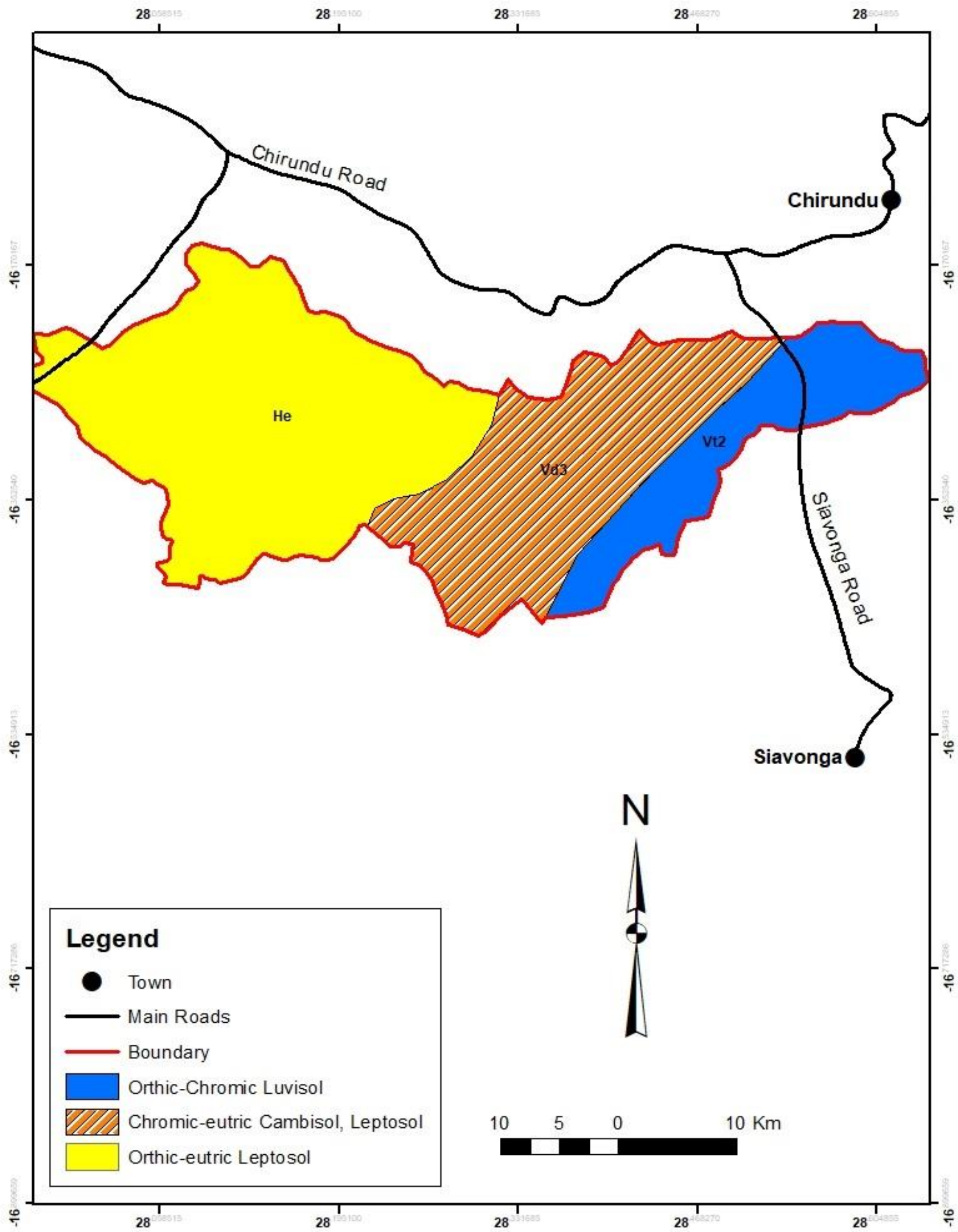


Figure 5: Soils map for Lusitu River Catchment

Cambisols are soils in an early development stage with at least an incipient subsurface soil formation. They are shallow and gravelly soils derived from acid rocks, occurring in rolling to hilly areas, including escarpment magmatic and metamorphic rocks of the escarpment zone in the Zambezi Valley (Baumle *et al.,* 2007). The upper catchment is dominated by the Leptosol. These soils have a very shallow profile depth which is an indication of little influence of soil forming processes and are highly susceptible to erosion.

3.2.4 Geology

The geology of the catchment mainly belongs to the Karoo Supergroup in the Zambezi Valley and adjacent escarpment zone (Baumle *et al.* 2007). The study area lies entirely over the sedimentary rock formation which belongs to the Upper Karoo (Figure 6).

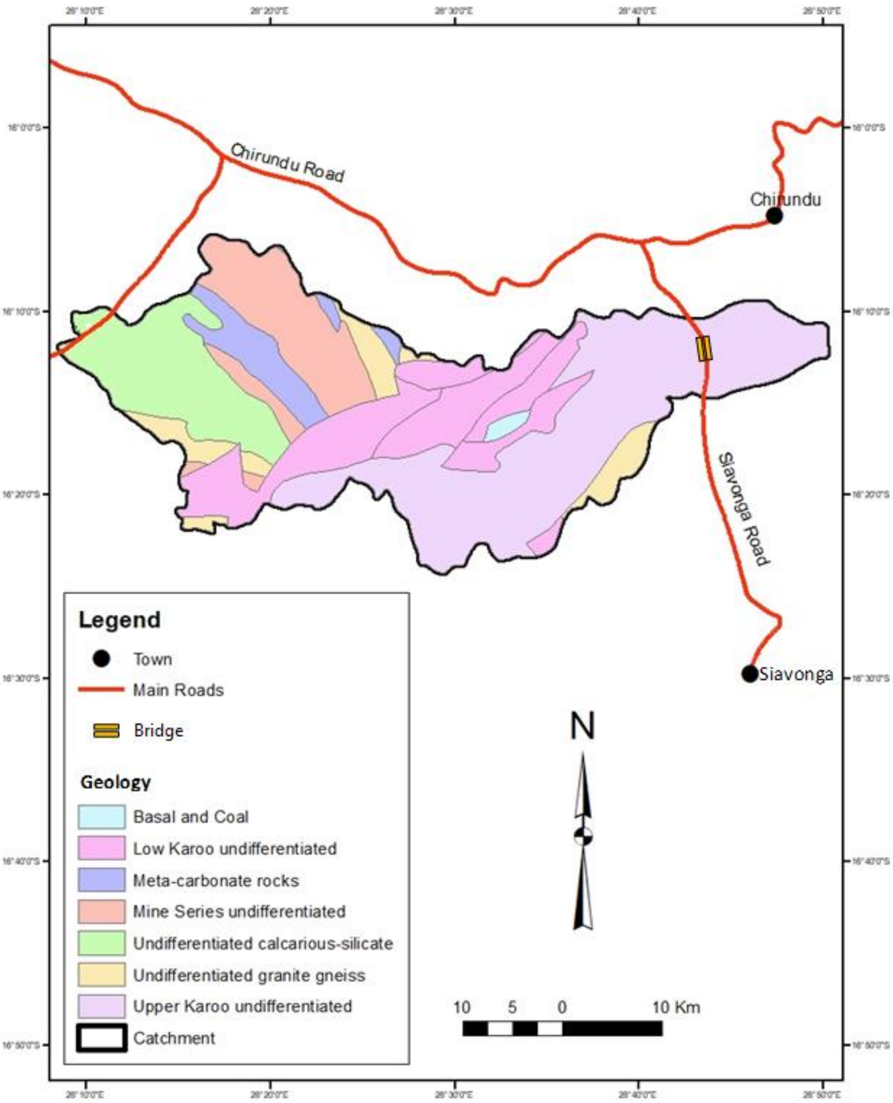


Figure 6: Geology map of Lusitu River Catchment (Source: Geological Department of Zambia (GDZ), 2013)

The dominant rocks covering the Lusitu area are sandstones and inter-bedded mudstones and red sandstones. Most of the sandstones are calcareous and some contain pyritic concretions. Other geological formations are low Karoo undifferentiated, dominant in the middle of the catchment. The upper catchment comprises of undifferentiated calcarious-silicate, Meta-carbonate rocks, and undifferentiated granite gneiss, Mine Series undifferentiated and basal and coal.

3.2.5 Topography and Hydrology

Lusitu River is non-perennial. It is a major tributary of the Zambezi River between Kariba dam and Chirundu town. Lusitu River stretches across Chirundu, Siavonga and Chikankata districts of Southern province, Zambia (Figure 7).

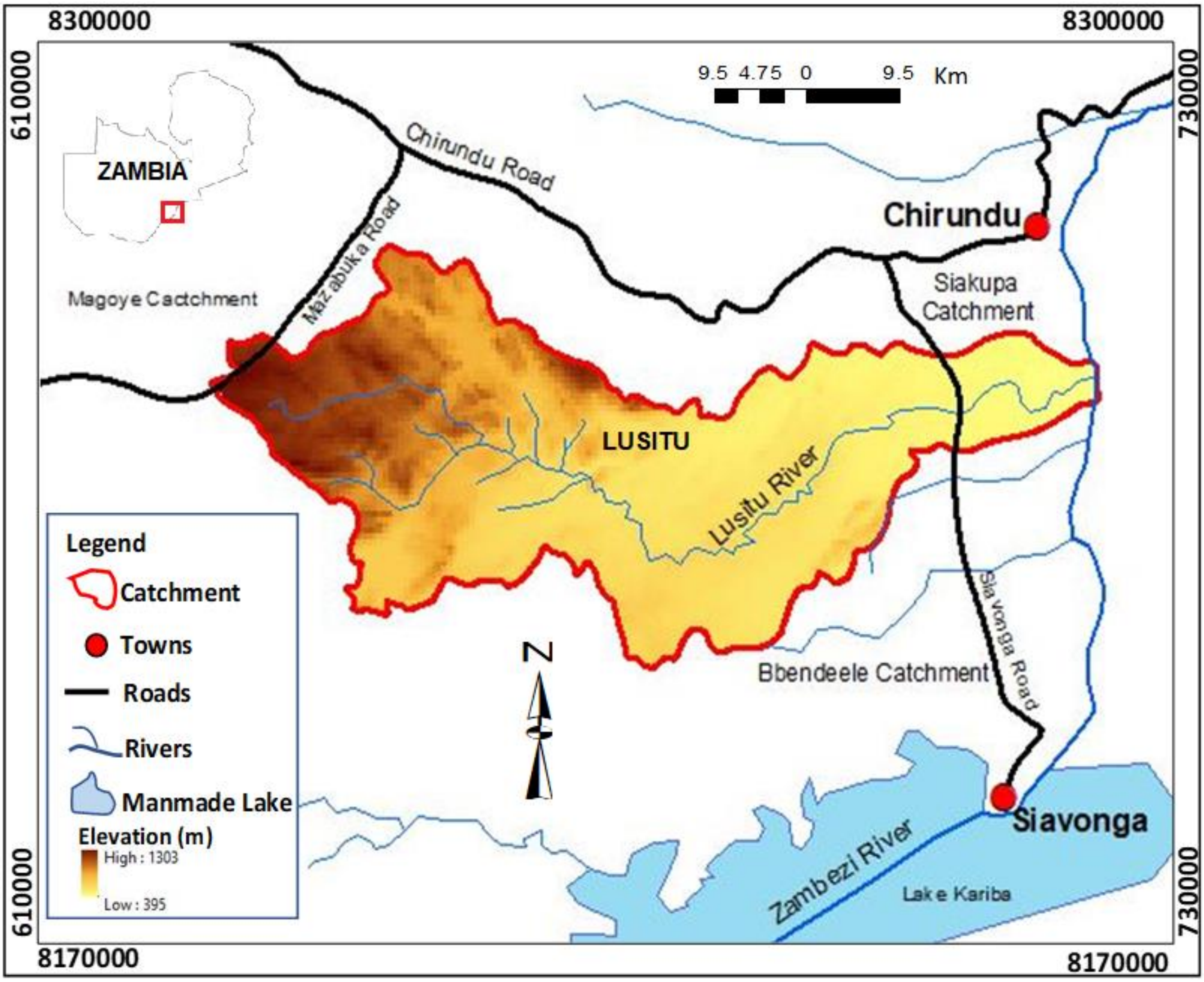


Figure **7:** Topography and hydrology map for Lusitu River Catchment.

3.2.6 Vegetation

In terms of vegetation, this part of the catchment is mainly composed of Mopane and Munga woodland (Balkiaea). The catchment is composed of mosaic vegetation including herbaceous savannah and woodland savannah with large areas lying bare during dry season and under seasonal grass cover/crop cover during rainy season (Figure 8).

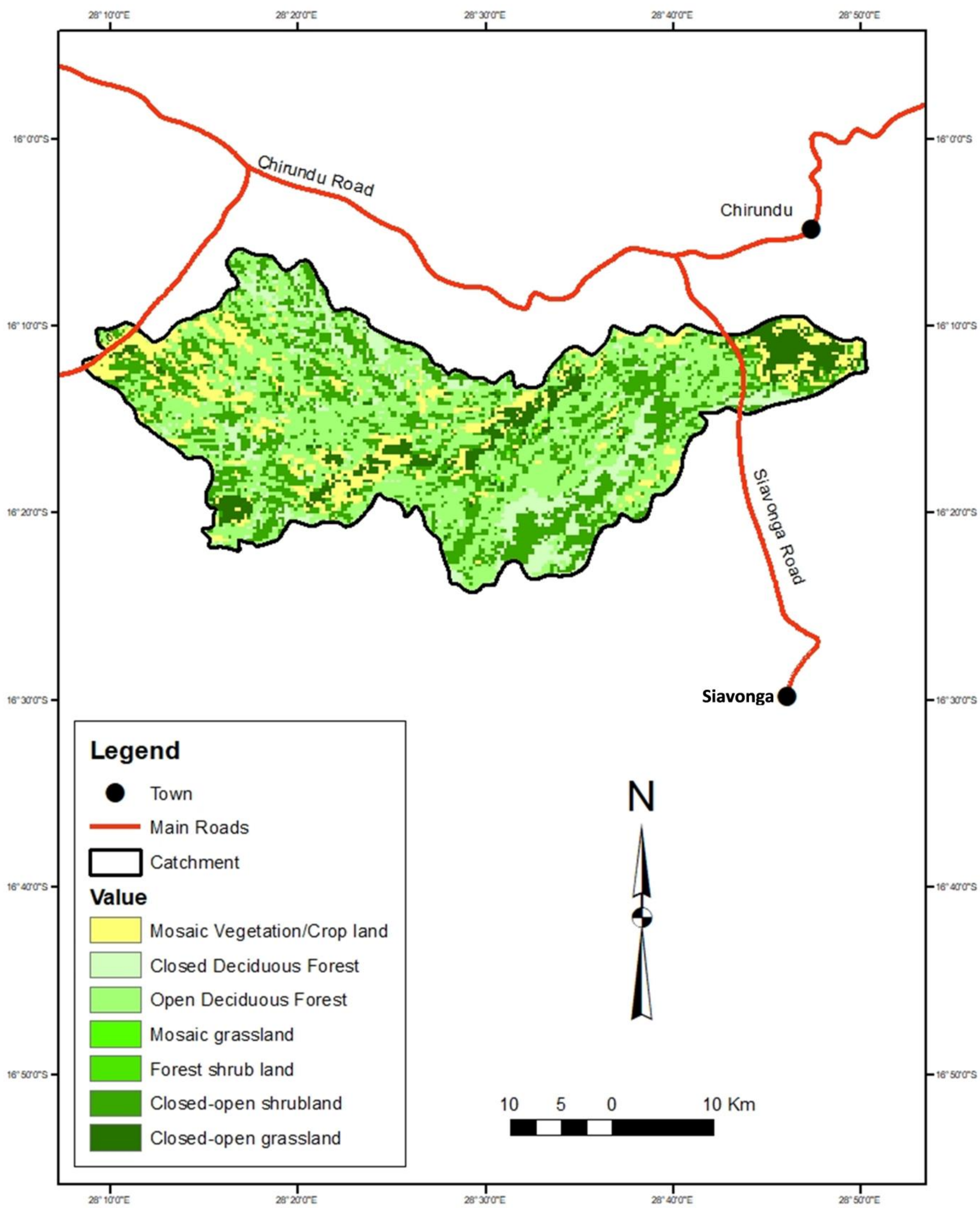


Figure 8: Vegetation cover map for Lusitu River Catchment.

3.3 Agro-Ecological Region

The study area lies in Zambia's Agro-Ecological Region 1, semi-arid region.

3.4 Socio-economic Characteristics

In terms of economic activities, Lusitu River supports rural communities in terms of source of water for domestic use, crop irrigation and for livestock (ZRA, 1996; Lusitu IDSP, 2015). Lusitu is an agrarian community. Landuse is dominantly rain fed cultivation of cereals, sorghum, maize, and millet. Intensive gardens on the banks of Lusitu River produce vegetables such as giant rape, pumpkin leaves, tomatoes, and green maize among others. Livestock ownership accounts for 30% of net farm income (Lusitu IDSP, 2015). The area has great potential in goat rearing as evidenced from large goat population in the area (CSO, 2017) and as such, Lusitu River is an important source of water for livestock watering for improvement of livelihoods in these rural communities. Flora Species of economic value include Baobab (*Adansonia digitata*), Musau (*Ziziphus mauritana*) and Musiika (*Tamarindus indica*) (Storrs, 1995). Fruits from these trees form part of the family diet and are sold in local markets and to traders mainly from Lusaka.

3.5 Justification for selection of study area

The study area was purposively selected because it poses unique characteristic of a semi-arid environment which is densely populated, highly degraded by erosion and, its Lusitu River severely impacted by sedimentation leading to its failure to provide continuous fresh water for a riparian community.

CHAPTER FOUR: METHODOLOGY

4.1 Chapter overview

This chapter describes the methodological procedure used in the study in terms of philosophical base, research approach and design, target population, sample size and sampling procedure, data collection and analysis, quality assurance and ethical considerations. The chapter ends with limitations and mitigation strategies.

4.2 Philosophical basis of the study

This study adopted analytic eclecticism as the philosophical framework (Sil and Katzenstein, 2010). The choice of analytic eclecticism is because this catchment study was complex and encompassed interrelated water-linked sectors which were small-scale crop farming, livestock farming and domestic water supply. Physical and human factors interplayed to induce sedimentation in Lusitu River Catchment and had varied effects on different water-linked sectors. This followed that a singular way of knowing and understanding realities could not be adopted to explain the problem of sedimentation in Lusitu River and to devise strategies for integrated restoration of the Lusitu River.

Analytic eclecticism was chosen because of it being flexible, not rigid to a single paradigm or set of assumptions. It draws ideas from a broad and diverse range of sources. According to Sil and Katzenstein (2010), the key feature of analytic eclecticism is that it produces complex, causal stories that capture the interactions among different types of causal mechanisms normally analysed in isolation from each other within separate research traditions. A purely quantitative or qualitative approach could not satisfactorily explain the problem of sedimentation in Lusitu because deforestation and high tillage farming practices which are human factors imbedded on highly erodible soils, steep slopes and weak rock formations; sandstones and mudstone to generate high sediments. Analytic eclecticism offered flexibility to accommodate a wide range of perspectives that were not contradicting each other despite being viewed from quantitative and qualitative lenses.

The ontological position of analytic eclecticism is inspired by the belief that realities in a geographical space could both be concrete and changeable depending on the human experiences (Sil and Katzenstein, 2010). According to Bryman (2008), ontology refer to philosophical consideration in research which concerns the nature of social entities, either being social entities or objective entities. The ontological position of this study was that understanding scientific realities and phenomena in a geographical space was dependent on the interaction of anthropogenic and physical processes (human and physical drivers of sedimentation). The epistemological stance was deconstructive in nature that advocated for the use of mixed scientific ways of understanding social and physical phenomena. It rejects the idea that geospatial reality inquiry could only be understood using a single quantitative method. Analytic Eclecticism favours pragmatic view of inquiry so that recasting problems have a more practical scope. Hence this study proposed measures needed to restore Lusitu River from sedimentation with the involvement of local people and relevant experts. This confirms what Sil and Katzenstein (2010) say that analytic eclecticism encourages the construction of narratives that generate pragmatic engagements with the social and physical conditions within which prevailing ideas have emerged.

4.2.1 Research approach and design

A mixed methodology approach informed this study. According to Dawadi *et al.* (2021), a mixed methodology approach brings together several methods that belong to quantitative and qualitative quadrants to address research questions in a way that involves collecting, analysing, interpreting and reporting both qualitative and quantitative data so as to better understand the phenomenon under investigation (Bryman, 2012; Creswell and Plano Clark, 2011; Creswell, 2015). Mixed-methodological approach was adopted because it offered a benefit to interweave quantitative and qualitative data in such a way that would help to meaningfully explain the results (Enosh, *et al*., 2014; Fetters, 2016; Dawadi *et al.,* 2021).

Specifically, a concurrent design was adopted for this study because it allowed for simultaneous collection of quantitative and qualitative data in this single research (Dawadi, 2021). This study has a quantitative part, which determined the magnitude of sediment accumulated in the Lusitu River, and a qualitative part which investigated socially lived perspectives on factors responsible for high sediment generation, how water-linked sectors were affected by sedimentation of Lusitu River, and proposed measures needed to restore Lusitu River. This helped to gather complementary quantitative and qualitative data about the phenomenon under investigation. Ventakesh *et al*. (2013), indicate that in a concurrent design, both qualitative and quantitative data are collected and analysed in single research and their combination gives a complete understanding of the problem at hand. A concurrent design helped to better explain the complexity of the problem of sedimentation in the Lusitu River Catchment. The local people being affected by the sedimentation of the Lusitu River, were involved in intensive farming practices, which were found to be major drivers of river sedimentation. Hence, they are part of the stakeholders, in the integrated catchment restoration framework.

4.2.2 Target Population

The study targeted Lusitu River Catchment due to high sedimentation than other catchments in Southern Province and secondly, on people who depended on water resources-linked sectors such as crop agriculture, livestock agriculture and domestic water supply in the Lusitu River Catchment. Southern Province is made up of several catchments namely, Lusitu, Kafue, Kalomo, and Itezhi-tezhi and Lake Kariba and Ngwezi-Kasaya, all of which are domiciled in the Lower Zambezi Catchment (Figure 9).

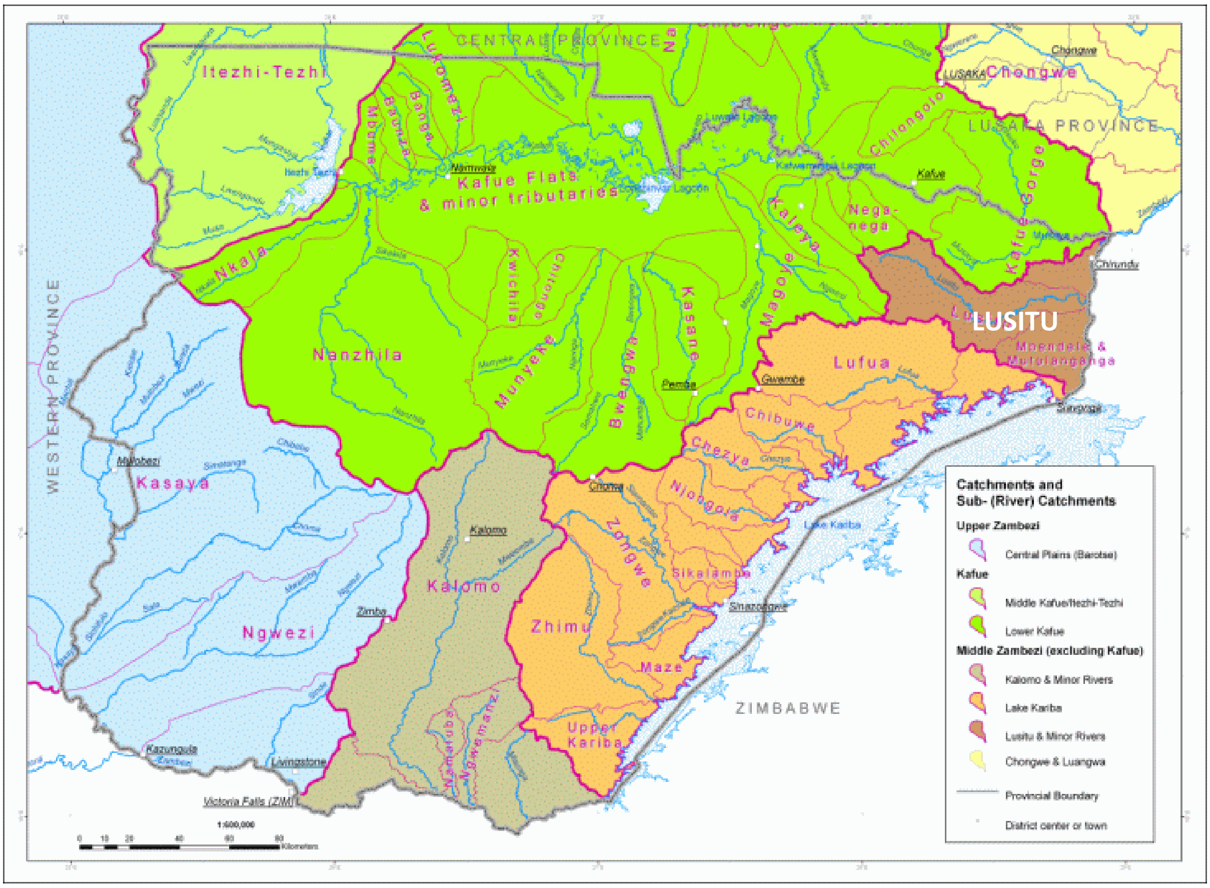


Figure 9: Hydrology map of Southern Zambia (Source: Baumle *et al*. 2007)

4.2.3 Sample size and Sampling Procedure

The study took place in the Lusitu River Catchment which was purposively sampled (Bryman, 2008) for investigation due to its economic importance as it supports larger communities relocated during the construction of Kariba dam and being one of the most severely hit by the problem of sedimentation (ZRA, 1996). The HydroAtlas by WWF (2021) helped the researcher in the purposive selection of Lusitu River as it was ranked highest in terms of siltation.

The sample size of the participants was 104 redistributed as shown in the sampling frame in Table 1 and was selected using homogenous purposive sampling because the study was targeting those who were dependent on water-linked activities and sediment generating activities, and the participants were not difficult to find. Dependency on water was the homogenous variable or inclusion criteria in the purposive sampling process. The sample size was large because the study also sampled in the middle and upper catchment, in order have a representation from the entire catchment. This was a mitigation measure to the problem of large catchment size. The Senior Headman was the first to be recruited, after getting permission from him. Crop farmers and livestock farmers were followed to their homes, in the gardens and water wells, spatially distributed across the study area (Figure 26), based on voluntary participation after the research problem was explained to them. Some of the participants were part of the resettlement in 1958. The sample size of 104 was reached through saturation of responses. Participants in the FGDs were recruited based on their intelligible participation during interviews; being knowledgeable about the research problem, people who had long-lived experiences of the Lusitu River, prominent charcoal burners, and others proposed by the Headmen and Agriculture Officers such as proactive farmers.

There were 13 Key informants who were selected from the Ministry of Agriculture, Ministry of Green Economy and Environment, Ministry of Community Development, among others as shown in the sampling frame in Table 1., using expert purposive sampling.

Table 1: Study sample

Description of Participants	Population
Crop farmers	45
Livestock farmers	45
Charcoal Producers	10
Community Leaders (Headmen)	4
Total	**104**
Description of Key Informants	Population
Crop Agriculture Officers	5
Livestock Agriculture Officers	2
Community Development Officer	1
Forestry Officers	2
Water Development Officers	2
Chirundu Town Council Officer	1
Total	**13**

4.2.4 Data Collection

Data on Objective One was collected using direct observations with the aid of GPS and photography. Some of the observed variables include gully erosion, human activities, among others. Semi-structured interviews were used to collect qualitative data on main drivers of sedimentation which participants were aware of in the Lusitu River. They were also asked to rank severity of anthropogenic activities using a Likert scale where 1 was equal to less severe, 2 moderately severe and 3, very severe (Appendix C).

For Objective Two, sediment coring method was used to collect data on the magnitude of sedimentation in Lusitu River by digging pits on the dry riverbed and using interlocking angle bars in areas with deep sediment, to measure sediment depth. This involved physical transect walk covering 15km distance along the riverbed from the Lusitu River Bridge to its confluence with the Zambezi River. The GPS was used for collection of XY coordinates for each pit, soil auger, shovels, picks, interlocking angle bars were used as tools for digging of sediment pits. A measuring tape and ranging poles were used for taking actual values of sediment depth on the field measurement sheet with the aid of local research assistants from UNZA and local community.

Figure 10: Sediment Coring (a) and (b); Using angle bars (c) Measuring sediment depth.

Data on Objective Three, that is, how sediment affected water linked sectors, was gathered by direct observation and use of semi-structured interviews (Figure 11b; Appendix C) to the participants and key informants to establish how sedimentation affected water-linked sectors in Lusitu River Catchment. Semi-structure questions were administered to them with follow up questions were necessary. The water-linked sectors considered were:

(a) Small scale crop farming
(b) Livestock farming
(c) Domestic water supply

Data on Objective Four whose focus was to collect restorative and protective measures was collected using three Focus Group Discussion (FGD) with selected local communities (2 FGDs; composed of 7 participants and 8 participants) and key informants (1FGD with 6 participants) to collect data on strategies for integrated restoration of the Lusitu River (Figure 11a). FGDs were used because they allow interaction among participants (Thomas *et al.*, 1995, Gibbs, 1997). Participants owned the discussion and contributed much more with diverse perspectives (Dreachslin, 1999) on the restoration of the Lusitu River. This provided a chance to get more data about their views and perspectives towards restoration of the Lusitu River. The discussion followed a guide (Appendix E) to explore more detailed measures needed to restore the Lusitu River.

Figure 11: (a) Focus Group Discussion: discussing Lusitu River Catchment restoration measures used in the development of the ICRF (b) Semi-structured interview: A participant relocated in Lusitu in 1958 narrating on Lusitu River sedimentation.

4.2.5 Data analysis

For Objective One, on main drivers of sedimentation in Lusitu River, data was analysed using descriptive statistics and thematic analysis. The descriptive statistics used were the mean, standard deviation, and coefficient of variation to measure participants' ranking of severity of activities which were drivers of sedimentation in the Lusitu River Catchment. The standard formula used for Standard Deviation (Formula 1) and CV (Formula 2) were as shown in Formula 1 and 2, respectively. The Excel Spreadsheet was used as a tool to implement the analysis based on Formula 1 and 2.

$$s = \sqrt{\frac{\sum(X-\bar{X})^2}{n-1}} \quad (1)$$

Where:

S Standard Deviation

X Measured value of each variable

$\bar{X}$ Mean rank value of severity of drivers/processes of sedimentation

n Sample size

$$CV = SD/Mean \quad (2)$$

Where:

CV Coefficient of Variation

SD Standard Deviation

According to Yellapu (2018), relationship in a population can be summarised more effectively by using descriptive statistics. In a case that another similar detailed research is conducted, descriptive statistics are a critical part of initial data analysis because it provides the foundation for comparing variables with inferential statistical tests (Yellapu, 2018). SD and CV were useful in determining the clustering or spuriousness of the rankings about the mean, which were assigned by different participants. Thematic analysis was used to analyse responses on factors influencing accelerated sediment generation in the Lusitu River

Catchment and participants' observations of the Lusitu River between 1958 and 2023. The procedure followed involved transcribing raw data from semi-structured interviews. Data was thoroughly read and coded to generate themes for presentation from which interpretations were made, following Creswell's standard procedure (Creswell, 2015).

Data on Objective Two, on the magnitude of sedimentation in Lusitu River was analysed using 3D spatial analysis tool namely Inverse Weighted Distance (IWD) in ArcGIS 10.4. Input data comprised UTM coordinates (XY), sediment depth (m) (Z) and the boundary of Lusitu River channel. The river channel boundary was converted into geocoded points on a geocoded shape file from Google Earth. The created river boundary point data were merged with sediment depth data. This task was done using the merge tool in ArcGIS 10.4. This was followed by interpolation of a continuous raster surface using raster interpolation tools in 3-D Analyst in ArcGIS 10.4. The Sediment Choropleth map for the 15 km downstream section of the Lusitu River channel was generated to display the spatial variations in sediment depths. Sediment volume was determined using the area-volume plugin in ArcGIS 10.4. Further analysis involved generation of a sediment rating curve in Microsoft excel spreadsheet to determine depth-area and volume relationship so as to generate regression model for sediment volume projects based on sediment depth.

Data on Objective Three; on how different water-linked sectors were affected by sedimentation of the Lusitu River and Objective Four concerning integrated strategies for restoration of Lusitu River was analysed using thematic analysis. The standard procedure described by Creswell (2015) was used. This involved transcribing raw data from semi-structured interviews and Focus Group Discussions. Data was thoroughly read and coded to generate themes for presentation from which interpretations were made. Thematic analysis was used because objectives three and four were dealing with participants' experiences of the problem of sedimentation of the Lusitu River and opinions and knowledge of measures needed to restore Lusitu River from sedimentation respectively. This generated large data sets which were analysed by sorting them into themes. In this analysis, an inductive approach was used where data determined the themes. This meant that themes were generated from data collected using semi-structured interviews and FGDs with participants and they acted as theoretical lenses through which meanings were derived.

According to Malhojailan (2012), thematic analysis provides a systematic element to data analysis which helps to understand the phenomena being studied more widely for the researcher to determine the exact relationships between concepts. By using thematic analysis this study was able to link processes which influenced prevailing drivers of sedimentation in Lusitu and opinions of the local people (participants) regarding causes of sedimentation. This led to collectively arriving at measures needed to restore Lusitu River from sedimentation.

4.2.6 Quality assurance

Quality assurance relates to the validity of the research (Creswell, 1994; Zohrabi, 2013). Burns (1999) stressed the importance of validity as an essential standard for evaluating the quality of research. According to (Zohrabi, 2013), collecting information from multiple sources and using a variety of techniques can confirm findings.

The instruments for data collection and analysis were piloted before use in the actual research to determine their intelligibility. Internal validity and trustworthiness were achieved through methodological triangulation; through which different methods of data collection were used to confirm some claims. For example, interviews were followed by ground observations where necessary. Key informants from various relevant ministries were engaged as outlined in the sampling frame (Table 1) to give expert insights in answering the research questions. Two interpolation methods IDW and Kriging were used to check consistency of results on the magnitude of sedimentation. Participants who were relocated in 1958 were also asked to qualitatively describe the changes they observed in the depth of sediment on the riverbed to confirm the changes over the years. Content validity was achieved by presenting the research results to the Department of Geography and Environmental Studies at the University of Zambia for expert review.

4.2.7 Ethical considerations

The requirement for ethical conduct in research has increased across institutions of higher learning, in response to society's expectation of greater accountability of the research findings (Haggerty, 2004; Zegwaard *et at*., 2015; Zegwaard *et al*., 2017). The researcher and participants undertake an informed consent (Denzin & Lincoln, 2011) to which anonymity and confidentiality is an important aspect in protecting the participants from current or future harm (Zegwaard, et al., 2015). Therefore, many educational institutions, do not allow researchers to collect data from human participants without ethical approval. This study was approved by Natural and Applied Sciences Research Ethics Committee (NASREC), the research ethics committee of the School of Natural Sciences at the University of Zambia (Appendix G). The researcher sought permission from Traditional leaders in Lusitu to interview people. Coding was used and not actual names of places and participants. Participants were given information on the aim and importance of the study and their participation was voluntary and based on anonymity. Where pictures were captured with permission of participants, assurance was given that, their facial identity would be hidden.

4.2.8 Limitations and mitigation strategies

Table 2: Limitations of the study

Limitations	**Mitigation**
One research assistant suffered from heat stroke due to intense heat.	Repatriated and replaced with another assistant.
Subjectivity	Triangulation
Focus on downstream section of the river.	Interviewed participants in the middle and upper section of the catchment to compare the results.
Participants wanting to be paid money.	Explained the academic purpose of research and how they may benefit as a community.

CHAPTER FIVE: PRESENTATION OF RESULTS

5.1 Chapter overview

This chapter presents the findings in the context of the objectives. The first section presents results on the main drivers of sedimentation in the Lusitu River. The second section presents results on the magnitude of sedimentation of Lusitu River from Lusitu Bridge to its confluence with the Zambezi River. The third section presents results on how sedimentation affected water-linked sectors in the catchment. The fourth section presents results on the proposed catchment restoration measures.

5.2 Main drivers of sedimentation in the Lusitu River Catchment

The study conducted ranking of severity of occurrence of drivers of sedimentation in the Lusitu River Catchment. It was evident that anthropogenic activities were the most responsible for sediment generation. The study found that agricultural activities were a major contributor of sediment into Lusitu River. Riverbank gardening had mean rank of 3 with no deviation. This was followed by dry season crop field preparation prior to the onset of rainfall and intensive soil tillage farming practices. Sand mining was found to be the least contributor of sediment into the Lusitu River (Table 3).

Table 3: Participants' rankings of severity of drivers of sedimentation in the Lusitu River Catchment

	Charcoal Burning	**Vegetation Clearance for New Crop Fields**	**Dry Season Crop Field Preparation**	**Intensive soil tillage farming**	**Animal Grazing**	**Riverbank gardening**	**Sand Mining**	**Brick Moulding**	**Soil Erosion**
Mean Rank	2.65	1.89	2.86	2.86	2.68	3.00	1.00	1.59	2.68
SDV	0.54	0.81	0.35	0.35	0.47	0.00	0.00	0.55	0.47
CV	0.20	0.43	0.12	0.12	0.18	0.00	0.00	0.35	0.18

n= 104

Rankings: 1-1.69= Not severe; 1.7-2.39=Moderately severe; 2.4-3= Very severe

Below are pictures showing gully erosion in Lusitu.

X: 687346 Y: 8211321 X: 686844 Y: 8211814

Figure 12: Gully erosion in Lusitu River Catchment

Based on semi-structured interviews with 104 participants, it was further noted that most of their perspectives on drivers of sedimentation were clustered around human activities, which perhaps they were more familiar with than the geomorphic process. Generally, the frequency of responses oscillated between 20%-29% across all emerging themes (Figure 13).

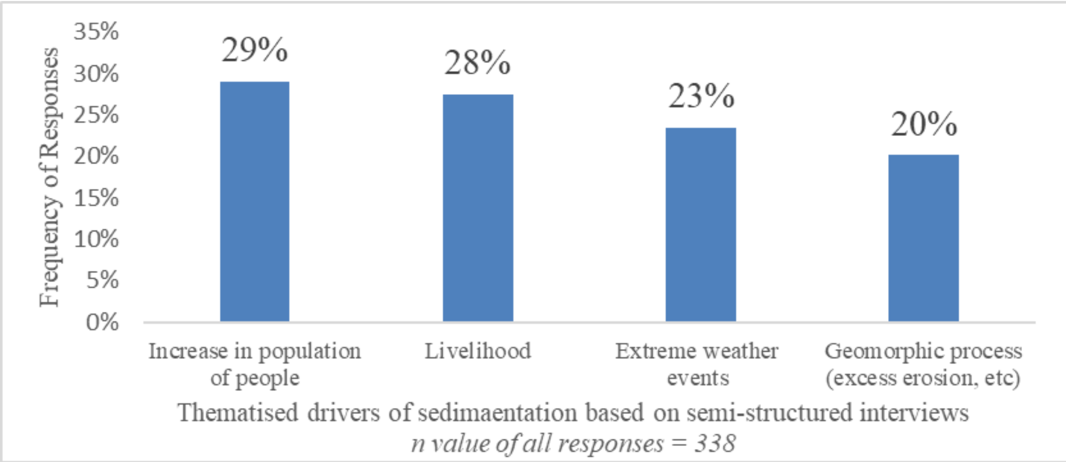


Figure 13: Factors influencing sedimentation.

Through thematic analysis of responses, the study established that over population, search for alternative livelihoods, climatic and geomorphic factors were influencing accelerated sediment generation in the Lusitu River Catchment and some of the qualitative descriptors are shown in Table 4. The general impression that emerged from the findings is that sedimentation in the Lusitu River Catchment was a function of combined process of human and geophysical processes.

Table 4: Factors influencing accelerated soil erosion in Lusitu.

Themes	Description of themes
Increase in human population	• Population has increased since the resettlement in 1958. • Land was limited due to Chiefdom boundaries of the resettled population under chief Chipepo and the native population under chief Sikoongo. • Number of livestock exceeded carrying capacity.
Livelihoods	• No capital is required to start charcoal burning. • Charcoal business is very profitable. • Selling irrigated crops in dry season is very profitable.
Extreme weather events	• Occurrence of flush floods • High frequency of droughts.
Geomorphic factors	• Loose soils which are highly erodible. • Unstable riverbanks.

Below are some of the verbatim on drivers of sedimentation of the Lusitu River, showing participants perspectives on population increase, charcoal production, and extreme weather events.

One of the participants said, "*citupa kuumpa malasya nkuyanda mali akuligwasya. Kayi kuti wakkala biyo ulafwa nzala. Nyika yakulima munsi amulonga njisyoonto alimwi meenda alafwaambaana kuyuminina nkaambo museenga wakavwula mu mulonga".* (We burn charcoal as an alternative source of money for our livelihood. There is limited land for cultivation along the river and water dries up early because there is too much sand in the river).

Another participant said that *"cajeya nyika yesu nkuvwula kwabantu azivwuubwa. Masena akulima amacelelo aceya. Alimwi basikugonka malasya balilika biya zisamu."* (What has caused degradation of our land is over increase in population of people and livestock. Also, charcoal burners are harvesting trees by burning them from ground level).

A male participant aged 75 years at the time of study recalled that, *"mu 1978 kwakawa mvula mpati cimwi ciindi. Meenda akali kwandula mulonga, museenga wakavwula wakeetwa a meenda mu mulonga."* (There was a heavy flood event in 1978 which cut several meanders and deposited a lot of sediment in the river channel).

Furthermore, the six participants who were relocated at the time of the construction of the dam, were purposively engaged in a discussion to narrate the changes they had observed in the flow regimes of the Lusitu River between 1958 and 2023. Based on the verbatim presented in Table 5 below, the study findings resonated with what experts and records from ZRA (1996) were showing that, Lusitu River used to be perennial up to the early 1980s.

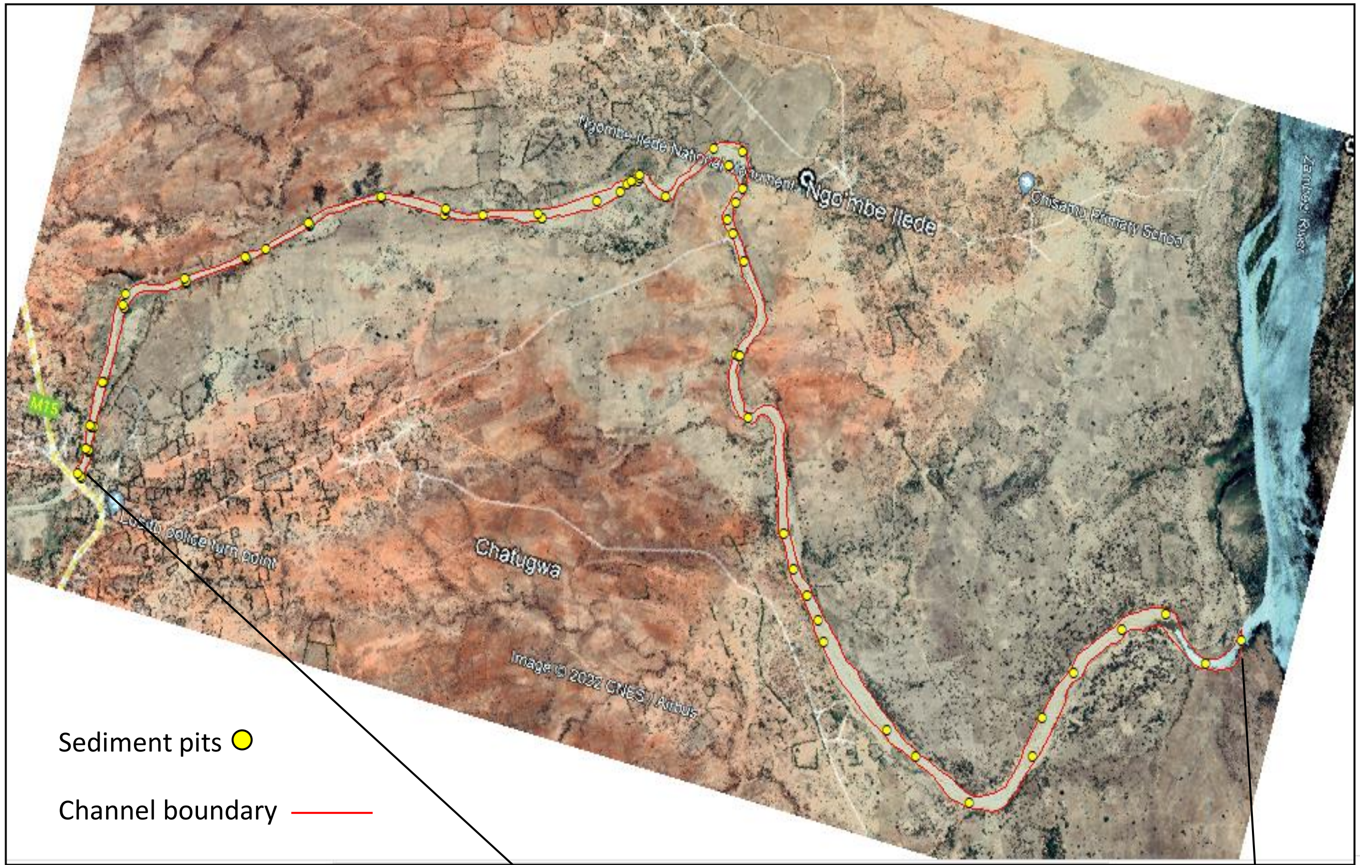
Table 5: Narratives on the evolution of the Lusitu River flow

Narrative		Participant's Year of Birth
Original Language Expressed (Chitonga)	**English Language Translation**	
"Nitwakalonzengwa mu 1958, twakasika mu October ookuno. Twakajana meenda akali kweenda. Akali malamfwu meeda".	We were resettled here (Lusitu) in October 1958 and found Lusitu River flowing. The river had deep water.	1938
"Basikutulonzya bakaamba kuti nkumuya kuli mulonga mupati munakulima acilimo. Lino tupengede meenda. Kumatongo twakali kulima acilimo. Tuyanda meenda ngibaka tusyomezya."	During resettlement, we were told that there is a big river with water for irrigation farming in the dry season, as this was our lifestyle. We need the water we were promised".	1940
"Nitwakasika ookuno ku Lusitu, ooyuu nulonga tiwakali kuyuminina pe. Twakali kujeya baswi mwaka oonse. Masamu akali manji mumbali amulonga".	When we arrived in Lusitu, the river was perennial. We used to catch plenty of fish throughout the year. There were plenty of trees along the riverbanks.	*1947*
"Ooyu mulonga wakalijisi meenda manji kusika muma 1970 katucili basankwa. Nkomwe zyamulonga zyakali zilamfwu. Wakali wa Malende. Bantu tibakali kuzumizigwa kusanzyila kumulonga mitiba.	Lusitu River had plenty of water up to 1970s when we were still youths. The river channel was deep. People were not allowed to clean dishes from the river because it was believed to host rainy spirits.	1950

5.3 Magnitude of Sedimentation in Lusitu River

The study quantified sediment burden in Lusitu River based on 68 sampled points (Appendix A) along the 15 km river channel stretch from Lusitu Bridge to its confluence with the Zambezi River (Figure 14). The results showed spatial variation of sediment accumulation along the Lusitu River. A sediment choropleth map using 3D spatial analyst tool showed overwhelming evidence that, sedimentation was a serious problem in the Lusitu River premised on the finding that, almost Three Million cubic metres of sediment had accumulated on the bed (Figure 15). This implied reduced access to water by all water-linked sectors because this enormous quantity of sediment deposit had taken up space that would have otherwise been occupied by water, thereby affecting various water-linked sectors in the catchment. The intensity of sediment accumulation was further confirmed by the observed strong positive linear relationship between sediment depth and sediment volume ($r^2 = 0.99$, $p = < 0.01$) (Figure16).

X	Y	SEDIMENT DEPTH (M)
687394	8210417	0.6
687384	8210425	1.2
687361	8210443	0.53
687443	8210502	1.62
687433	8210510	3.6
687421	8210519	0.49
687483	8210602	0.35
687462	8210609	3.5
687448	8210617	1.59
687570	8211197	3.8
687551	8211203	1.02
682531	8211209	3.7
687666	8211676	3.5
687649	8211694	1.27
687636	8211707	1.83
688131	8211794	1.18
688125	8211810	4.05
688118	8211824	1.34
688614	8211968	1.44
688608	8211983	4.7
688602	8211995	3.5
689069	8212232	1.31
689064	8212240	1.38
689057	8212255	1.52
682588	8212351	2.8
689586	8212365	3
689587	8212379	1.07
690070	8212229	3.1
690074	8212251	2.9
690077	8212271	2.1
690784	8212258	1.85
690781	8212258	1.08
690778	8212279	1.28
691551	8212474	3.5
691555	8212488	4.5
691560	8212510	3.5
692168	8212734	4.5
692159	8212762	3
692158	8212773	1.57
692346	8211396	2.5
692379	8211379	3.1
692388	8211376	0.8
688645	8212005	1.7
690335	8212240	3.5
691274	8212386	2.5
691424	8212472	4.5
691458	8212499	4
691485	8212509	4.8
691766	8212435	4.5
692362	8212556	3.5
692301	8212466	4.5
692246	8212347	4.5
692200	8212252	4.8
692224	8212126	3.6
692394	8210867	4.5
692604	8210190	2.5
692686	8209951	4
692780	8209754	4.5
692882	8209597	4.3
692978	8209453	5.1
693443	8208836	5.2
693633	8208633	5.8
694078	8208410	5.8
694911	8209248	5.3
695299	8209464	5.9
695650	8209395	6
695700	8209309	6.1
695754	8209251	6



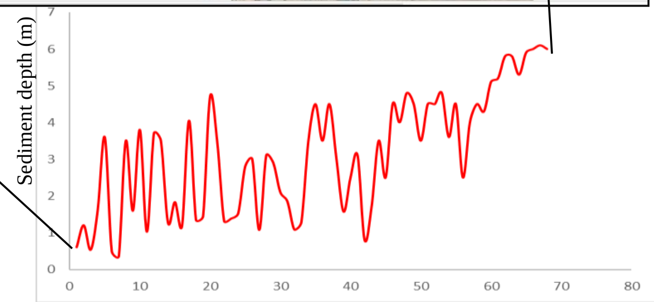


Figure 14: Distribution of Sediment Pits on the river Channel bed from Bridge to the Mouth.

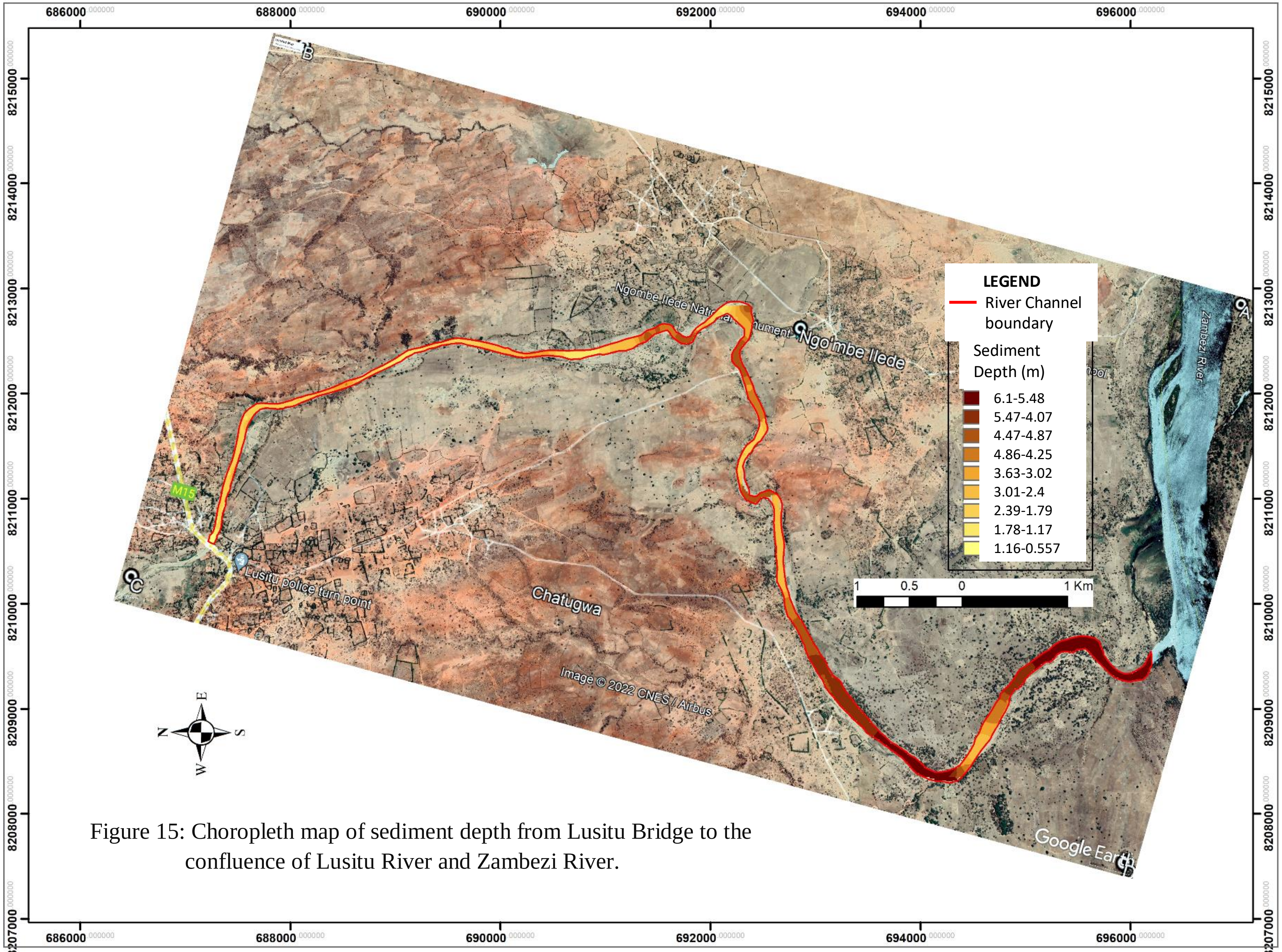
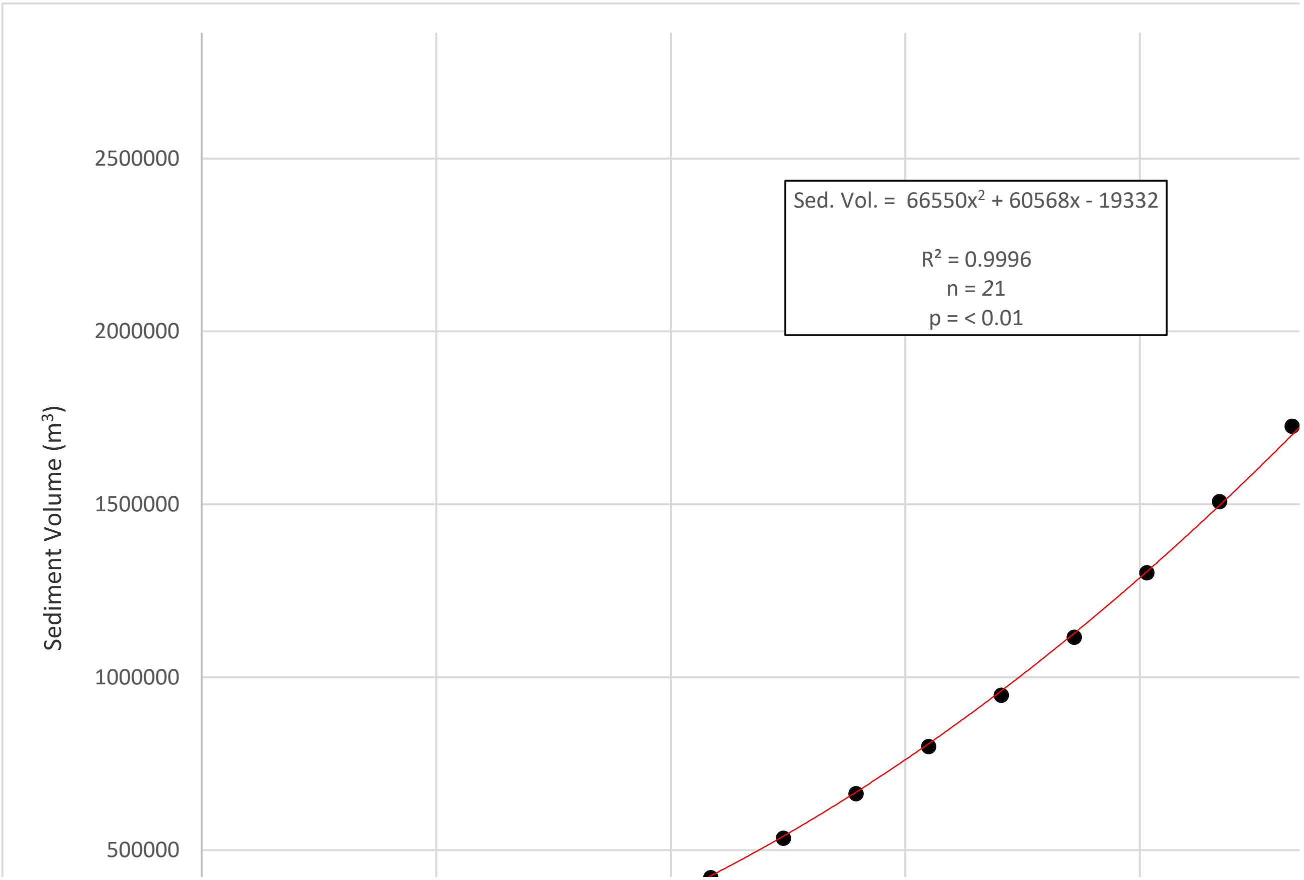


Figure 15: Choropleth map of sediment depth from Lusitu Bridge to the confluence of Lusitu River and Zambezi River.



Depth (m)	Area (m^2)	Volume (m^3)
0	0	0
0.31	85792.23	9501.56
0.62	136190.4	45696.99
0.93	159265	89911.72
1.24	220895.9	149989.27
1.55	263022.8	227647.6
1.86	319143.2	316211.78
2.17	347221.9	419970.11
2.48	388475.6	534302.47
2.79	430706.6	662752.25
3.1	453624.6	799784.33
3.41	510093.8	947933.84
3.72	579680.1	1115878.47
4.03	633374.5	1302027.8
4.34	687987.6	1507736
4.65	713169.2	1725803.98
4.96	733123.6	1951269.21
5.27	734638.8	2178875.43
5.58	736527.5	2407219.72
5.89	736550.3	2635577.31
6.2	736569.3	2863913.78

Figure 16: Relationship between sediment depth and sediment volume

5.4 Effects of Sedimentation of the Lusitu River on Water-Linked Sectors

The study found consistent evidence that the drying up of the Lusitu River due to high sediment load was directly affecting water-linked sectors within Lusitu community which were small-scale crop farming, rearing of cattle and goats and domestic water supply.

5.4.1 Effects of sedimentation on Small-scale crop farming

The study assessed small scale crop farming and found that farmers adapted to the semi-arid climate of the area by mainly growing sorghum during rainy season (Figure17a). Small-scale riverbank gardening was found to be a major economic activity in the area and the number of farmers involved in a year varied in relation to Lusitu River flow regime (Figure 18). Giant rape, pumpkin leaves, tomato, and maize were the main cash crops cultivated in the gardens (Figure 17b).

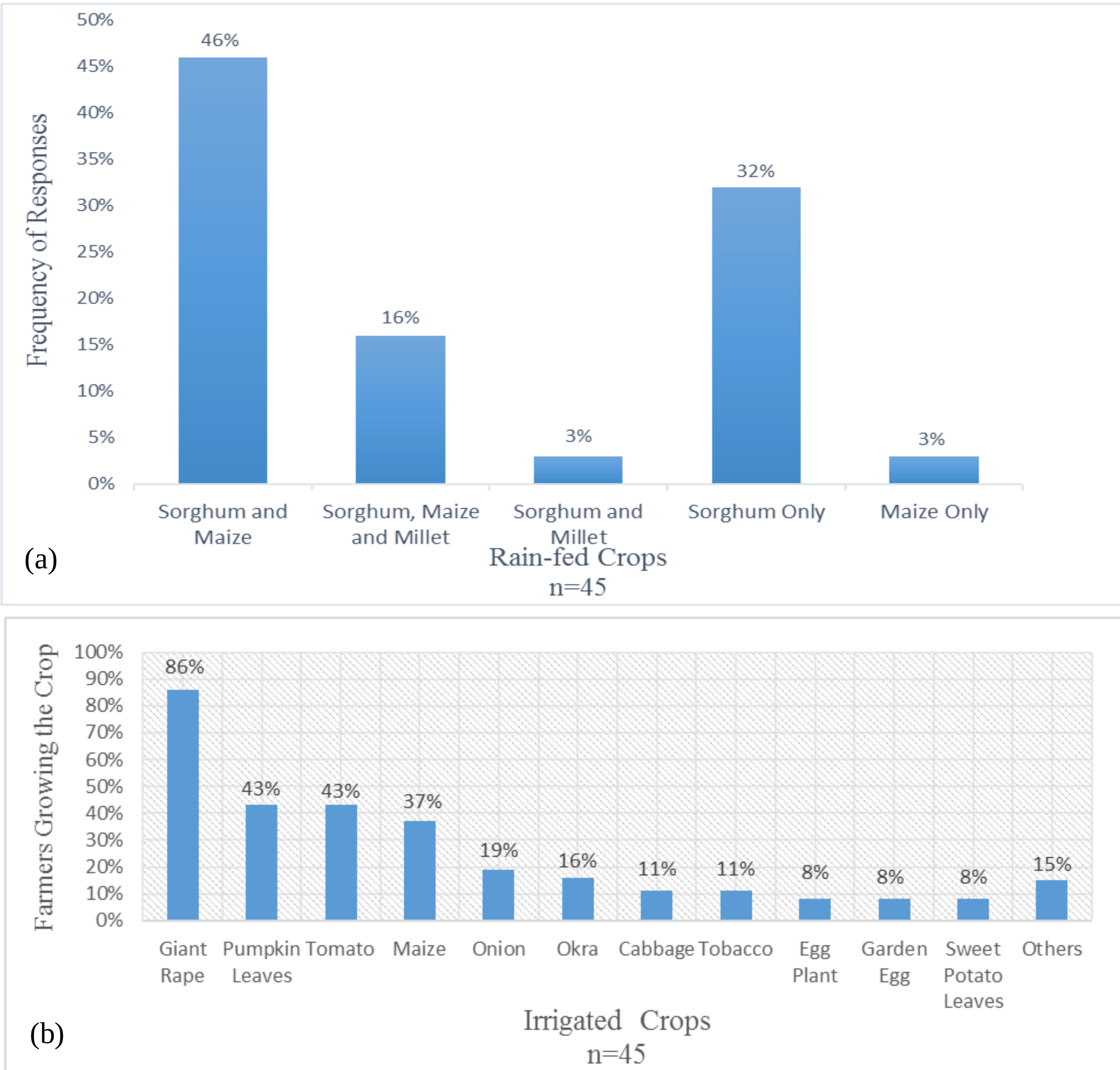
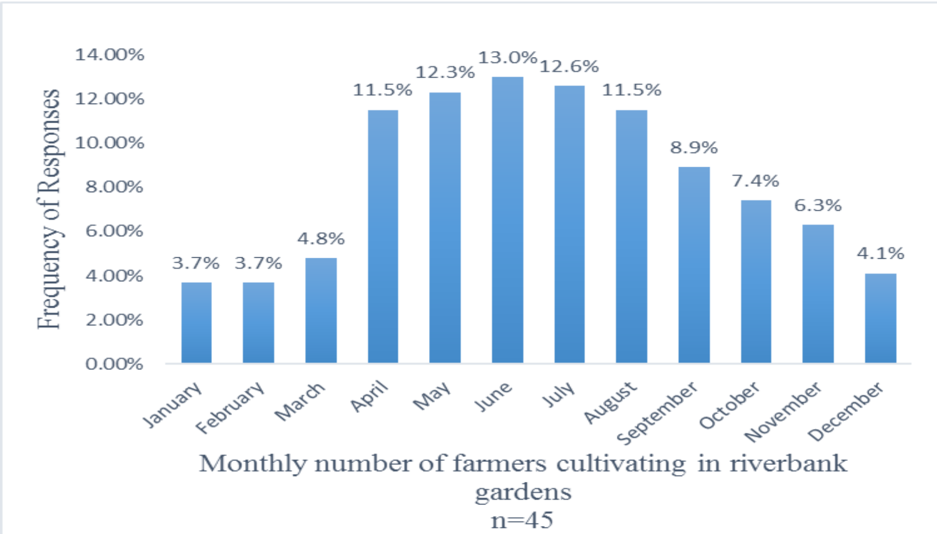


Figure 17: (a) Cultivation of rain-fed crops in Lusitu; (b) Irrigated cash crops on riverbank gardens

The drying up of the Lusitu River due to sedimentation reduced the period of growing irrigated crops by small-scale crop farmers. The study found that farmers abandoned their gardens in dry season because water was difficult to access in the dry riverbed. During rainy season, most farmers abandoned gardens (Figure 18) because they were prone to flooding due to reduced channel depth because of river channel sedimentation. The study found that many farmers who abandoned gardens during the periods January to March, and September to December, lost income from the gardens, hence most of the farmers had low annual income (Figure 19).



Month	Abandoning of Gardens (n=45)
Jan	32
Feb	32
Mar	28
Apr	5
May	2
Jun	0
Jul	1
Aug	5
Sep	14
Oct	19
Nov	23
Dec	31

Figure 18: Monthly number of farmers involved in riverbank gardening along Lusitu River.

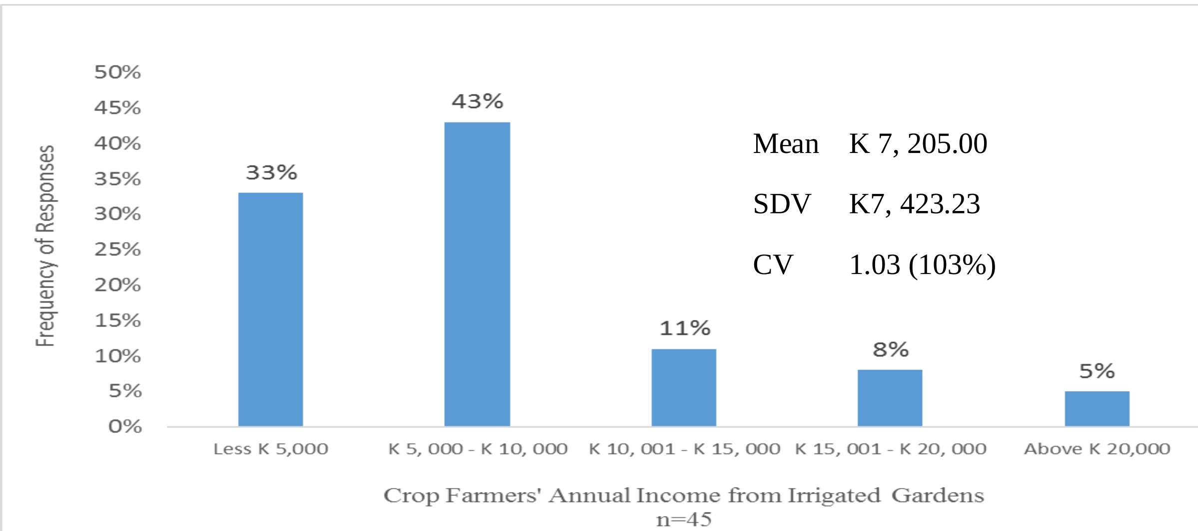
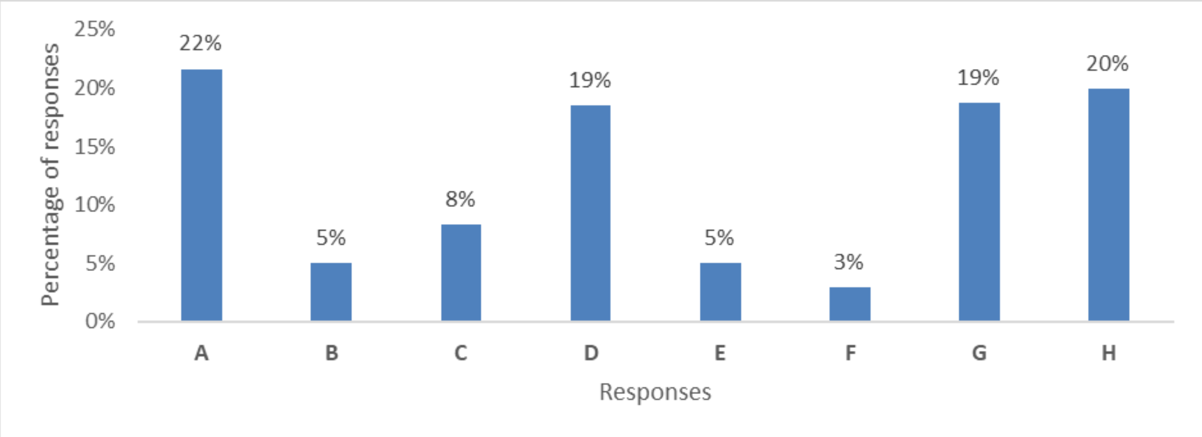


Figure 19: Crop farmers’ annual income realised from gardens along Lusitu Riverbanks.

Premised on semi-structured interviews with 45 participants, it was further noted that the major effects of drying up the Lusitu River on small-scale crop farmers were abandoning of irrigation farming, reduced income, crop destruction by livestock and forced camping at the gardens. Generally, the frequency of responses was ranging from 3% to 22% across all emerged themes (Figure 20).



A	Farmers abandoned gardens as Lusitu River dried up.
B	The size of area cultivated within a garden reduced as the dry season progressed.
C	Most farmers do not have water pumps to pump water from wells.
D	Reduced income from the gardens.
E	Collapsing of water wells due to unstable sediment
F	Increased cost of digging wells
G	Destruction of crops by cattle and goats as they search for water.
H	Forced camping at the gardens during water stressful periods so that animals don't eat crops

Figure 20: Effects of drying up of the Lusitu River on the Small-scale crop farmers

Themes which emerged from the semi-structured interviews on effects of sedimentation of the Lusitu River on small scale farming were, shortage of water for irrigation, difficult to dig water wells in the sandy riverbed and conflict with livestock (Table 6).

Table 6: Effects of the drying up of the Lusitu River on small-scale crop farming.

Themes	Frequency (%)	Description of themes
Shortage of water for irrigation	45	• Farmers abandoned gardens as the river dried. • The size of area cultivated within a garden reduced as the dry season progressed. • Most farmers do not have water pumps. • Crop farmers lost income from the gardens.
Difficult to dig water wells in the sandy riverbed.	16	• Collapsing of water wells due to unstable sediment. • Increased cost of digging wells. especially among female headed homes as the dry season progressed.
Conflict with livestock	39	• Destruction of crops by cattle and goats as they search for water. • Relocating to the gardens

In relation to conflict with livestock, one of the participants said that *"ngo'mbe zyakapola mu garden mu August (2022). Zyakalya zisyango zyoonse. Candipa kupenga uuno mwaka."* (Cattle broke into my garden last year (2022) in August and destroyed all my crops. This has led me into financial difficulties this year).

Concerning water shortage, a participant said that "*Mulonga alafwambaana kuyumina. Cilaminya kususa meenda amutwe kuti zyikala zyalampa cilimo, nciitupa kusiya myunda kuya kumunzi."* (The river (Lusitu River) dries up quickly. It is stressful carrying buckets of water from deep wells during the dry season. This makes us to abandon the gardens).

5.4.2 Effects of sedimentation on livestock farming

The study assessed the effects of the drying up of the Lusitu River on livestock rearing and found that, there was a serious shortage of water for livestock watering which led to relocation of livestock to areas outside Lusitu with plenty water supply. The study found that shortage of water led to poor animal health which affected the market value of cattle in Lusitu. Cattle were left on free range during dry season leading to theft, and being speared by crop farmers as they broke into riverbank gardens, in search of water in wells which were not properly protected by fencing (Table 7). Based on the responses from semi-structured interviews with 45 participants, it was found that the major effects of sedimentation of Lusitu

River to the livestock farmers included shortage of water for livestock watering, relocation of cattle and a reduction in the number of goats being reared (Figure 21).

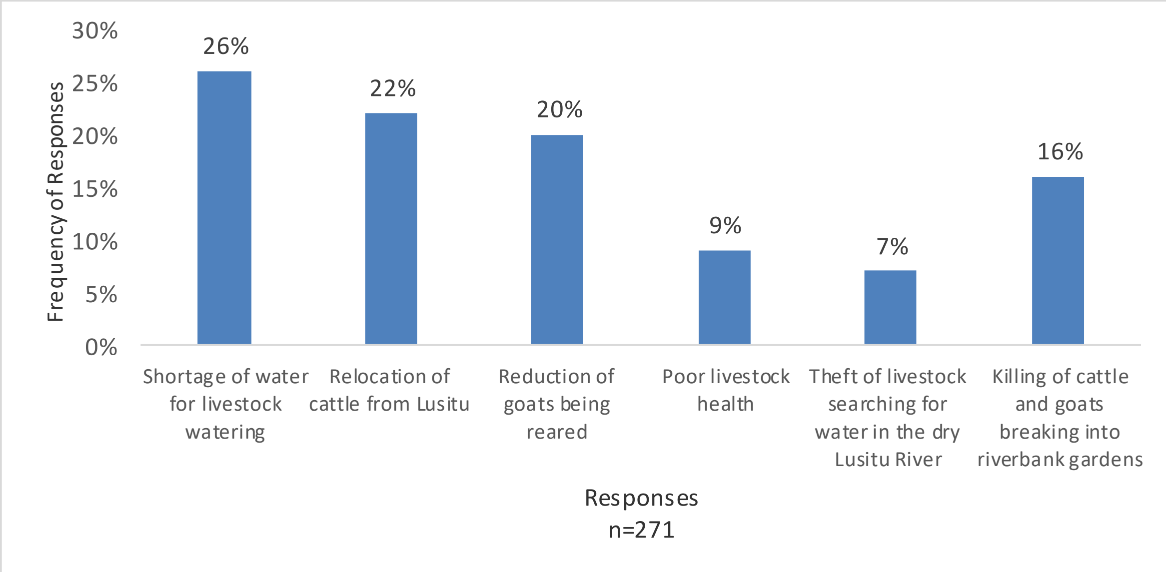


Figure 21: Effects of sedimentation of the Lusitu River on livestock farming

Themes which emerged from the semi-structured interview of 45 livestock farmers were shortage of water for livestock watering, relocation of cattle, reduction of livestock being reared, poor livestock health and theft of livestock (Table 7).

Table 7: Effects of the drying up of the Lusitu River on livestock farming.

Themes	Description of themes
Shortage of water for livestock	• Chirundu Town Council delay digging reservoirs on the riverbed. • Some boreholes have no provision for livestock watering. • Conflict with gardeners who sometimes kill livestock. • Difficult to draw water for goats being watered at home.
Relocating of cattle from Lusitu	• Long distances covered by herdsmen to relocate cattle. • Loss of livestock due to crocodile attack in Zambezi River.
Reduction of livestock being reared	• Maintaining only small number of livestock. • Reduced income from livestock farming.
Poor livestock health	• Loss of weight due to water shortage.
Theft of livestock	• Cattle and goats are left on free range. • Cattle rustling in Lusitu River as cattle search for water and pasture.

The study found that shortage of water for livestock watering was a serious problem which led to loss of livestock. One participant said *that "mwaka wamana, ngo'mbe zyangu zyotatwe zyakayaswa kumulonga aba simagaadeni."* (Last year (2022), I lost three herds of cattle which were speared by the gardeners in the Lusitu River).

5.4.3 Effect of sedimentation on domestic water supply

Based on 493 responses from semi-structured interviews of 104 participants, the study established that, the main effects of the sedimentation of the Lusitu River on domestic water supply were increase in time and distance taken to draw water (Figures 24 and 25).

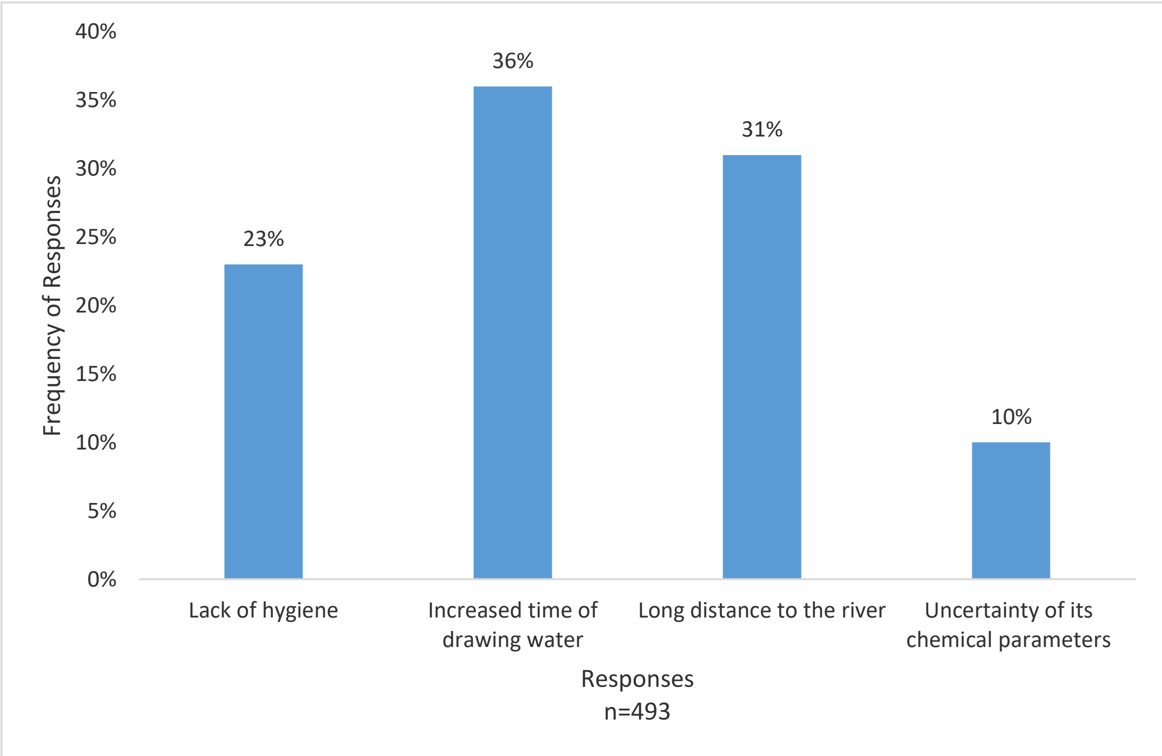


Figure 22: Effects of the drying of the Lusitu River on domestic water supply

While the drying up of the Lusitu River led to an acute shortage of water for irrigation farming and livestock watering, the study found strong evidence suggesting that the dry Lusitu Riverbed improved household water supply, especially water for drinking (Figure 23). The study found that the local people had a preference of the water trapped in the sediment to the borehole water and this led to increase in distance covered (Figure 25) and time taken by women to draw water for household use (Figure 24).

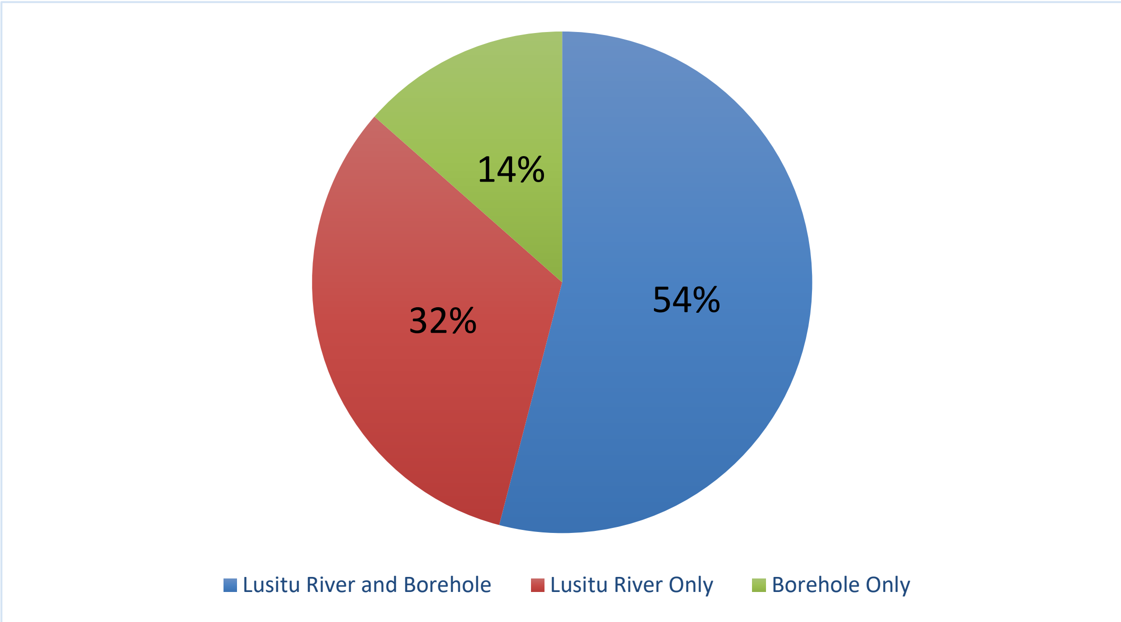


Figure 23: Water sources for domestic use in communities near Lusitu River.

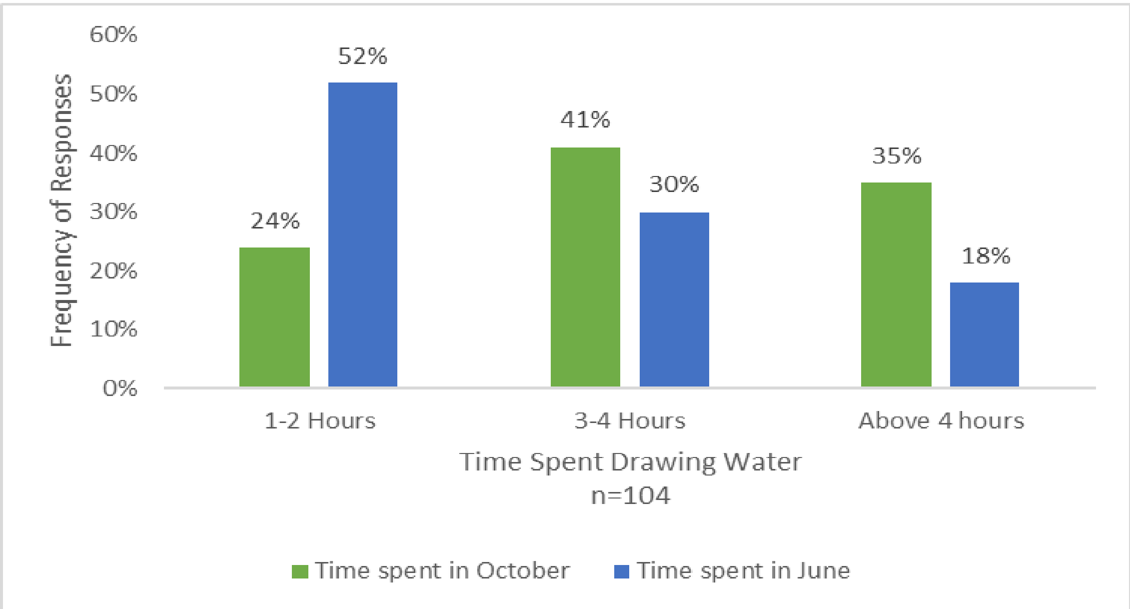


Figure 24: Time taken by women in Lusitu to draw water

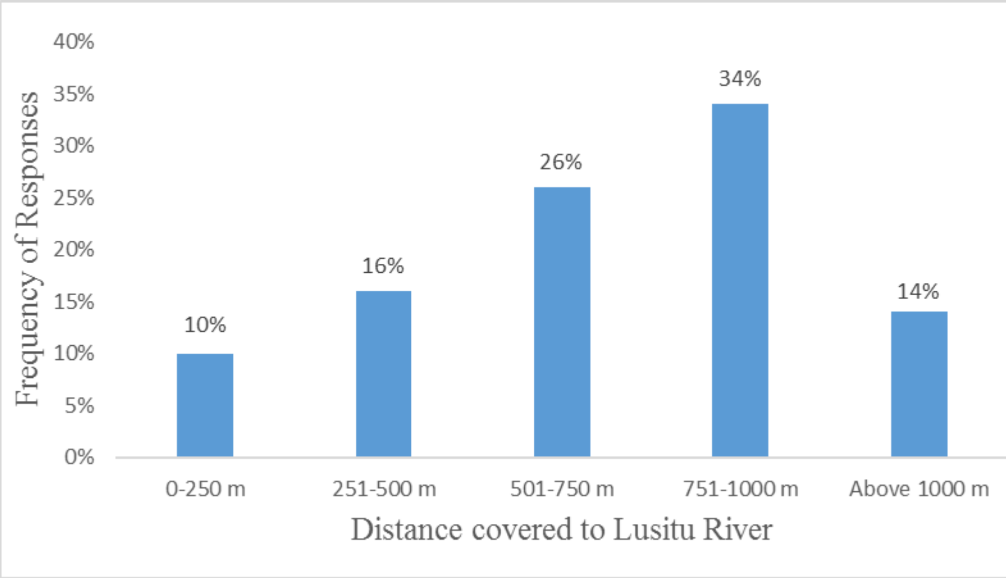


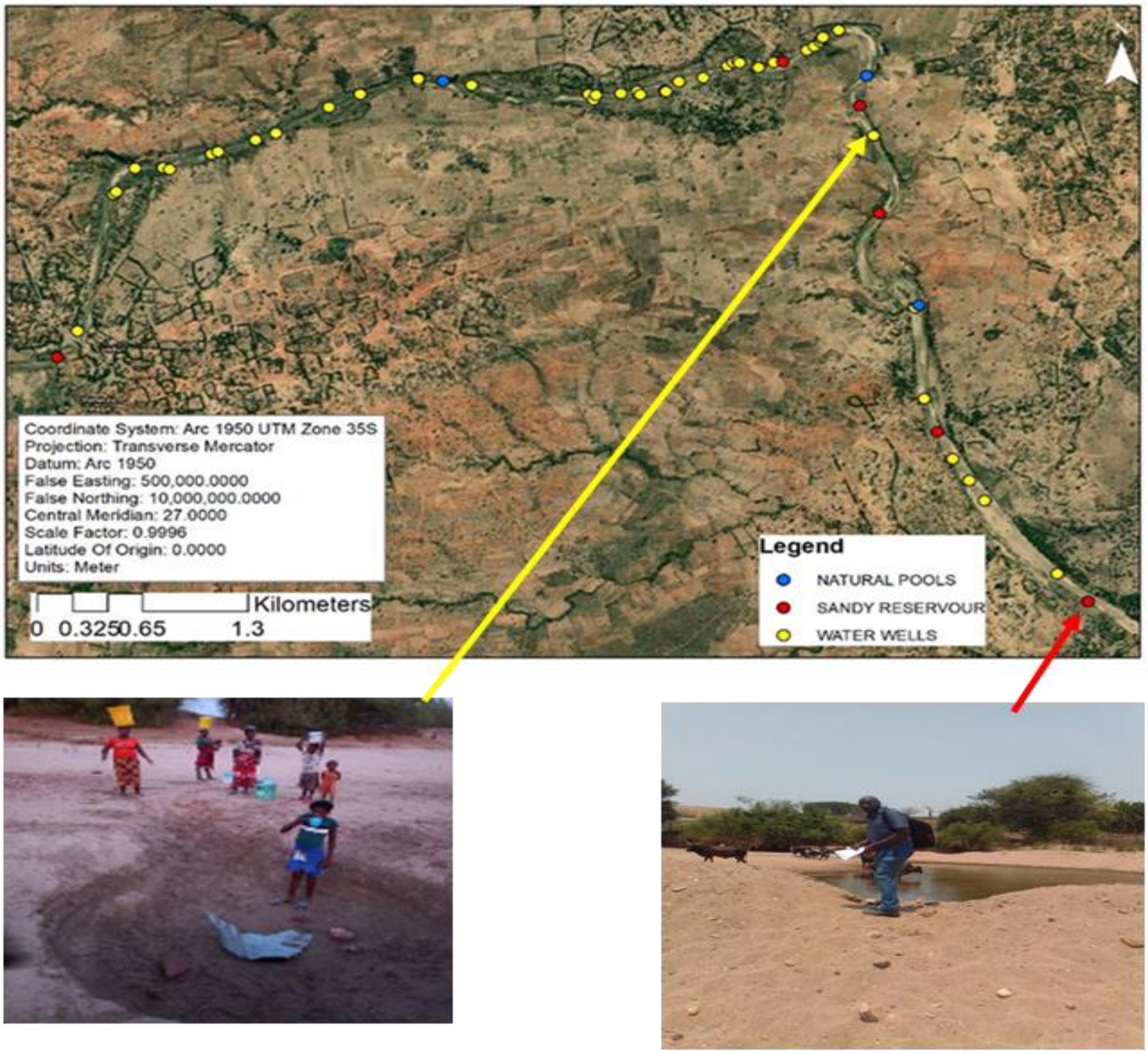
Figure 25: Distance covered by women to fetch water in the Lusitu River

The study found that even though the drying up of the Lusitu River provided sediment filtered water for domestic use, its accessibility was marred with challenges of hygiene as the resource was shared with livestock, frequent digging, and maintenance of collapsed wells, long distance to the river and the uncertainty of its effects on human health (Table 8).

Table 8: Effects of the drying up of the Lusitu River on domestic water supply.

Themes	Description of themes
Increased time of drawing water	• Collapsing water wells due to unstable sediment. • Number of water wells reduce with progression of the dry season.
Lack of hygiene	• Sharing water wells with livestock • Wells not covered properly. • Water being linked to outbreaks of diarrhoea in Lusitu
Long distance to the river	• Boreholes nearby are salty. • Water in the sand has good taste.
Uncertainty of its chemical parameters	• Not certain of the biological and chemical composition of the water.

The study found that local communities in Lusitu adapted to water scarcity by digging wells on the riverbed which supplied water for crop irrigation, livestock watering and household use. Further, Chirundu Town Council dug small sandy reservoirs for livestock watering. The water wells and sandy reservoirs were spread along the river channel (Figure 26). Data for the same is provided in Appendix B.



(X: 0692222, Y: 8212315) (X 0692246, Y: 8212347)

Figure 26: Resilience strategies to water scarcity adopted in Lusitu.

5.5 Strategies for integrated restoration of the Lusitu River from sedimentation

Based on Focus Group Discussions with the local community members in Lusitu, and the Key Informants, the study identified nine issues which needed to be addressed. These were severe gully erosion, river channel sedimentation, intensive tillage farming practices, disregarding of cultural practices, poor management of communal resources, deforestation, limited livelihoods, reduced water storage capacity of the river channel and weak enforcement of existing legal frameworks. To resolve these issues, the study took an integrated approach to design an ICRF for the Lusitu River Catchment. Catchment restoration measures were nature based, engineering and sustainable agriculture (Table 9). Intervention strategies to protect the catchment from further degradation were use of indigenous knowledge, community engagement, stoppage of unstainable practices, provision of alternative livelihoods, development of sediment business model and enforcement of existing legal frameworks. The development of an ICRF for Lusitu River Catchment was premised on the designation of the period 2021-2030 as the UN decade on ecosystem restoration (spray *et al*. 2022,) to which Zambia subscribes. The emphasis is to halt and reverse degradation in freshwater ecosystems which called for adoption of resilient integrated catchment-wide approach (UN, 2020). In this regard, the study proposed declaring Lusitu Catchment a protected area to facilitate natural regeneration of trees, and a successful implementation of the ICRF.

The importance of an integrated approach was evident in the Focus Group Discussions, where, one Headman said that "*bantu tabatulemeki pe tubamasibbuku. Twasola kubalesya kuumpa malasya, tabamvwi pe*." (People disregard our authority to stop them from burning charcoal." Another participant said, "*bantu tabakonzyi kuzumina kusimpa zisamu naa kwiina ncipapegwa. Kayi bakazibila kubelekela cakulya myaka yanzala*." (People cannot work to plant trees if there is no incentive given. They are used to incentives during drought years." These views pointed towards the need to include community education in the restoration framework. The participants were eager to have Lusitu River Catchment restored. One participant said that "*Kuti kuli mbutunga twacita, kubambulula nyika, tweelede kufwambaana nkaambo nyika yanyonyooka*." (If there are possible measures to restore the land, we should be quick because land degradation is serious." Another participant said that "*ooyu mulonga inga wabambululwa. Ciyandika nkubelekela antoomwe.*" (It is possible to restore the river if we work together).

Table 9: Integrated Catchment Restoration Framework (ICRF) for the Lusitu River Catchment

Issue	Intervention Measure	Specific Approach	Description of Approach	Objectives and goal	Stakeholders
Severe gully erosion	Catchment Restoration	Nature-based Approach	• Restocking Vegetation: Planting indigenous trees of economic importance, ficus trees, fruit trees and Euphorbia. • Trench dams in the upper catchment. • Stone bans on hill slopes.	• Reduce runoff. • Control gully erosion. • Increase infiltration.	• Local Community • Ministry of Green Economy and Environment. • Ministry of Technology and Science.
River channel sedimentation		Engineering approach	• Check dams. • Mechanical flushing of sediment. • Construction of weirs. • River dredging.	• Reduce sediment transportation. • Increase sediment sinks. • Reduce sediment load in the river channel.	• Local Community • Ministry of Technology and Science. • Ministry of Local Government and Rural development.
Intensive soil tillage farming practices		Sustainable Agriculture	• Agro forestry; fertiliser trees and vetivergrass. • Conservation farming; minimum tillage, crop rotation, crop diversification and contour ploughing.	• Reduce sediment generation. • Reduce sediment transportation. • Increase infiltration capacity of the soils.	• Local Community • Ministry of Agriculture. • Ministry of Fisheries and Livestock.

Table 9: Integrated Catchment Restoration Framework (ICRF) for the Lusitu River Catchment

Disregarding of cultural practices and lived experiences	Catchment Protection	Use of indigenous knowledge	• Role of traditional practices such as Malende shrines (rainfall shrines) and Nkolola (girls' initiation ceremony) in land and forest resources conservation. • Encourage the practice of demarcation of residential and crop field boundaries with trees.	• Create a link between indigenous knowledge and scientific approaches for sustainable restoration of the Lusitu River from sedimentation. • Build on local knowledge and initiatives in solving the problem of soil erosion and sedimentation of the Lusitu River.	• Local Community • Ministry of Green Economy and Environment. • Ministry of Agriculture. • Ministry of Local Government and Rural development.
Lack of responsibility in managing communal resources		Community engagement	• Teaching the community on importance of trees in relation to rainfall activities and soil erosion.	• Create awareness on drivers of sedimentation. • Create sense of responsibility in the protection of communal resources; land and trees. • Enhance sustainable management of the Lusitu River buffer zone, agricultural land and harvesting of forest products.	• Traditional leaders within the catchment. • Ministry of Green Economy and Environment. • Ministry of Agriculture.

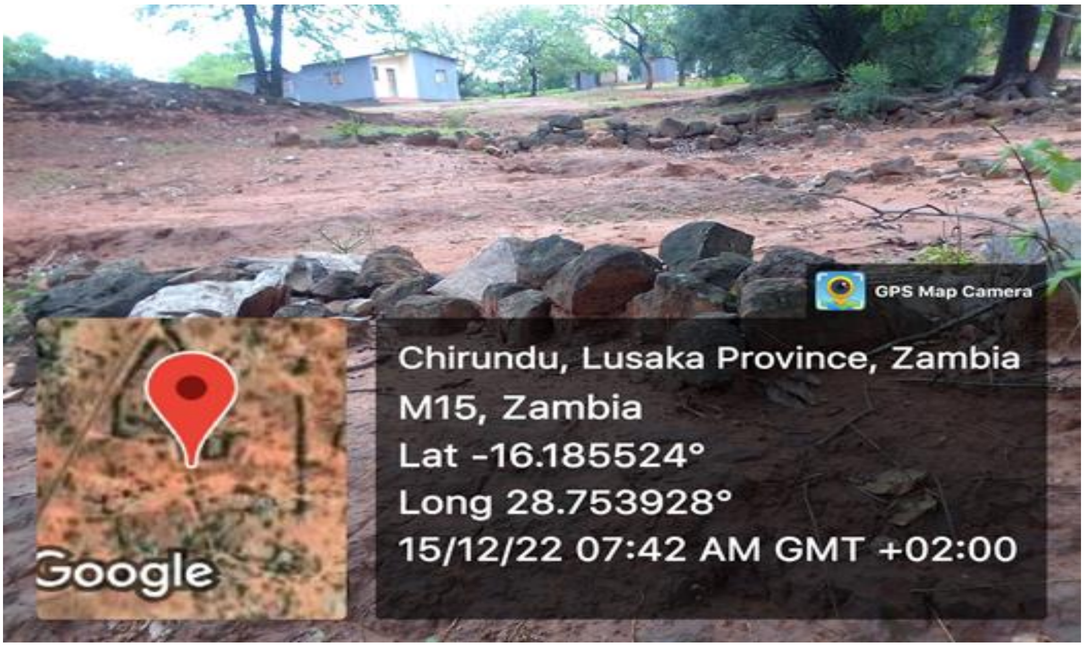
Table 9: Integrated Catchment Restoration Framework (ICRF) for the Lusitu River Catchment

Deforestation		Stopping unsustainable practices	• Use of ox-drawn sledges for transport encourage development of gullies. • Increased deforestation due to charcoal production.	• Ban the use of sledges in Lusitu to reduce development of gullies. • Bring to an end the practice of burning trees from ground level being harvested for charcoal production to encourage tree regeneration.	• Local community • Ministry of Green Economy and Environment. • Ministry of Agriculture
Limited livelihoods		Provision of alternative livelihoods	• Encourage Bee keeping and honey marketing. • Commercialise basket making and marketing. • Provide training to Charcoal Producers in skills such as Carpentry and Brick Laying.	• Reduce the number of people involved in charcoal production. • Encourage voluntary tree planting to grow the bee keeping industry. • Diversify the local economy by providing skills training to the youths.	• Local community • Ministry of Community Development and Social Services. • Ministry of small and Medium Enterprises Development. • Ministry of Local Government and Rural Development. • ZRA
Reduced water storage capacity of the river		Development of sediment business model	• Formation of cooperatives specifically with business plans to mine sand in Lusitu	• Create market opportunity for the sediment deposited in the Lusitu River channel	• Local community • Ministry of small and Medium Enterprises

Table 9: Integrated Catchment Restoration Framework (ICRF) for the Lusitu River Catchment

channel			River for sell to nearby towns.	whose estimated value was over four hundred and sixty million Zambian Kwacha (over twenty five million US dollars).	Development. • Ministry of Community Development and Social Services.
Weak enforcement of legal frameworks		Enforcing legal frameworks	• Effect the existing legal frameworks such as: i. Water Resources and Management Act of 2011. ii. SI 1 of 2000. iii. Forest Act of 2015. iv. Environmental Management Act of 2011. v. Energy Regulation Act of 1995. vi. National Heritage conservation Act 173.	• Declare Lusitu River Catchment as a protected area. • Bridge the existing gap in the enforcement of statutory regulations in management of natural resources under government gazette and those under traditional ownership. • Increase private stakeholders' participation in restoration of the Lusitu River.	• Traditional leaders. • Ministry of Local Government and Rural Development. • Ministry of Green Economy and Environment. • Ministry of Agriculture.

Below are some geocoded pictorial evidence of some measures that local people employed to control soil erosion which need to be harnessed for sustainable soil erosion management in the Lusitu River Catchment.



(a)

(b)

Figure 27: Soil erosion control practices in Lusitu (a) Use of stone bans on hill slope (b) Plant vetivergrass to control gully erosion (X: 687572 Y: 8210773).

CHAPTER SIX: DISCUSSION OF RESULTS

6.1 Chapter overview

This chapter discusses the results in line with the objectives of the study. The first section discusses main drivers of sedimentation in the Lusitu River Catchment. The second section discusses results on the magnitude of sedimentation in the Lusitu River. The third section discusses the effects of sedimentation of the Lusitu River on small scale crop farming, livestock farming and domestic water supply. The fourth section discusses measures needed to restore Lusitu River from the problem of sedimentation.

6.2 Main drivers of sedimentation in the Lusitu River

The ranking of severity of occurrence of drivers of sedimentation in the Lusitu River Catchment showed that anthropogenic activities were the most responsible for sediment generation. These findings are consistent with those found by UNESCO (2011), Zhao *et al.* (2013) and Daramola (2022). The practice of gardening on the riverbanks among the Gwembe Tonga of Lusitu was historical. It was practised when they occupied the section of the Zambezi River, now the central part of Lake Kariba. This section of the Zambezi River was a flood plain (ZRA 1996). As the floods receded, maize, pumpkins and sweet potatoes were cultivated up to the riverbanks. Participants who were part of the resettlement into Lusitu in 1958, narrated that, the then, Federal Government told the people to be resettled that Lusitu River was perennial with plenty of water for gardening. However, people resisted to be moved away from the fertile alluvial soils which enabled them to grow crops throughout the year. As resistance and hostilities grew, the Chisamu War (in Chisamu village, now near Ng'ombe Ilede) broke out, where at least, eight people were killed while thirty two were wounded. This was a defence of riverbank gardens. These narratives are similar to the documentation by ZRA (1996). Hence, the practice of riverbank gardening along the Lusitu River started immediately they were resettled in Lusitu, in 1958. The gardens mainly produced crops for home consumption. The above scenario confirms Sichingabula (1997) earlier argument that sedimentation in Zambia was accelerated by long history of sedentary agriculture.

Based on participants' narratives, the commercialisation of gardening along Lusitu River was an adaptive measure to droughts, especially the 1994 and 1995 droughts. Since then, people realised the monetary economic value of riverbank gardens, other than merely contributing to domestic food supply. The commercialisation of gardens led to destruction of riverine vegetation such as reeds and ficus trees, to clear land for gardens and reclaiming parts of the river channel for gardening. Hence, augmenting soil erosion. The situation was hastened by cleared trees in the buffer zone for rain-fed crop cultivation where prior to the onset of the rainfall, the fields were cleared of any regenerating vegetation which was heaped and burnt, comparable to the Chitemene System of farming which Sichingabula (1999), reported to induce high sediment generation. This practice left crop fields bare, thereby encouraged high sediment generation which was transported by runoff into streams and deposited in the Lusitu River. Intensive soil tillage farming practices, which were ox-drawn ploughing and weeding by hoes loosened the soil, and increased sediment generation. The common mode of transporting ploughs to the fields was usage of sledges, which overtime, led to development of gullies. The effects of agricultural practices on sediment generation have been widely discussed by UNESCO (2011); Zhao (2013); Chomba and Sichingabula (2016); Liu (2016); Yao and Liu (2018), Muchanga (2020), Daramola (2022), Muchanga *et al.* (2023), among others who similarly found that change of landuse from forest to agriculture generically increased sediment yield and deposition.

Livestock grazing, which was ranked very severe, with a mean rank of 2.68 out of 3, a standard deviation of 0.47 and a coefficient of variation of 18% showed that majority of people (82%) in Lusitu were aware that overgrazing contributed to land degradation. Grazing areas became bare because there was limited land for animal grazing due to strict chiefdom boundaries between Chief Sikoongo (native to the area), and Chief Chipepo (resettled to the area). This was evidenced by the practice of relocating cattle to other chiefdoms with sufficient grazing lands such as Simamba near Lake Kariba (Table 7). As mentioned earlier, Chirundu District had a total of 7, 126 cattle and 32, 800 goats (CSO, 2017) mainly concentrated in the downstream section of the Lusitu River. Sichingabula (1997); Muchanga (2020) and Muchanga *et al*. (2023) have shown that large herds of cattle kept by the local people in Southern Province accelerated the process of sedimentation.

The deforestation of Mopane woodland due to charcoal production activity had a mean rank of 2.65 out of 3 with 20% coefficient of variation implying that it was a serious driver of sediment generation. Charcoal production had left large tracts of land cleared of vegetation. Similar findings were reported by Mulenga *et al*. (2015) that, the current contribution towards forest degradation resulting from charcoal production in terms of both spatial extent and produced charcoal is surpassing deforestation for agriculture expansion. The impetus for large-scale charcoal production in Lusitu, was driven by high preference of charcoal from mopane trees in nearby towns; Chirundu, Siavonga, Kafue and Lusaka. It was reported to burn slowly, lasting longer than charcoal from other tree species. Hence, helped to save household energy costs in the face of load shedding, and increased electricity costs. Dlamini *et al*. (2016) and Samboko *et al.* (2016) have documented that, increase in charcoal demand in Lusaka (and other towns) was driven by long hours of load shedding, which has led to diminishing of tree species preferred for charcoal production. In Lusitu, Charcoal Producers showed that, it was easier to engage in charcoal burning because it did not require any capital other than an axe, a hoe, shovel, and personal labour. Even though Chief Chipepo banned charcoal production in his chiefdom, the study found that it was difficult to control, or even to end the practice of charcoal production because it was a lucrative alternative source of livelihood, in response to consistent droughts in Lusitu. The study found that Charcoal Producers were hostile to any effort made by traditional leaders to end charcoal burning. These findings are related to those by Dlamini *et al.* (2016). In Lusitu, Charcoal Producers demanded for an alternative source of livelihood which could give them financial gains, as did charcoal production business. Such a demand was impossible in the existing local economy.

The contribution of sediment generation into Lusitu River due to sand mining was found to be minimal. It had lowest mean rank of 1, with no deviation. The study found that sand deposited on the riverbed was not utilised due to presence of construction sand in streams such as Machembele, near Chirundu town, and Bbendeele closer to Siavonga town. However, in 2019, sand was commercially mined in Lusitu River by Sino Hydro Corporation, a Chinese construction firm. Sand was ferried to Kafue for construction of Kafue Gorge Lower Power Station. This provided evidence that, sand deposited in Lusitu River is of high grade for construction of super structures. The limited contribution of sand mining activities in Lusitu to the geomorphic change of the Lusitu River differ from the findings by WARMA (2019) and Mafwabo *et al.* (2023), where sand mining was found to be a serious contributor to the Magoye River channel degradation due to high demand from the construction sector.

One most notable and unique driver of sedimentation in Lusitu Catchment was associated with Indigenous practices such as the *Nkolola* Initiation Ceremony for girls. The local people were mining a red sedimentary rock, which they used to make powder locally called *Munsila* and is used for body make-up for girls undergoing initiation ceremony, called *Nkolola*. This was found to have a weakening influence on the riverbanks, hence contribute to sediment generation from collapsing riverbanks.

(X: 0690235 Y: 8212214 Date: 23.10.2022)

Figure 28: Mining of a red sedimentary rock used for producing makeup powder for the Nkolola Initiation Ceremony.
Picture source: Michelo Himaambo (Times of Zambia, April 1, 2016).

Such a scenario goes on to show that, even cultural practices should not be left out in the mainstreaming of sustainability principles around river management and protection. In fact, UNESCO (2015) shows that, culture, if well utilised, could be the main driver of sustainability messages around various environmental resources such as rivers. Contextually speaking, the river protection and restoration framework or measures must decisively include custodians of such ceremonies.

The population of the resettled Gwembe Tonga people increased from an initial population of 6, 000 people in 1958 to about 28,000 by 2022 (Zamstats, 2022). This increase of population over time potentially signals pressure on cultivated land, which could have been contributing to pressure on resources and land degradation leading to siltation. This is similar to Ethiopia experiencing land degradation in the Blue Nile highlands hosting about 90% of the country's population where such population pressure severely triggered erosion and sedimentation of rivers and reservoirs (Hurni *et al*., 2005; Bewket and Sterk, 2005; Nyssen *et al*., 2010; Rientjes *et al*., 2011 and Asfaw *et al*., 2018 and Mersha *et al*., 2022).

Even though Lusitu Catchment receive less rainfall (Figure 4), occurrence of flush floods induces sediment generation and transportation. Leopold (1995); Sichingabula (1999); Das and Saika (2009); Viessman and Lewis (2012) among others, have widely documented the influence of rainfall in sedimentation. The occurrence of flush floods on steep slopes of the upper Lusitu River Catchment with Leptosols which are highly erodible (Baumle *et al*. 2007) (Figure 5), and on land with less vegetation cover (Figure 8), could have played a significant role in the generation of high amounts of sediment, leading to the drying up of the Lusitu River. These results are similar to those found by Lu (2013), Wang *et al.* (2015), Wu *et al.* (2015) and Shi *et al.* (2017) that natural factors such as highly erodible soils, steep slopes and high rainfall intensities increased rates of erosion and sediment loads.

6.3 Magnitude of sedimentation in the Lusitu River

The problem of sedimentation in rivers around the world require serious attention owing to its adverse effects on water availability for sustainable development. In Southern parts of Zambia, sedimentation is a serious problem as documented by Sichingabula, (1997); Sawunyama *et al*. (2006); Dalu *et al*. (2013); Sichingabula *et al*. (2014); Chitata *et al*. (2014), Chomba and Sichingabula (2016); Muchanga (2017); Muchanga (2020); Muchanga and Sichingabula (2021); Hamatuli and Muchanga (2021), Simweene and Muchanga (2021); Muchanga *et al*. (2023) among others. There are other studies outside Zambia that have confirmed the spatial distribution of sedimentation problem even though they were not really done on rivers (Ferreira *et al*.,2013, in the Amazon, Chitata *et al*., 2014 at Mutangi reservoir in Zimbabwe, Yin *et al*., in China and Kats, 2016 in Myanmar).

This study quantified sediment burden in downstream section of the Lusitu River and measured a huge sediment volume of 2,863,913.78m^3 (Figure 15) with mean sediment depth of 3.13m. Many studies in Zambia and the sub region have concentrated on reservoir sedimentation where high loads of sediment accumulation have been documented. For example, studies in Zimbabwe with similar climatic conditions with Lusitu by Chitata *et al.* (2014) at Mutangi Reservoir; Mupfiga *et al.* (2016), at Tuli-Makwe dam and Tundu *et al.* (2018), at Chimhanda dam calculated loss of reservoir storage capacity due to sedimentation at 37.0%, 40.8% and 39.0% respectively. In Zambia, Muchanga (2020) at Makoye reservoir calculated loss of storage capacity due to sedimentation at 53.5%. However, such findings could only be attributed to dams unlike rivers as was the case for Lusitu. In Lusitu River, the average channel depth was calculated at 1.45m. This implied that the original average channel depth for Lusitu River was 4.58m when the average is added to the current channel depth. Therefore, the downstream section of the Lusitu River had lost 68.34% of its storage capacity due to sedimentation as of October 2022. This has led to loss of economic importance of the river which has only remained with 31.66 % of its original water storage capacity. This result is similar to the findings by Ren *et al*. (2002); Zhang *et al*. (2005); Fang *et al*. (2008); Qin *et al*. (2011); Ran *et al*. (2012); Fan *et al*. (2013); Ta *et al*. (2013); Wang *et al*. (2016); Huang *et al*. (2017); Si *et al*. (2017); Zhang *et al*. (2017) and Yao and Liu, (2018) who found that the Yellow River's capacity had reduced due to river channel siltation. Through interviews, it was found that, reduction in channel volume due to sedimentation led to loss of perenniality of the Lusitu River which began in the early 1980s.

Even though flooding is a natural process which is vital in maintenance of ecosystems, Dalu *et al*. (2016) and Liu *et al*. (2016) showed that flooding can be altered by land use changes resulting into increased sediment accumulation in river systems thereby raising the level of the riverbed. In Lusitu, flood events were reported to have cut several meanders, uprooted riverine vegetation and deposit enormous loads of sediment as flood waters receded. Occasional high rainfall intensities overrode on anthropogenic activities which had left the land bare to generate more sediment than could have otherwise been prevented had natural vegetation not been indiscriminately cleared off. These results are related to the findings by Sichingabula (1999), Zhao *et al*. (2013) and Liu *et al*. (2016) that natural factors such as high rainfall intensities interact with anthropogenic factors such as landuse types in sediment generation. Similarly, Munthali (2011) in his study of Songwe River Watershed in Malawi found that most of the sediment in Songwe River was generated in the upper catchment in built up areas and degraded natural land. The interaction of natural and anthropogenic factors in sediment generation is depicted in the conceptual framework of this study. In Lusitu, as earlier mentioned, floods led to high sediment generation because much land was bare, the dominant Leptosols in the upper catchment and rock formations of sandstones and mudstones in the lower catchment are both highly susceptible to erosion (Baumle *et al.,* (2007). It is in this respect that, the mixed methods approach and a concurred design were adopted to adequately address the interaction of these physical and human processes thus fulfilling the philosophical stance of analytic eclecticism that phenomenon must be understood both from the social and geophysical contexts.

The results showed spatial variation of sediment accumulation along the Lusitu River. The mean sediment depth of 3.13m confirmed participants' description of Lusitu River before its sedimentation that, it had a small deep channel, with plenty of water which guaranteed sufficient water supply for water-linked sectors throughout the year. The study found that this deep river channel which had deep water in the dry season, before Lusitu River become non perennial was now covered by deep sediment load, as the results showed a positive linear relationship between sediment depth and sediment volume (Figure 16) with $R^2 = 0.9996$ and $p < 0.01$. This enormous load of sediment deposit took up space that would have otherwise been occupied by water thereby affecting various water-linked sectors in the catchment. This scenario confirms the findings of 145 rivers, 50% of which had statistically lost channel storage due to sedimentation postulated to lose about 50% of their storage capacity by the year 2100 (Walling and Fan, 2003).

6.4 Effects of sedimentation of the Lusitu River on water-linked sectors

The drying up of the Lusitu River due to high sediment load affected water-linked sectors within Lusitu community which were small-scale crop farming, livestock farming and domestic water supply.

6.4.1 Effects on small-scale crop farming

Small scale crop farmers adapted to two scenarios: High frequency of floods during rainy season due to reduced storage capacity of the Lusitu River and its drying up during the dry season. Over 97% of the farmers adapted to the semi-arid climate of the area by mainly growing early maturing varieties of sorghum during rainy season (Figure 17). The adoption of early maturing varieties of sorghum was promoted by the Ministry of Agriculture after the failing of a late maturing traditional variety. There was also a ready market for sorghum by breweries companies in Kafue and Lusaka. Maize was least grown because it was not only susceptible to drought, but also required more fertilizer to grow, because most crop fields were degraded due to overuse through intensive tillage farming without farrow hence, had lost most topsoil with essential nutrients. High sediment generation degrades farmlands. Chen *et al*. (2021) showed that, the interaction between water and sediment significantly affected agricultural soil physical and biological properties, and nitrogen transformation. Sediment increased soil bulky density, and significantly reduced the soil porosity and pH (Chen *et al*., 2021).

Riverbank gardening which was a major economic activity in the area had its intensity varied in accordance with water availability in the Lusitu River (Figure 18). Riverbanks had alluvial soils deposited when the river flooded. Yang *et al*. (2003) documented that sediment plays an important role as source of nutrients for agricultural land. Farmers utilised the fertile riverbank soils for gardening. This practice is contrary to the laws of Zambia which protect the buffer zone (SI 1 of 2000). The study found serious variation in the farmers' annual income from the gardens. About76% of the farmers had an annual income of less than K10, 000.00. Only 5% of the farmers had an annual income of over K20, 000.00. This disparity in income levels was shown by a standard deviation of K 7, 423.33, which was above the mean annual income of K7, 205.00, with a coefficient of variation of 103% (Figure 24).

The study found that, only about 5% of farmers who used water pumps managed to cultivate larger portions of their gardens, even at the height of water crisis between September and December. These farmers sold their crops at a higher price, due to increase in demand because of reduced production, putting the law of demand and supply into effect (Ministry of Agriculture and Livestock, 2023). Most of the farmers cultivated portions within their gardens which declined in size, as water became difficult to access in the sediment, and eventually abandoned the gardens, beginning in September. Most farmers resumed gardening in April after harvesting of sorghum. This resulted in loss of income from the gardens. This seasonal water shortage as a result of river sedimentation was documented in studies by Kamtukule, (2008) in Malawi; Addo *et al*. (2011) in Ghana; Globbler (2011) in the Limpopo Basin, in Botswana and South Africa, and Chen *et al*. (2018) in China; and, in Zambia by Chomba and Sichingabula (2016); Muchanga (2017; 2020); Mwiinde 2017; and Muchanga *et al*. (2023). This also confirms how spatially and temporally distributed the problem is across different parts of the world.

The intensity of gardens on both banks of the Lusitu River from Lusitu Bridge up to its confluence with the Zambezi River, corresponded with Lusitu River flow regime and had undoubtable serious implications on livelihoods of the local community. Between January and March, there were few gardens because farmers concentrated on growing of sorghum, the main food crop. Growing of sorghum required intensive labour to scare birds which were destructive to the crop. Further, much of the land used for gardening was prone to flush flooding due to reduced storage capacity of the river because of high sediment deposit. The problem of flooding due to sedimentation was documented in several studies such as Munthali (2011); Dalu *et al*. (2013) and Liu *et al*. (2016). Flush floods in the rainy season presented a risk to farmers, hence less gardening during the same period. There was a high concentration of gardens between April and August. During this period water was easy to access in the sediment. Between September and December, there was a steady decline in the number of gardens because it was difficult for farmers to access water in the sediment (Figure 18). The complete depreciation of flows on the bed surface of Lusitu River led to shortage of water for crop irrigation. Water was buried in the sediment and was difficult to access as the dry season progressed, especially in areas with very deep sediment load. The problem of water shortage due to sedimentation has been widely reported in a number of sediment studies such as Kalyocha, (1988); Sichingabula, (1997); Kalyocha, (2000); UNESCO, (2011); Addo *et al*. (2011); Munthali, (2011); Dalu *et al*. (2013); Sawunyama *et al*. (2006); Sichingabula *et al.* (2014); Chitata *et al*. (2014), Chomba and Sichingabula, (2016); Liu *et al*. (2016); Muchanga, (2017); Muchanga (2020); Muchanga and Sichingabula, (2021); Hamatuli and Muchanga, (2021) and Simweene and Muchanga (2021); Chisola *et al.* (2022); Muchanga *et al*. (2023), among others. Meaning that, the problem has really persisted in literature and thus, requires continuous investigation.

There was serious competition for water in wells dug in the dry Lusitu Riverbed between livestock (cattle and goats) and crop farmers (Figure 20). This resulted in loss of crops which were destroyed by cattle and goats. Livestock could easily break into poorly fenced gardens in search of water in the wells, and the green vegetables. This forced crop farmers to temporarily relocate to the gardens to safeguard their crops. As the dry season progressed, farmers had difficulties to dig deep wells because the unstable sediments easily collapsed. For female headed homes, this increased the cost of farming because charges to dig a well increased as water levels in the sediment dropped. The cost of digging a well ranged from K50.00 to K250.00 with additional maintenance costs when the well collapsed or required deepening. Digging wells on the dry riverbed to access water for irrigation was an adaptive strategy. The water wells were either collectively or individually owned.

6.4.2 Effects on livestock farming

The assessment of effects of the drying up of Lusitu River on livestock rearing established that, there was a serious shortage of water for livestock watering which led to relocation of livestock to areas outside Lusitu with plenty of water supply such as Chalokwa near Zambezi River and Chief Simamba's area near Lake Kariba. This practice of relocating cattle was also influenced by shortage of pasture in Lusitu due to degraded grazing lands which did not support sufficient growth of grass. In addition, the area was overstocked (ZRA, 1996). The study established that cattle relocated to the protected Mutolang'anga Important Bird Area, where tsetse flies had not been controlled resulted in outbreak of Trypanosomiasis in Lusitu. Shortage of water led to poor animal health which reduced the market value of cattle in Lusitu. The problem of poor animal health and diseases due to shortage of water was reported by Muchanga (2017) in his study of the Makoye reservoir in Southern Zambia. During rainy season the colour of water in Lusitu River indicated high level of turbidity. Tundu *et al.*, (2018) found that water high in turbidity can aid the formation of nuclei, where gastrointestinal disease pathogens can attach. If that water is consumed untreated, it can cause diseases (Tundu *et al.*, 2018). UNESCO, (2011) indicated that water high in turbidity could negatively affect animal health. Cattle were found to have been stressed due to shortage of water. In response, farmers left cattle on free range during the dry season, which exacerbated cattle rustling. Apart from theft, cattle were being speared by crop farmers as they broke into riverbank gardens, in search of water in wells. To protect theft of livestock in Lusitu River, farmers fetched water for goat watering at their homes. This led to farmers maintaining small number of goats. Goats were less affected by shortage of pasture as they consumed a wider variety of foliage than cattle. The participants' adaptive measure of reducing the number of goats due to water shortage can be viewed serious when you take into consideration the dairy water requirement of about 4 litres per goat (Abdulwaheed *et al.*, 2016). This water demand is strenuous to a farmer. The adaptive strategies to water scarcity by livestock farmers involved digging water wells on the dry riverbed for livestock watering. This was supplemented by small sandy reservoirs dug on the dry riverbed by the local authority for livestock watering.

6.4.3 Effects on domestic water supply

While the drying up of the Lusitu River led to an acute shortage of water for irrigation farming and livestock watering, some participants claimed that it improved the quality of household water supply, especially water for drinking because of the filtering power of sand. There was preference of water trapped in the sediment to the borehole water as at least 86% of the participants used water from Lusitu River. Water in boreholes was avoided because it was salty. Therefore, borehole water was avoided due to the geological formation of the area which determined the taste of the water (Baumle *et al*., 2007). When the river dried, water trapped in the sediment was purified by sand and accessed by digging shallow wells. This scenario was similar to the findings of Kalyocha (1988; 2000) that sediment trapped water could be accessed by digging into the sediment. Beginning in December when Lusitu River resume flowing, the colour of water was brown suggesting high turbidity and could not be drawn for domestic usage. The general observation is that, although sedimentation could be a problem, it may potentially provide solution to the local people from their social context.

The Department of Water Affairs indicated that water supply in Chirundu town was affected because the authority was usually overwhelmed to purify water from Zambezi River, which was partly inundated by sediment from Lusitu River. Similarly, Tundu (2018) in Mazowe Catchment in Zimbabwe, found that, high turbidity levels made the treatment of water expensive, comparable to several studies which found that sediment accumulation increase operational costs across the world such as Pradhan (2004) in the Himalaya at Jhimruk Power Station, Nepal; Michell (2006) in the United State of America, at Conesville Power Station; Moussa (2011) at the Rowd El-Farag pumping station on the Nile River in Egypt; Hasan (2011) at Ijok Intake on the Ijok River in Malaysia; Charafi (2019) in Morocco; Shrestha and Shrestha (2019) at Kulekhani First Hydropower Station in Nepal and Mohammad (2020) at Mosul Dam Pumping Station on the Tigris River in Iraq. This goes on to show that, sedimentation triggered cost implications in the treatment of water by local authority thereby confirming that, the problem of sedimentation may have both onsite and offsite effects and the problem is serious across the world.

Even though the drying up of the Lusitu River provided an alternative source of water for domestic use, its accessibility was marred with challenges of hygiene as water was shared with livestock, which induced frequent digging and maintenance of collapsed wells and the uncertainty of its effects on human health. In terms of hygiene, outbreaks of diarrhoea in Lusitu were being associated with water drawn from Lusitu River. Although there was no evidence to validate the claim, sediment could adsorb chemicals harmful to human and livestock health (Yi *et al.,* 2011; Tundu *et al.,* 2018). Bhadja and Vaghela (2013) found that sediment in areas dominated by human activity (like Lusitu) usually contain chemical pollutants which threaten human health. This threat encompasses all the surrounding ecosystems. Even though this study did not test the quality of water trapped in the sediment, it is necessary that this aspect is considered in future studies on Lusitu River, owing to the large number of people using this water. The study further found that, distance and time women covered to fetch water increased, as some households who had communal boreholes located in their vicinity travelled long distances to draw water from the Lusitu River (Figures 24 and 25). Most women (76%) spent more than three hours fetching water for their households. This figure was closer to the 86% of women who draw water from Lusitu River and the 74% of women who covered more than 500m to draw water for domestic use. Women spent more time at the wells waiting for their turn to draw water as the dry season progressed, because the number of water wells reduced. In some sections, there were completely no wells at the peak of the dry season. Women covered extra distance to draw water from nearby wells. This implied that drawing water from Lusitu River increased distance covered, and time taken by women to draw water. As the dry season progressed, water become more and more difficult to access. This is related to the water shortage in South Africa, Mutale River (Rankoana, 2020). Hence, this scenario brings to view the need to consider gender perspectives around sedimentation in river systems.

6.5 Measures needed to restore Lusitu River from sedimentation

The ontology of the study required understanding of how physical factors and human factors driving sedimentation interplayed to influence sedimentation of the Lusitu River. Hence, the proposed catchment restoration measures considered this interaction, by proposing interdisciplinary measures which catered both physical and human drivers of sedimentation, as depicted in the conceptual framework.

Epistemologically, deconstructivism allowed for independent investigation of different ways in which water-linked sectors were affected through water shortage. The integrated approach involved various stakeholders in the catchment, including the local community members to arrive at the restoration measures. Analytic eclecticism embodies pragmatic ethoss (Sil and Katzenstein (2010), which require scientific research to generate solutions to the problem investigated. In this context, this study developed an ICRF, which involved catchment restoration approaches that were nature-based, engineering and conservation agricultureoriented. Catchment protection approaches were use of indigenous knowledge, community engagement, stoppage of unsustainable practices, enforcement of legal frameworks, and provision of alternative livelihoods, and development of sediment business model (Table 9).

6.5.1 Nature based approach to restore Lusitu River

Nature-based Solutions (NbS) are actions which use the power of nature to boost natural ecosystems, biodiversity and human well-being to address societal problems (Spray *et al*. 2022). Examples of NbS to be used are restocking of vegetation, use of stone bans and trench dams. The study found that, planting indigenous trees of economic importance on degraded land could reduce soil erosion. These indigenous trees are Mwaani (Mopane) (*Colophospermum mopane*), Musiika (*Tamarindus indica*), Mubuyu (*Adansonia digitata*) and Muzwamalowa (Mukwa- Zambian teak) (*Pterocarpus angolensis*) (Storrs, 1995). These trees should be planted on degraded areas away from the riverbank because they are not ficus species, except for *Tamarindus indica*, which naturally grow on the riverbanks of the Lusitu River. The use of vegetation cover as catchment restoration measure has yielded good results in some catchments such as the Yellow River Basin in China. Xu and Cheng (2002), Wang and Hu (2009) and Liu *et al*. (2019) found that erosion intensity gradually decreased with an increase in vegetation coverage. Prasetyo *et al*. (2021) showed that increase of vegetation cover in the Upper Progo Watershed in Indonesia from 4.8% to 30% significantly reduced about 76% of soil erosion. Similarly, Chen *et al*. (2019) recommended restoration in areas with vegetation cover of 0-40% within which Lusitu, with almost bare land falls. Afforestation brings along environmental quality improvement (UNESCO, 2011and Zhao *et al*., 2013).

The indigenous Mopane and Mukwa trees produce valuable timber (Storrs, 1995), which the local people can harvest for sell once the trees mature. *Tamarindus indica* and *Adansonia digitata* produce fruits which have a readily available market, within the community and from traders coming from other towns especially Lusaka. Planting fruit trees: Mango (*Mangifera indica*), pawpaw (*Carica papaya*) and Lemon (*Citrus limon*) could supplement domestic food supply. Apart from providing fruits, trees provide the much needed shed in this semi-arid environment. Enhancing planting of Neem trees (*Azadirachta indica*) was advocated because, the tree did not only provide shed, but also, was being used as a biological control of aphids in vegetables, army worms in maize and ticks on livestock. Planting of ficus trees to improve water retention along Lusitu Riverbanks, especially the indigenous Mukuyu tree (*Ficus carica*) would result in enhanced riverbank protection. Other trees of economic value which were proposed to be planted alongside the ficus tree were Musau (*Ziziphus mauritiana*) and Musiika (*Tamarindus indica*). These trees naturally grow on the banks of the Lusitu River. Chen *et al*. (2019) recommended adoption of restoration in highly degraded landscapes (such as Lusitu).

The study found that planting of Euphorbia tirucalli and vetivergrass in Lusitu was useful in the quest to control gully erosion. There was evidence in Lusitu that planting *Euphorbia tirucalli* and vetivergrass on gullies was effective in controlling gully erosion (Figure 12b). Liu *et al*. (2019) documented successful gully erosion control in Northern China, using biological measures by shrub plant and arbor plant enclosure of gullies. Commercializing vetivergrass cultivation on abandoned crop fields with gullies could provide folder for livestock and reclaim degraded farmlands. This could increase the carrying capacity for livestock. This can go together with livestock restocking programme under the Ministry of Livestock and Fisheries, especially goats. On the Loess plateau, Yellow River in China, Zhao *et al*. (2013) found that one of the measures which reduced sediment loads transported by the Yellow River was conversion of crop land on slopes into grazing land.

Trenches and stone bans on hill slopes could be useful in reducing sediment generation through reduced rate of runoff and trapping sediment. This is akin to the findings by Godwin *et al.* (2011), who recommended barriers on slopes to slow runoff, whereas Frankl *et al*. (2017) used fascines on ephemeral gully erosion. The anticipated results of nature-based approach are reduction in runoff, control of gully erosion and increased infiltration. In Zambian context, GIZ (2020)-(AWARE) used some of these Nature based Solutions to restore degraded river channels in Mutema-Bwengwa catchment, which yielded positive results.

6.5.2 Engineering approach

The study found that, some of the engineering approaches which could be applied in the restoration of the Lusitu River were construction of settling basins, check dams, weirs, river dredging and mechanical flushing of sediment. These measures are known to be effective (Palme, 2005; Godwin, 2011; Frankl *et al*., 2017; Spray *et al*., 2022). However, they are complex and dependent upon the application of other measures for sediment control (Zhao *et al*., 2013). Construction of settling basins in the upper catchment could be effective in trapping coarse sediment particles. To be effective, they require proper regular maintenance. However, some studies have shown that they pose a challenge of finding a place for continuing long-term disposal of sediment as they quickly fill because they are small (UNESCO, 2011; Zhao *et al*., 2013; Xu *et al*., 2014). Regardless of these inadequacies, settling basins could provide water for residents and agriculture, and increase infiltration needed for the recharge of the river in the dry season (Frankl *et al*., 2017).

Construction of check dams on streams which join the Lusitu River could reduce erosion by runoff and control the development of gullies as documented by Liu *et al*. (2019) in the control of gully erosion in Northern China. Construction of Weirs on the Lusitu River could help control the flow of water, stabilise water levels thereby reduce the period the river is completely dry (Liu *et al*., 2019). This is necessary in ensuring availability of water for the water-linked sectors. Further, the study proposed construction of a dam on the upstream from Lusitu Bridge. Owing to high levels of sediment transport in Lusitu River, mechanical and pressure flushing of sediment could be employed to increase useful life of the dam as documented by Shen (1999) and Karmacharya *et al*. (2021). Even though river dredging is an expensive undertaking, the study found that if proper method and technique were used, supported by studies related to changes of morphological behaviour of the river due to dredging, sediment accumulated on the Lusitu Riverbed could be reduced (Islam *et al*., 2018). The study postulated that engineering solutions to the problem of sedimentation could reduce sediment transportation and increase sediment sinks, which could lead to reduced sediment load in the Lusitu River channel.

6.5.3 Conservation Agriculture based approach

The study found that agroforestry could regenerate degraded farmland (Prasetyo *et al.*, 2021). Planting Musangu tree (Faidherbia albida) and Gliricidia sepium which are fertilizer trees, could improve vegetation cover (Sileshi *et al*., 2014). These trees add nitrogen to the soil and do not compete with crops for sunlight, because they shed off leaves during rainy season (Sileshi *et al*., 2014). As earlier mentioned, increasing vegetation cover significantly reduce soil erosion (UNESCO, 2011; Chen *et al*., 2019; Prasetyo *et al.*, 2021). In Zambia, Nyanga (2012) documented that, conservation farming can improve food supply for smallholder farmers. Despite being promoted by the Ministry of Agriculture, under sustainable farming practices, agroforestry practice in Lusitu is limited because trees in crop fields attract birds which eat sorghum and millet, the main crops grown in Lusitu. However, there is a red sorghum variety which is not eaten by birds and has a market value mainly by breweries. Promoting growing of this variety of sorghum could lead to increase in adoption of agro forestry practice in Lusitu.

The other sustainable farming practices which could lower sediment generation are minimum tillage farming, crop rotation, and crop diversification, and contour ploughing (Sileshi *et al.*, 2014). Minimum soil tillage could be attainable in Lusitu by using Ox-drawn Rippers and Chaka hoes for making basins. Apart from minimum soil tillage, the study found that crop rotation and crop diversification farming practices could reduce sediment generation and transportation thereby increase infiltration capacity of the soil. Seitz *et al.* (2019) in Switzerland found that, organic farming reduced soil losses through reduced tillage. Soil erosion rates were lower when soil cover was above 30%. A project was found running in Lusitu on conservation farming by SCRALA (Strengthening Climate Resilience in Agriculture) Project. The project was among other things focussing on minimum soil tillage by use of implements such as Chaka hoes for making basins and ox-drawn ripper plough for ripping. Herbicides were used to control weeds. However, few farmers were enrolled under this project, hence most farmers continued with conventional farming practices which could have contributed to generation of high loads of sediment. Adoption of conservation farming using basins was limited because it required intensive labour. This could be overcome through community mobilisation and teaching on importance of conservation farming as documented by Sichingabula (1997), Nyanga (2012) and Monde *et al.* (2023). These studies show that adoption of conservation farming in Zambia has lagged overtime. Hence, there is need for intensified research in this area because farming practices are a major source of sediment (Sichingabula, 1999; Chomba and Sichingabula, 2016; Muchanga *et al.*, 2023).

6.5.4 Lusitu River Catchment Protection Measures

In order to create a link between indigenous knowledge, and scientific approaches for sustainable restoration of the Lusitu River, the study found that it was impeccable to build on local knowledge and initiatives which were practiced in solving the problem of soil erosion, and sedimentation of the Lusitu River. In this regard, the role of traditional practice of Malende shrines (rainfall shrines) promoted biodiversity of species through conservation of trees. Cutting of trees for whatever purpose was not allowed in places designated as rain shrines under the custody of the Rain Maker. This tradition encouraged forest conservation as rainy spirits 'do not' dwell in deforested areas. Based on participants' responses, the study found that, Lusitu River was considered a 'shrine river.' There were restricted areas along the river where tree cutting was not allowed. In the current state, rain shrines barely exist. Identifying these areas and gazetting them as historical sites could protect Lusitu River buffer zone and contribute to Zambia's heritage. The study found that some farmers demarcated their residential and crop field boundaries with Euphorbia tirucalli. Hence encouraging this practice would result into increased vegetation cover in Lusitu which reduce soil erosion as mentioned earlier (Chen *et al*., 2019; Prasetyo 2021).

To successfully build a resilient scientific approach towards Lusitu River restoration, there was need to actively engage the local community in implementation of river restoration measures and to continuously teach the community on the importance of trees in relation to rainfall activities and soil erosion (Monde *et al.,* 2023). This is expected to create awareness on drivers of sedimentation of the Lusitu River which would create a sense of responsibility in the protection of communal resources, land, and trees. This was postulated to enhance sustainable management of the Lusitu River buffer zone, agricultural land and harvesting of forest products. This approach has been documented by scholars such as Sichingabula (1997) and Liu *et al*. (2019).

This study found that some practices among the local people were not sustainable in the management of natural resources. These included use of ox-drawn sledges for transport which encouraged development of gullies. Hence there was need to ban and replace the use of sledges with oxcarts with rubber wheels. This would reduce development of gullies. Deforestation due to charcoal burning activity was on increase. The study established that one of the methods of harvesting Mopani trees for charcoal production was by burning the trees from ground level. This method of tree harvesting should be banned to encourage tree regeneration. The practice of girls' initiation ceremonies called Nkolola involved mining of a red sedimentary rock on the riverbanks. The study found that regulating this mining activity would lead to stability of riverbanks. Studies by Sichingabula (1997) and Wang and Hu (2009) have shown that unsound practices which lead to high sediment generation needed to be stopped. However, these practices have persisted as shown in the literature above, and as such, the practitioners should be brought on board in planning and implementation of catchment restoration. Hence, the integrated approach proposed in this study, as informed by the philosophy of analytic eclecticism.

The commercialisation of riverbank gardening and engagement in charcoal production which led to the degradation of the Lusitu River Catchment were a result of a search for alternative livelihoods. The study found that local people needed to be provided with livelihoods which are environmentally friendly such as Bee keeping (which could encourage voluntary tree planting to grow the industry) and basket making. Charcoal producers needed to be provided with training in skills such as carpentry, brick laying and driving using Constituency Development Fund (CDF). This would lead to reduced number of people involved in the obliteration of land and trees in Lusitu River Catchment.

In the quest to diversify the economy, sediment accumulated in Lusitu River could generate income for the local people through formation of cooperatives specifically with business plans to mine sand in Lusitu River for sell to nearby towns. Sediment deposited in the 15km downstream section of the Lusitu River channel has a market value which this study estimated at over four hundred and sixty million Zambian Kwacha (over twenty five million US dollars at an exchange rate of US$ 1 to K 18.00). Where:

(a) 1m^3 of sand weighs on average 1,620 kg
(b) 2,863,913.78m^3 (measured volume of sand) x 1,620 = 4,639,540.32 tonnes of sand.
(c) 4,639,540.32/30 tonnes (Tipper truck tonnage) = 154,651 truckloads of sand.
(d) 154,651 x K 3,000.00 (price per truckload in Chirundu town) = K 463,953,000.00 equivalent to US$ 25,775,170.00 by the time of the study.

Studies have shown that sediment can be utilised for engineering purposes in construction as documented by the Great Lakes Commission (2013). Similarly, Mwiinde (2017) did a cost benefit analysis of sediment. The result for Chipapa Dam showed that the cost of excavating and transporting accumulated sediment within 10km radius was K5, 212,499.50 while sale of the same sediment would gain K20, 849,922.50 translating to K15, 637,423.00 monetary benefit, equivalent to over 74% profit. To reduce the impacts of dredging of sand in the Lusitu River, relevant institutions such as Ministry of Mines and WARMA need to be exclusively engaged for expert guidance and regulations.

In order for catchment restoration and protection measures to be successfully implemented by the local community, government technocrats and other cooperating partners, there is need to effect the existing legal frameworks such as the SI number 1 of 2000, Forest Act of 2015, Environmental Management Act of 2011, Water Resources and Management Act of 2011, Energy Regulation Act of 1995 and the National Heritage conservation Act 173. This is because lack of effective legal regulation frustrates the efforts in environmental management because noncompliance to the statutes is left unpunished. As a result, people go on destroying the environment. The study found that it was necessary to declare Lusitu River Catchment as a protected area in order to halt and reverse the process of desertification taking place in the area as was observed by ZRA (1996). Declaring Lusitu as a protected area would bridge the existing gap in the enforcement of statutory regulations in management of natural resources under government gazette and those under traditional ownership. This would attract attention of and increase private stakeholders' participation in restoration of the Lusitu River.

The challenge associated with effecting legal frameworks to control land degradation was acknowledged by GRZ (2016) that there was conflicting application of legislation by various ministries and departments, and that there was inadequate enforcement (GRZ, 2016). It was for this reason that this study adopted an integrated approach. Different stakeholders will have to work together towards the common goal of restoration of Lusitu River from sedimentation in order to provide sustainable water supply for the water-linked sectors in the catchment upon implementation of the developed Integrated Catchment Restoration Framework (ICRF) for the Lusitu River Catchment.

This study has provided new epistemic insights in the science of sediment and river systems management, by developing a catchment-based Integrated Catchment Restoration Framework or ICRF for Lusitu River Catchment, which can be replicated in other catchments with similar environmental and social characteristics. This study has documented inclusion of a cultural dimension for sustainable management of rivers. It has demonstrated that, sediment can be used to improve human societies, by proposing a sediment business model for the local people involving dredging of the sediment in the Lusitu River for economic benefit of the local people.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 Chapter overview

The first section of this chapter provides a conclusion of the results of this study in respect of the objectives. The second section provides recommendations needed to successfully restore Lusitu River from sedimentation in order to sustainably provide water for the water-linked sectors by implementing the ICRF.

7.2 Conclusions

The study found that agricultural practices were the main drivers of sedimentation. These were riverbank gardening, dry season crop field preparation prior to the onset of rainfall and intensive soil tillage farming. Sand mining was found to be the least contributor of sediment contrary to the findings of other studies in different catchments like Magoye. There was interaction of human and physical processes leading to the degradation of Lusitu River Catchment. Population increase, search for alternative livelihoods which involved riverbank gardening and charcoal production, climatic (flush flooding) and geomorphic factors (highly erodible soils) influenced accelerated sediment generation. The study found spatial variation of sediment accumulation along the Lusitu River from Lusitu Bridge to the confluence with the Zambezi River, with mean sediment depth of 3.13m. The study further concluded that, Lusitu River downstream had an overwhelming problem of sedimentation. The colossal load of sediment deposit took up space that would have otherwise been occupied by water. It was noted that, Lusitu River had lost over 68% of its water storage capacity resulting into high frequency of floods.

The study found that sedimentation of Lusitu River affected small-scale crop farming, livestock farming, and domestic water supply due to shortage of water which was trapped in the sediment. On the other hand, the study noted that, although sedimentation spelled out diverse challenges, local communities thought, it partly helped them to access cleaner water than that which they would access from boreholes. Similarly, the same problem could be used as a source of sand business if due diligence is well done. Lusitu River restoration and protection would require an integrated approach as indicated in a framework (ICRF). This would require meshing together NbS, engineering and conservation agriculture, indigenous knowledge, and cultural practices, among others. The study postulated that restoration measures would in the long term reduce sediment generation by improving vegetation cover and sediment sinks. For sustainable implementation of the ICRF, participation of local people was emphasized.

7.3 Recommendations

The following are the recommendations from this study:

i. Following the high contribution of conventional farming practices to sediment generation, crop farmers should be engaged to shift to sustainable farming practices with low tillage which reduce sediment generation in line with existing guidelines by the Ministry of Agriculture.

ii. The high load of sediment deposited on the Lusitu Riverbed has market value which this study estimated at over four hundred and sixty million kwacha. Therefore, the local community should form cooperatives to specifically mine this resource subject to regulations and recommendations by responsible institutions such as WARMA. Regulated sand mining could contribute to the improvement of the welfare of the local people and expand the local economy.

iii. To improve water supply in the short term for livestock watering, Chirundu Town Council should work with relevant stakeholders such as WARMA to legalise the digging of small sandy reservoirs on the Lusitu Riverbed during the dry season.

iv. Due to the complex of the drivers of sedimentation of Lusitu River and various measures needed to restore the river, there is need to form an integrated committee (with membership from the local community, different relevant government ministries and other stakeholders working in Lusitu) to coordinate catchment restoration activities.

v. Declaring Lusitu River Catchment as protected area. This would allow trees to regenerate, and further, encourage various stakeholders to participate in Lusitu River restoration activities to halt and reverse the process of desertification taking place in the catchment and enhance the application of existing legal frameworks on river protection and restoration of degraded land.

vi. There is need to undertake a study to determine critical sediment generating areas for the entire catchment, which is vital in implementing the ICRF, and to determine the quality of water flowing during rainy season and the water trapped in the sediment during the dry season to ascertain its safety as it is consumed by people and livestock.

vii. Recommend further studies on the following: Culture, gender and river sedimentation, interstitial water quality assessment, assessment of volume of water trapped in sediment, action research implementing the proposed framework, SWAT-based assessment of sediment yields in the entire catchment, historical reconstruction of landuse in the catchment through sediment chemical analysis and dating.

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APPENDICES

Appendix A: Sediment depth data

PIT No.	X COORDINATES	Y COORDINATES	SEDIMENT DEPTH (M)	ELEVATION (M)
1	687394	8210417	0.6	400
2	687384	8210425	1.2	402
3	687361	8210443	0.53	399
4	687443	8210502	1.62	399
5	687433	8210510	3.6	403
6	687421	8210519	0.49	400
7	687483	8210602	0.35	401
8	687462	8210609	3.5	403
9	687448	8210617	1.59	402
10	687570	8211197	3.8	405
11	687551	8211203	1.02	400
12	682531	8211209	3.7	400
13	687666	8211676	3.5	401
14	687649	8211694	1.27	402
15	687636	8211707	1.83	396
16	688131	8211794	1.18	396
17	688125	8211810	4.05	394
18	688118	8211824	1.34	397
19	688614	8211968	1.44	397
20	688608	8211983	4.7	398
21	688602	8211995	3.5	400
22	689069	8212232	1.31	396
23	689064	8212240	1.38	397
24	689057	8212255	1.52	396
25	682588	8212351	2.8	396
26	689586	8212365	3	395
27	689587	8212379	1.07	396
28	690070	8212229	3.1	400
29	690074	8212251	2.9	398
30	690077	8212271	2.1	399
31	690784	8212258	1.85	394
32	690781	8212258	1.08	396
33	690778	8212279	1.28	392
34	691551	8212474	3.5	394
35	691555	8212488	4.5	390
36	691560	8212510	3.5	390
37	692168	8212734	4.5	385
38	692159	8212762	3	383
39	692158	8212773	1.57	381
40	692346	8211396	2.5	385
41	692379	8211379	3.1	385
42	692388	8211376	0.8	388

43	688645	8212005	1.7	397
44	690335	8212240	3.5	393
45	691274	8212386	2.5	390
46	691424	8212472	4.5	394
47	691458	8212499	4	396
48	691485	8212509	4.8	389
49	691766	8212435	4.5	391
50	692362	8212556	3.5	388
51	692301	8212466	4.5	389
52	692246	8212347	4.5	387
53	692200	8212252	4.8	390
54	692224	8212126	3.6	385
55	692394	8210867	4.5	390
56	692604	8210190	2.5	381
57	692686	8209951	4	390
58	692780	8209754	4.5	377
59	692882	8209597	4.3	377
60	692978	8209453	5.1	380
61	693443	8208836	5.2	387
62	693633	8208633	5.8	386
63	694078	8208410	5.8	389
64	694911	8209248	5.3	381
65	695299	8209464	5.9	379
66	695650	8209395	6	377
67	695700	8209309	6.1	380
68	695754	8209251	6	376

n=68

APPENDIX B: Water wells, sandy reservoirs and natural pools data

S/N	X COORDINATES	Y COORDINATES	ELEVATION (M)	DESCRIPTION
1	687384	8210417	400	Sandy Reservoir
2	687462	8210609	403	Well
3	687636	8211707	400	Well
4	687653	8211723	398	Well
5	687768	8211751	399	Well
6	687941	8211753	398	Well
7	687982	8211742	397	Well
8	688247	8211852	401	Well
9	688287	8211869	400	Well
10	688521	8211955	398	Well
11	688645	8212005	397	Well
12	688965	8212179	397	Well
13	689159	8212272	399	Well
14	689518	8212366	395	Well
15	689519	8212383	396	Well
16	689671	8212371	397	Natural Pool
17	689847	8212339	396	Well
18	690565	8212268	390	Well
19	690595	8212226	393	Well
20	690611	8212261	392	Well
21	690763	8212273	393	Well
22	690866	8212289	394	Well
23	690884	8212263	394	Well
24	691036	8212296	395	Well
25	691042	8212287	392	Well
26	691121	8212359	391	Well
27	691274	8212386	390	Well
28	691424	8212472	394	Well
29	691458	8212499	396	Well
30	691485	8212509	389	Well
31	691498	8212496	391	Well
32	691613	8212461	388	Well
33	691708	8212429	393	Well
34	691766	8212435	391	Sandy Reservoir
35	691925	8212586	393	Well
36	691969	8212615	390	Well
37	692008	8212648	388	Well
38	692016	8212668	392	Well
39	692024	8212679	387	Well
40	692120	8212730	391	Well
41	692362	8212556	388	Natural Pool
42	692246	8212347	387	Sandy Reservoir

43	692224	8212126	385	Well
44	692459	8211567	386	Sandy Reservoir
45	692417	8210888	390	Natural Pool
46	692394	8210867	390	Well
47	692604	8210190	381	Well
48	692686	8209951	390	Sandy Reservoir
49	692780	8209754	377	Well
50	692882	8209597	377	Well
51	692978	8209453	380	Well
52	693443	8208836	387	Well
53	693633	8208633	386	Sandy Reservoir
54	694078	8208410	389	Well
55	694911	8209248	381	Well
56	695700	8209309	377	Well

Appendix C: SEMI-STRUCTURED INTERVIEW GUIDE FOR WATER-LINKED SECTORS

SEMI-STRUCTURED INTERVIEW GUIDE

Introduction to the Participants

My name is Nordoft Singubi, identity number 20019964; a Post Graduate Student doing Master of Science in Geography at the University of Zambia. I'm undertaking a research on the effects of sedimentation of the Lusitu River on water-linked sectors. The aim is to restore Lusitu River from sedimentation by coming up with catchment based integrated restoration measures. Information to be gathered in this research is purely for academic purpose. Names and identity of respondents will not be disclosed.

Respondent General Information

Name of village/ward: ………….……X Y coordinates: ………..............Serial No. …….

Sector: ………………………………. Gender: ………

DRIVERS OF SEDIMENTATION IN LUSITU RIVER CATCHMENT

1. Rank the following anthropogenic activities according to level of severity.

S/N	Drivers of Sedimentation	Rank of severity of drivers of sedimentation in Lusitu River catchment		
		Less Severe (1)	Moderately Severe (2)	Very Severe (3)
01	Charcoal burning			
02	Vegetation Clearance for new crop fields			
03	Dry season crop field preparation			
04	Intensive soil tillage farming e.g., Ox- drawn ploughing			
05	Animal grazing			
06	Riverbank gardening			
07	Sand mining			
08	Brick moulding			
09	Human induced soil erosion			

2. Give a brief explanation to your rankings.

....

3. What other causes of sedimentation are you aware of?

....

4. Give a historic description of Lusitu River flow before 1980.

....

5. In which year did Lusitu River stop flowing throughout the year?

....

6. In which month does the Lusitu River dry up? ....

EFFECTS OF LUSITU RIVER SEDIMENTATION ON WATER-LINKED SECTORS

Effects of Lusitu River Sedimentation on Buffer Zone Crop farming

1. What crops do you grow for home consumption?

   ....

2. What crops do you grow for sale?

   ....

3. What is your approximate income per month from the sale of your irrigated crops?

   ....

4. How many months in a year are you not able to grow irrigated crops along Lusitu River?

   ....

5. How is the drying of Lusitu River affecting you?

   ....

Effects of Lusitu River Sedimentation on Livestock Rearing

1. How many animals are you keeping by type?

   ....

2. What is the source of water for animal watering during the period Lusitu River dries up?

   ....

3. How is the drying up of Lusitu River affecting livestock farming?

   ....

Effects of Lusitu River Sedimentation on Rural Water availability and Supply

1. What are the sources of water for domestic use?

   ....

2. How long is the distance women cover to collect water for domestic use?

   ....

3. How much time do women spend to fetch water in a day (In June and October)?

   ....

4. How is the drying up of Lusitu River affecting water supply in your community?

   ....

Appendix D: SEMI-STRUCTURED INTERVIEW GUIDE FOR KEY INFORMANTS

1. How can we protect parts of the Lusitu River catchment which are less affected by deforestation?

....
....

2. How can we restore degraded parts of Lusitu River catchment?

....
....

3. Which stakeholders should be involved to successfully protect and restore Lusitu River from sedimentation?

....
....

4. What measures are there to effect statutory regulations on river protection and restoration, such as SI 1 of 2000?

....
....

Appendix E: FOCUS GROUP DISCUSSION GUIDE

MEASURES TO PROTECT AND RESTORE LUSITU RIVER FROM SEDIMENTATION

1. What local knowledge and practices (local initiatives) can help to protect parts of the Lusitu River catchment which are less affected by deforestation?

....

2. What local initiatives can help to restore parts of the Lusitu River catchment which are severely affected by deforestation?

....

3. What else should be done to protect Lusitu River catchment?

....

4. What else should be done to restore parts of the Lusitu River catchment which are severely affected by deforestation?

……………………………………………………………………………………………..

5. Who are the best players to ensure protection and restoration of Lusitu River?

....

Appendix F: Riverine Degradation Assessment Tool

S/N	LOCATION COORDINATES		OBSERVED DEGRADATION	VISUAL EVIDENCE	EXPERT DEGRADATION RANKING		PROPOSED NATURE-BASED INTERVENTION	
	X	Y			Extreme	4	Restore (1)	Protect (2)
					High	3		
					Moderate	2		
					Low	1		
					None	0		

Date: …………. Name of Catchment: …………………. Name of Assessor: ………………

Appendix G: Study Approval

THE UNIVERSITY OF ZAMBIA
DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777
Fax: (+260)-211-290 258/253 952 | **E-mail**: director.drgs@unza.zm | Website: www.unza.zm

APPROVAL OF STUDY

IORG No. 0005376
NASRECREC IRB No. 00006465

16th January, 2023

REF NO. NASREC-2023-JAN. -006

Mr. Nordoft Singubi
The University of Zambia,
IDE,
P.O. Box 32379,
LUSAKA.

Dear Mr. Singubi,

RE: "EFFECTS OF SEDIMENTATION ON WATER LINKED SECTORS IN THE LUSITU RIVER CATCHMENT IN SOUTHERN ZAMBIA"

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	**ORDINARY REVIEW**	**APPROVAL NO. NASREC-2023-JAN. 006**
Approval and Expiry Date	Approval Date: 16th January, 2023	Expiry Date: 15th January, 2024
Protocol Version and Date	Version - Nil.	15th January,2024
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Semi-Structured Interview Guide.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

CONDITIONS OF APPROVAL

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.

- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.

- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.

- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.

- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.

- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.

- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.

- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.

- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC

- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.

- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.

- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.

- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. Mususu Kaonda

VICE-CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies