SEDIMENTATION AND ITS EFFECTS ON SELECTED SMALL DAMS IN LUSAKA PROVINCE, ZAMBIA

By

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DECLARATION

I, **Chomba Innocent Chomba,** hereby do declare that all the work done in this study originates from my own work and it has not previously been submitted for a degree or other qualification at this or another University. All secondary sources referred to in this work have been duly acknowledged. Therefore, this dissertation is submitted in partial fulfilment of an award of the degree of Master of Science in Environmental and Natural Resources Management of The University of Zambia.

Signature: ___________ **Date**: 12/01/2017.

CERTIFICATE OF APPROVAL

This dissertation of **Chomba Innocent Chomba** has been approved as partial fulfilment of the requirements for the award of Master of Science Degree in Environmental and Natural Resources Management by the University of Zambia.

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ABSTRACT

In Zambia, the need to conserve water resources through technologies that can easily be managed by the local communities has resulted in the construction of small dams. However, small dams are adversely impacted by sedimentation due to soil erosion in the catchment area. The aim of this study was to assess the water storage capacity loss for the selected small dams due to sedimentation in Lusaka Province. The studied small dams were; Lwiimba, Silverest, Morester and Katondwe dam. Data was collected by bathymetric survey for each small dam using hydrographic boat with echo sounding. The shape and area of each reservoir were determined by mapping reservoir perimeter with a boat equipped with DGPS, by taking several position points along the shore line. The initial storage capacity data were collected from the dam owners and through interviews with three key informants on the effects of sedimentation on dam uses and on the existence of sediment control measures. Analysis of data involved determination of reservoir surface area and storage capacities using the Area and Volume tool under ArcGIS 3-D Spatial Analyst. The deposited sediment volume was estimated by subtracting the measured storage capacities from the initial storage capacities of reservoirs. Thematic analysis was applied in analysing the effects of sedimentation on dam uses and the existence of sediment control measures. Results of the study revealed that the measured reservoir storage capacities for Lwiimba, Silverest, Morester and Katondwe dams were 101,051.43 m^3, 368,331.5 m^3, 14,724.32 m^3 and 10,714.88 m^3, respectively. The estimated sediment volumes equivalent to storage capacity loss for each dam were; Lwiimba (99,044.57 m^3), Silverest (379,480.5 m^3), Morester (13,805.68 m^3) and Katondwe dam with 9,937.12 m^3.The accumulation of these sediment volumes have led to capacity losses, drying of reservoirs especially in the dry season and reduced life spans of the dams. The estimated rates of sedimentation for Silverest dam was found to be 14,595.40 m^3yr^{-1}. At this rate, the reservoir lifespan was 26 years; Lwiimba (2,200.99 m^3yr^{-1}), with the lifespan of 46 years; Katondwe (283.92 m^3yr^{-1}), 38 years, and for Morester dam the rate was 251.01 m^3yr^{-1} giving a lifespan of about 58 years. Natural vegetation cover was found to be the main sediment control measure used in the catchments to reduce sediment deposition by runoff. It is concluded that the studied small dams are seriously affected by high rates of sedimentation from the time of their construction. This calls for periodic dredging of deposited sediment in small dams in order to increase reservoir storage capacity for sustainable use of the water resources. More sedimentation studies need to be conducted in Zambia.

DEDICATION

To the Sacred Heart of Jesus Christ. To my Parents Fredrick and Dorothy Chomba, who taught me to always work hard, strive courageously and have unceasing faith in God. To my dearest wife, Aaliyah Phelire Chomba, you are loved and appreciated. To my sister and brothers, may this work inspire you to reach for greater zeniths in all that you do for the greater Glory of God.

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Glory be to God! 'You are my God, and I give you thanks...complete the work that you have begun in me.' ***Psalms 118:28., 138:8.***

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ABBREVIATIONS/ACRONYMS

CNVP	Connecting Natural Value and People
CSO	Central Statistical Office
DWA	Department of Water Affairs
GIS	Geographical Information System
GRZ	Government of Republic of Zambia
ICOLD	International Committee on Large Dams
IPCC	Intergovernmental Panel on Climate Change
NBCBN	Nile Basin Capacity Building Network
SASSCAL	Southern African Science Service Centre for Climate Change and Landuse Management
UNEP	United Nations Environment Programme
WHO	World Health Organisation
ZAWEFA	Zambia Water Forum and Exhibition

CHAPTER ONE: INTRODUCTION

1.1 Background

Small dams are important for communities as the impounded water is used for various purposes including flood control, domestic supply, crops, animal drinking and recreation. The progressive loss of water-storage capacity resulting from sedimentation in dam reservoirs, coupled with increasing societal water demand, negatively affect environmental, social and economic benefits of small dams (Ainworth, 2005). Globally, there is evidence of steady rise in siltation in reservoirs, endangering reservoir projects which cause doubts about the viability of existing and future reservoirs (Shukla, *et al.*, 2012). The impoundment of water for irrigation, domestic and flood control is a necessary step towards socio-economic development. However, reduction in the storage capacity of a reservoir by sedimentation beyond a limit hampers the purpose for which the dam was constructed. Thus, assessment of sedimentation becomes very important for the management and operation of such reservoirs.

Reservoir sedimentation is a common problem in many parts of the world. It is reported that annually, an average of 0.5–1% of volume capacities of small and large reservoirs is lost because of sedimentation (Shavkat *et al*., 2011). Sedimentation is the process which fills up natural lakes and man-made reservoirs by sediment through the process of deposition and compaction (Kerr, 1995). In most developing countries, where sediment management measures are not carried out effectively, reservoir sedimentation is argued to be much higher. Storage loss is but one of the many sedimentation problems that affect reservoirs. Schleiss (2013) is of the view that neither current nor projected levels of population and economic activity can be sustained if today's inventory of storage reservoirs is lost due to sedimentation. As population and economic activities grow, reliance on the services provided by dams is increasing. Loss of the world's reservoir capacity can be a catastrophy of unprecedented magnitude, yet their gradual loss due to sedimentation receives little attention or corrective action due to high cost of dredging operations.

In Zambia, land degradation in different parts of the country is a major problem and is accelerating soil erosion such that mobilised soil particles end up in water bodies. It is argued that many of the dams constructed in Zambia in the 1950s and 1960s are today silted up and need to be dredged (Sichingabula, 1997). This implies that if sedimentation is not checked, the usefulness of small dams in future will be much lower than at present. This study focused on assessing the dams' storage capacity loss due to sedimentation and its effects on the usefulness of small dams in Lusaka Province.

1.2 Problem statement

In most developing countries like Zambia, the need to conserve water resources through technologies that can easily be managed by the local communities has resulted in the construction of small dams. These dams were constructed by the government or by the local communities themselves or by individuals, as sources of water for the development of irrigated crop farming, for livestock and domestic use. However, the development of small dams is vulnerable to sedimentation. Sedimentation process is one of the most important problems that affect directly the performance of reservoirs due to the reduction of the storage capacity. Sedimentation is a single process that all reservoirs worldwide share in common, to differing degrees due to the natural process of erosion in catchment areas. However, it has to be pointed out that though erosion is a natural process, it is speeded up by anthropogenic activities. The main anthropogenic activities increasing sediment supply to water bodies include; changes in land use in catchment areas; increased areas of sedentary agriculture and deforestation leading to greater areas of bare soils susceptible to erosion Sichingabula *et al* (2000). Sichingabula (1997) highlighted the seriousness of soil erosion and sedimentation in small dams in Southern Province and in some parts of Lusaka Province. He reported that this was due to increased human and cattle populations and the existence of large cultivated areas in catchment areas. The problem is that in Lusaka Province, there has been limited research done on current storage capacities of small dams and the effects of sedimentation on the usefulness of these dams. This is because dams dry during dry season partly due to sediment accumulation. In this study a new method of collecting bathymetric data in Zambia was used using a hydrographic eco sounding survey boat which allowed for quick and accurate estimation of storage capacity and sedimentation assessment.

1.3 Aim

The aim of this study was to assess the water storage capacity loss for selected small dams due to sedimentation and its effects on dam usage in Lusaka Province.

1.4 Objectives

The objectives were fourfold.

1. To determine the current water storage capacities of small dams.
2. To determine the volume of deposited sediment in small dams.
3. To establish the effects of sedimentation on the uses of small dams.
4. To evaluate sediment control measures undertaken for small dams in catchment areas.

1.5 Research Questions

The following four questions guided this study.

1. What is the current water storage capacity of the small dams?
2. What is the volume of deposited sediment in small dams?
3. What are the effects of sedimentation on the uses of small dams?
4. What sediment control measures exist for small dams in catchment areas?

1.6 Significance of the Study

This research has highlighted the effects of sedimentation on the selected small dams East of Lusaka. This study has also provided the rates of sedimentation for the studied small dams in Lusaka Province. Additionally, it has estimated the volumes of deposited sediment. This information can be used in planning for dredging of these dams and in understanding why small dams are drying out just after the rain season. This study is also a valuable source of baseline data for future sediment related research on small dams in Lusaka Province in particular and in Zambia general. It is hoped that the findings of this study will bring to light the need for capacity building on sediment abatement and monitoring in the management of water resources.

1.7 Limitations of the study

Lack of adequate baseline data on bathymetric and reservoir sedimentation in Lusaka Province for small dams was a problem in estimating deposited sediment. This also limited the spatial distribution of the small dams that were studied because only those dams that had initial storage capacity data were selected for the investigation. This did not affect the scope of the study and the problem investigated.

1.8 Organisation of the dissertation

This dissertation consists of six chapters. The first chapter provides the background and problem statement. It also outlines the aim, specific objectives, research questions, significance of the study and the limitations. Chapter Two reviews literature while Chapter Three geographically describes the study area, Lusaka Province. Chapter Four presents the methodology in terms of data collection and analysis that were used. Chapter Five outlines the study findings and discussion of results. Chapter Six presents the conclusion and recommendations. Finally, this dissertation ends with References and Appendices.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature on sediment studies and sedimentation of reservoirs in different parts of the world including Zambia. The main focus is on sedimentation of reservoirs in general and how it affects water resources.

2.2 The Role of Small Dams in Water Resources Development

A small dam is an impoundment of water by a barrier constructed across a natural stream or surface run-off. A small dam has height measured from lowest point of natural ground level being less than 15 meters and does not cause significant damage in life and properties to downstream environment in case of breach (NBCBN, 2005). The multiple uses of small reservoirs cannot be underestimated. They contribute significantly to ensuring reliable domestic water supply and livestock watering, small scale irrigation, and regulate seasonal flows to provide reliable flows all-year round. Small reservoirs also directly support local and commercial community initiatives to safeguard against water scarcity due to drought so that small holder farmers can realize the ultimate goals of increased production of food, reduced poverty, and improved rural livelihoods (Van de Giesen, 2007). In a study carried out in Zimbabwe on small dams, it was observed that people living in arid areas with highly variable rainfall, experience droughts and floods and often have insecure livelihoods. As such small dams are widely used for water storage and provision of water services to the communities with multiple uses such as domestic use, livestock watering, small scale irrigation, brick making and supporting wild life (Senzanje, 2006). Similarly, in Brazil's Preto River Basin it was found that small reservoirs play very important roles especially for rural community livelihoods. Small reservoirs provide a year round supply of water allowing small farmers to irrigate their crops during the wet and dry seasons and this supports a critical livelihood strategy of market oriented crop production (Balazs, 2006).

In Zambia, the government recognises that dams have important functions of sustaining livelihoods of local communities through multiple uses such as: (i) enhanced domestic water security, (ii) increased agriculture yields of smallholder farming, (ii) fish farming opportunities, (iv) water for livestock and (v) several water dependent activities such as tree growing to mention but a few. They are also beneficial instruments for climate change adaptation through impact attenuation (GRZ, 2010). In addition, the GRZ recognises that effective development of the nation's water resources is fundamental to its economic growth and poverty reduction, especially in rural areas.

2.3 Sediment Generation and Transportation in a Fluvial System

Reservoir sedimentation begins with runoff and soil erosion. Magnus and Magnus (1999) state that erosion is a natural process which takes place in all fluvial systems. Erosion processes and sediment delivery form an integral part of aquatic systems, influencing their geomorphology, habitat distribution and water quality. Sediments are loose particles of clay, silt, sand, soil or other solid substance, which when transported and deposited into reservoirs, result into sedimentation (Kerr, 1995). Sediment delivered to reservoirs originates from a number of upstream primary and secondary sediment sources, including cultivated fields and stream bank erosion (Collins *et al.,* 1997). However, it has to be pointed out that though erosion is a natural process, it is speeded up by human activities. The main anthropogenic activities increasing sediment supply to water bodies include; changes in land use in catchment areas; increased areas of sedentary cultivation; deforestation in the catchment area leading to greater areas of bare exposed soil susceptible to erosion and increased bank erosion due to loss of natural hydrology (Greig *et al.*, 2005).

Tarbuck and Lutgens (2000) are of the view that the sediment in a fluvial system are transported in three broad ways: in solution (dissolved load), in suspension (suspended load) and scooting or rolling along the bottom (bed load). It is worth noting that sediment transport in a fluvial system varies with discharge over time and in space within a stream network. Sediment transport is controlled by the rate of entrainment, the amount of sediment available for transport in a reach and by the transport length of individual particles (Kerr, 1995). The rate of entrainment and availability of sediments in a reach are controlled by factors such as the number of particles in a reach, particle size, the packing of particles on the stream bed, and the distribution of the velocity field over the stream bed (David *et al.,* 2003).

In a study of suspended sediment transport in two major rivers in Zambia, Sichingabula (1996) stated that the Kafue and Luangwa rivers transported a total of 908,700 tonnes and 24.5–25.6 million metric tonnes of suspended sediment, respectively. Walling (2009) argues that the magnitudes of the sediment loads transported by streams have important implications for the functioning of the earth system. High sediment loads can, in particular, result in major problems for water resource development, through reservoir sedimentation and the siltation of water diversion and irrigation schemes, as well as increasing the cost of treating water abstracted from a river. High sediment inputs into lakes and coastal seas can result in sedimentation and changes in nutrient cycling. Furthermore, high sediment loads can result in pollution and habitat degradation in river systems. Rachold *et al* (1996) in their study of Lena River found that the total annual water discharge and sediment transport by Lena River accounted for 700 km^3 and 27 x 10^6 tonnes, respectively. The specific sediment discharge of the river basins varied between 5 and 100 tons per km^2**.** It was concluded that the material transport of Lena River strongly influences the sedimentation in the Laptev reservoirs and the Arctic Ocean.

In Zambia, the studies conducted by Sichingabula *et al*. (2000) in the Upper Kaleya River of Southern Province, estimated that the daily suspended sediment loads in the catchment ranged from 0 to 253.9 tonnes, with a daily mean of 3.15 tonnes. Most of this sediment load was transported during flood events, which occurred in a few days of each year. The highest flood during the study period had a peak discharge of 3.65 m^3s^{-1}. It was reported that this event alone transported 111.9 tonnes of suspended sediment. Over the duration of the study period, the total cumulative discharge was estimated at 34.8 million m^3, whilst the corresponding total suspended sediment load was estimated at 3,130 tonnes. It was concluded that, the Upper Kaleya River, though small in size, was characterized by reasonably high discharges and suspended sediment loads.

2.4 Reservoir Deposition and Sedimentation

As earlier stated, sedimentation is a single process that all reservoirs worldwide share in common, to varying degrees. Whenever a stream slows down, its competence is reduced and the sediment begins to drop out, largest particles first in a process called sorting. Each particle size has a critical settling velocity. As stream flow drops below the critical settling velocity of certain size, sediment in that category begins to settle out (Tarbuck and Lutgens, 2000). As stated above, when a dam is built and a reservoir forms, the stream's base level is raised. This reduces the stream's velocity and leads to deposition (CNVP Foundation, 2013; Tarbuck and Lutgens, 2000). After the sediment is trapped in the reservoir, it will be compacted through time by its own weight and the weight of the overlying water. During this time there is a process of consolidation and compaction of the sediment (CNVP Foundation, 2013). The main environmental factors affecting the sediments yield at the catchment area are; precipitation (quantity, intensity and frequency); type of soil and soil vegetation coverage; soil management (cultivation practices, grazing grass, forest exploitation, building activities and conservation measures); the nature of the drainage network (density, slope, shape, size and channels configuration) and surface runoff (ICOLD, 1989).

Kerr (1995) consolidation is an important phenomenon in the sedimentation process. Two types of consolidation are usually considered: primary and secondary. Primary consolidation is caused by the self-weight of sediment, as well as the deposition of additional materials. Primary consolidation begins when the self-weight of the sediment exceeds the seepage force induced by the upward flow of pore water from the underlying sediment. During this stage, the self-weight of the particles expels the pore water and forces the particles closer together. The seepage force lessens as the bed continues to undergo self-weight consolidation. Primary consolidation ends when the seepage force has completely dissipated. Secondary consolidation is caused by the plastic deformation of the bed under a constant overburden. Secondary consolidation begins during the primary consolidation and may last for weeks or months. However, it should be highlighted that the uncertainty of reservoir sedimentation do exists due to a number of factors such as sediment inflow into the reservoir, water discharge, and the type of sediment. These factors contribute to the uncertainty in (1) the amount of sediment that is deposited in the reservoir on a yearly basis; (2) the accumulated sediment in the reservoir over a number of years of reservoir operation; and (3) the time it will take for the accumulation of a certain amount of sediment in the reservoir (CNVP Foundation, 2013).

Schleiss (2013) argues that most natural stream reaches are approximately balanced with respect to sediment inflow and outflow. Hence, dam construction dramatically alters this balance, creating an impounded river reach characterized by extremely low flow velocities and efficient sediment trapping. The impounded reach will thus accumulate sediment and lose storage capacity until a balance is again achieved, which would normally occur after the impoundment has become filled up with sediment and can no longer provide water storage and other benefits. Declining storage reduces and eventually eliminates the capacity for flow regulation and with it all water supply and flood control benefits, plus those recreation, and environmental benefits (Graf, 1984; ICOLD, 1989).

2.5 Effects of Sedimentation in Reservoirs

According to Ainworth (2005) loss of storage due to sedimentation exacerbates the problem of providing enough storage for the rising population with its rising aspirations and standards. The report states that demand for additional storage was assumed to be 1.6 percent in 2000 and fell to 1.2 percent in 2030. The analysis showed that South America, Africa and Asia water storage demands would outstrip supply in the foreseeable future and the storage shortage was attributed to high sedimentation rates in these regions. In another study, Chao (2004) observes that sedimentation problems are a matter of global concern as they include issues arising from erosion, desertification, sediment yield, transport and deposition in reservoirs and lakes. The study findings showed that about 0.5 to 1 percent of the precious storage capacity of the world's reservoirs is annually lost due to river-related sedimentation with more floods and droughts induced and leading to deteriorated ecosystems as a result.

In another study, Hargrove (2008) states that The United States government made significant investments in building reservoirs in the 1950s and 1960s, which changed much of the rural environment in Kansas. Although many reservoirs were built with a projected lifespan of 150 to 200 years, current projections indicate these lifespan could be cut short by 50 to 100 years due to sedimentation. DeNyelles and Jakubuskas (2008) further state that more than 300,000 acres of public and private reservoirs constructed in Kansas during the past century are steadily filling with sediments. Sedimentation is said not only to be reducing water-storage capacity of these reservoirs, but deposited sediments containing nutrients, trace metals, and other compounds are significantly affecting reservoir water quality. Sichingabula (1999) argues that sedimentation creates a number of water quality problems. This is because sediment pollution of streams and lakes tend to increase the expenses of treating water for municipality and industrial uses.

There are a number of direct and indirect consequences of reservoir sedimentation on environment with the loss of water resources being the most obvious consequence. According to Halcrow (2001), there are both positive and negative impacts of reservoir sedimentation. The positive impacts include; generation of valuable wetland habitat with biological diversity, reduction of fine sediment discharge and hence improved water quality. Further, there is an opportunity for uses of sediment deposits in substitution of other peat based compost (manure) and finally the control on the use of reservoir catchments may significantly benefit the environment.

Onwuegbunam *et al.* (2009) report of a study conducted in 2009 on a small reservoir constructed in 1987 at the Afaka Forest Reserve in Kaduna State in Nigeria. The study findings showed that about 35 percent of the reservoir storage capacity was covered with sediments within a period of 26 years, which was a serious problem that was undermining water uses of the dam. It was further ascertained that there were several similar small-dams within Kaduna State, some of which were almost completely silted. Meanwhile, Rooseboom and Lotriet (1992) reported that reservoir sedimentation was an increasing problem in the management of Southern African water resources. They highlighted that Welbeck reservoir in South Africa completed in 1973 lost most of its storage capacity (66%) within the first 13 years of its existence due to sedimentation. In Zimbabwe, Magnus and Magnus (1999) reports that water resources in Zimbabwe are a matter of national concern. The main concern in Zimbabwe is mainly on how to supply the farming areas with water for irrigation purposes and domestic use. Since Zimbabwe's economy is agro-based water resources are key for sustainable development. They further went on to state that several countries in Southern Africa are likely to face inadequate freshwater supplies within 30 years and Zimbabwe is one country that would face serious water shortages. Zimbabwe lacks natural lakes as well as large quantities of ground water. Therefore, around 8000 dams of different sizes have been built in order to store water. However, siltation processes, due to large sediment transport in fluvial systems, have rapidly reduced the storage capacity of water reservoirs in several dams in Zimbabwe with negative impacts on farming communities that depend on them. It is estimated that in Zimbabwe, smaller dams lose up to half their storage capacity within 20 years.

In northern Ethiopia, a study was conducted on the volume of sediment deposited in two small dams, Filiglig and Grashito. The result indicates that, the volumes of sediment depositions in the reservoirs were 13,856 m^3 and 23,974 m^3 for Filiglig and Grashito reservoirs, respectively. The annual rate of sedimentation of Filiglig and Grashito reservoirs were found to be 6,928 $m^3\ yr^{-1}$ and 11,987 m^3yr^{-1}, respectively. In Malawi, a study to investigate the impact of sedimentation on water availability in Chamakala small dam revealed that the annual rate of sedimentation in the dam was 2,250 $m^3\ yr^{-1}$. The assessment showed that if no appropriate measures were put in place to arrest the rate of sediment deposition, the dam would continue losing its capacity thereby leaving a growing human population and livestock with no water for the most part of the year as the dam dried out a few months after the rain season (Kamutukule, 2008).

Meanwhile in Zambia the Department of Agriculture have documented that small dams are losing storage capacity due to sedimentation (Sichingabula, 1997). However, data on an inventory of small dams, the current storage capacity of small dams and the status of sedimentation in small dams in Zambia is inadequate and for most small dams it is non-existent. Sichingabula (1997) in his investigation of dams in Southern Province argued that sedimentation in small dams was serious and needed further research. It was further argued that human activities and lack of soil conservation practices in catchment areas contributed to soil erosion and silting-up of many small dams in the Southern Province and other parts of Zambia.

2.6 Techniques of Sediment Removal from Reservoirs

According to Brabben (1988), there are a number of practical means of removing sediments from reservoirs such as hydraulic methods by flushing as well as mechanical methods such as dredging, excavation and siphoning. Sediment removal methods depend on the reservoir characteristics and quality of the sediments and as such, sediment may be removed from the shore or from a boat. Since some dredging techniques have a disadvantage in that they may increase turbidity and cause water quality problems, hydraulic methods or mechanical excavation methods that usually require the reservoir level to be lowered or by-passed and emptied are more preferred (Brabben, 1988). An example is given of Dashidaira Dam in Japan by Kashiwai (2002) which had a major inflow of sediment during 1995 but subsequent flushing resulted in the reduction of sediment volume stored in the reservoir by approximately 40 percent. Kashiwai (2002) outlines five methods used in Japan to mitigate sedimentation in reservoirs. The five methods are; sediment flushing, sediment bypassing, excavation and dredging, discharging turbid water and reservoir emptying. However, most of these methods may be very costly in other circumstances so proper assessment should be made before a particular method is applied (Ainsworth, 2005).

2.7 Methods for estimation of small dam storage capacity

To calculate the volume of water contained in a reservoir requires estimating the shape of the reservoir as close as possible. This is not easy as the reservoir is usually irregular both in cross and long sections. In many cases small dams are designed without carrying out a full topographic survey and the storage volume is estimated based on the formulae were the reservoir width, the throwback, and maximum impounded water depth are measured. Several formulae methods are used for estimating small reservoir storage capacities. The formulas are based on the equation below, with different values for the two constants (Sawunyama, 2005).

$C=K_1*K_2D*W*T$...*Equation 1*

Where:

K_1 = a constant.

K_2 = second constant related to the shape of the valley cross-section.

D = the maximum water depth.

W = the width of water surface at the dam at the spillway crest level.

T= the "throwback" at the spillway crest level (the throwback is the distance from the dam wall along the reservoir axis usually to the point where river enters.

However, the formulae methods are not quite accurate as they are based on quick surveys. A more accurate method of estimating capacity would be to consider area enclosed by contours at appropriate intervals by conducting bathymetric survey (Lawrence and Lo Cascio, 2004). Using this method the actual storage capacities of reservoirs are calculated using echo-sounding traverses. Data obtained are used in special computer software to construct the bathymetric maps and calculate the existing storage volume. The volume between two successive contours can then be calculated and these volumes are then summed up to get the total storage capacity of the dam (Sawunyama, 2005).

Besides the above mentioned methods there also exist indirect methods used to estimate surface areas from topographical maps or satellite images, from which a power relationship between surface area and capacity of a reservoir is used to estimate reservoir capacity. For example, Meigh (1995) used 1:50 000 topographic maps to estimate surface areas of the small farm reservoirs in determining the impact of small farm reservoirs on urban water supplies in Botswana. He cautioned that area estimated from the maps would be poor measures of the actual area because the aerial photography on which the maps are based was unlikely to correspond to the times when the reservoirs are full, and because some of the reservoirs were so small that they may not be representative of the actual areas of the reservoirs. Another study carried in Ghana by Liebe (2002) on the use of remote sensing data to estimate reservoir storage capacities for small reservoirs indicated that there exist relationships among area, depth and volume for the small reservoirs. In the study a relationship was established to estimate small reservoir capacities using remotely sensed surface areas and storage volumes in savannah climates. The model uses Geographical Information System and Remote Sensing in the estimation of area and volumes of reservoirs. Such a model does not currently exist in Zambia for use on small reservoirs.

While so many studies have been done in other countries on sedimentation in reservoir, there is limited data on the effects sedimentation in reservoirs in Zambia and in Lusaka Province in particular despite having so many small dams. Thus, this study endeavored to assess the storage capacity losses of the studied small dams due to sedimentation and the effects this has on the usage of small dams. It further looked at the volume of deposited sediments and the rates of sedimentation per year.

CHAPTER THREE: STUDY AREA

3.1 Location

This study was carried out on four small dams known by their owners or place name, namely; Lwiimba in Chongwe District, Silverest in Lusaka District, Morester in Chongwe District and Katondwe in Luangwa District, located in Lusaka Province (Figure 3.1). Lusaka lies between latitudinal 14°40’’South to 16^{o} 00’’South and longitudes 27^{o} 45’’East to 30^{o} 26 ‘’East. The approximate size of Lusaka Province is 21,896 km^2 (Chileshe, 2004).

3.2 Physical characteristics

3.2.1Climate

Lusaka Province exhibits a tropical continental type of climate with three distinct seasons: a dry cool season lasting from mid April to Mid August; a hot dry season lasting from mid - August to October and hot rainy season lasting from mid-November to early April. Relief has a strong influence on climatic patterns of the province. The plateau areas have higher rainfall (800 –1200 mm) and lower temperatures than the Luangwa and Zambezi rift troughs where the average altitude is 650 mm in Agro-Ecological Region I (AERI)being in a low rainfall belt of less than 800 mm. The AER cover much of the valley areas while AER II covers much of the plateau areas lying at higher elevation. Over the period of a year, potential evaporation exceeds actual rainfall in Lusaka Province. The average rainfall around Katondwe dam is 350 mm, while for Silverest, Lwiimba and Morester dams the average rainfall is 600 mm (Chileshe, 2004). This level of rainfall has important effects on available water that can be harnessed in small dam reservoirs for agricultural and other uses.

3.2.2 Geomorphology

The physiography of Lusaka Province ranges from Luangwa Hills of Luangwa district, Lunsemfwa-Lukusashi Valley of Rufunsa and Chongwe districts, Kafue Basin of Kafue district and the Central Plateau of Lusaka. The best known karst features in the province are those located around Lusaka urban district where both pinnacled and buried karst types are found. In these areas streams and valleys are generally absent and the drainage is poorly developed (Dalal-Clayton, 1985). To the east of Kafue town the Kafue River cut a gorge through a massif of ancient metamorphic rocks. The eastern part of the province is an area of upland, with hilltop elevations rising in excess of 900 m above mean sea level (masl), dropping down to the main stream and river valley floors with elevations ranging from 650 m to 540 m (Dalal-Clayton, 1985).

3.2.3 Hydrology

Surface water drainage system constitutes less than one percent of the total land mass of Lusaka Province and is represented largely by the three major rivers in the country, the Kafue and Zambezi running through the Kafue district and the Luangwa through Luangwa district. The Province also has about forty small dams (Sichingabula *et al.,* 2014). The major drainage catchments for Lusaka Province include the Zambezi, Luangwa, Chongwe, Kafue and Chalimbana catchments (Figure 3.1). The geomorphology of Lusaka Province has a major influence on the sitting of small dams and hence the sparse distribution of dams in the Province. For instance, the eastern part of the Province is largely hills and not quite suitable for construction of small dams due to high potential for erosion and sedimentation.

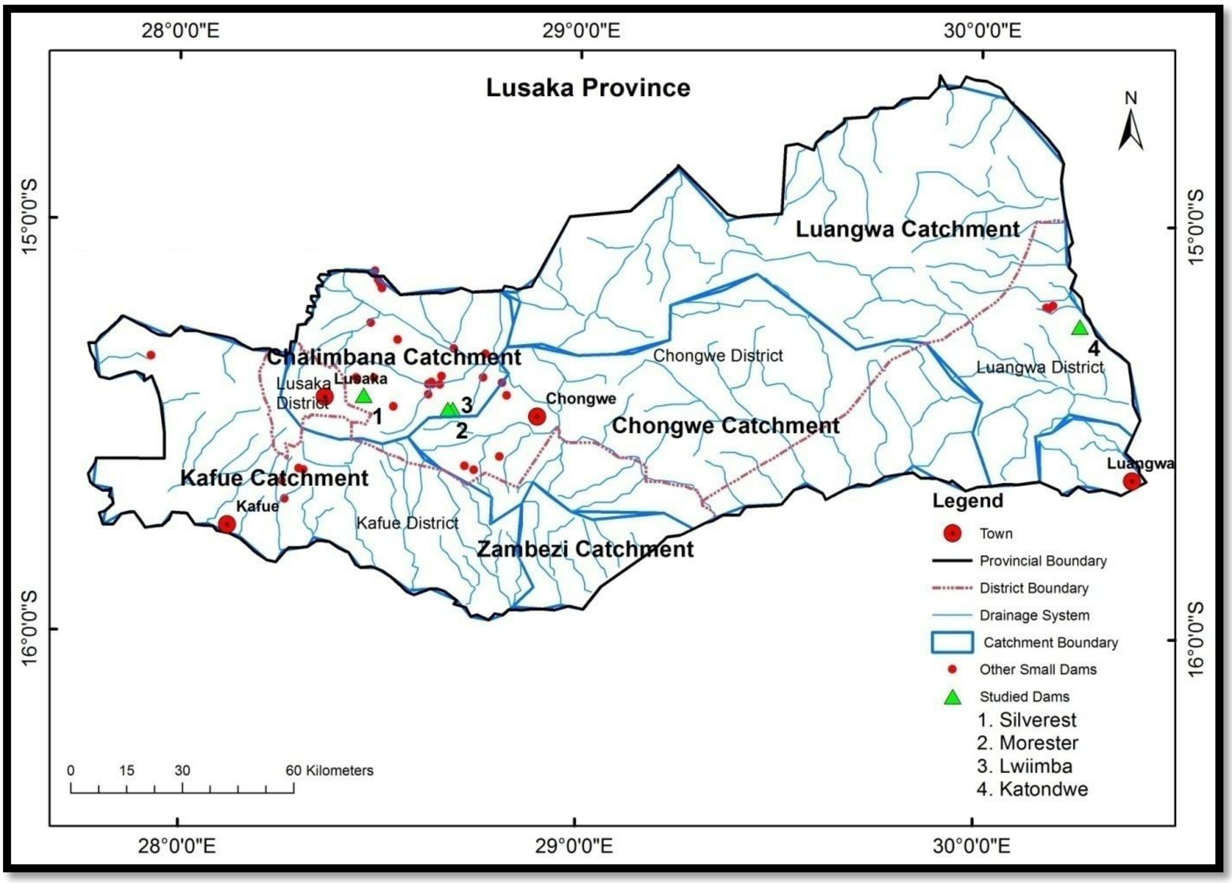


Figure 3.1: The drainage system of Lusaka Province, places and spatial distribution of existing small dams.

3.2.4 Soils

The most dominant soils in Lusaka Province are Ferric, Luvisols and Ferric/Orthicacrisols. Eutirc Nitosols are also widespread though very scattered. Lithosols also form a considerable unit in the Province (Magai, 1985). Limitations of these soils include poor workability due to clayey topsoil, which is difficult to till; soil depth which is occasionally limited by bedrock and soil erosion which may occur as gully erosion. Soil erosion and runoff processes in the catchment of small dams are the main causes of sedimentation (Magai, 1985).

3.2.5 Forest Resources

Forests are widespread in the province and the main vegetation types are Miombo and Mopane woodlansds. The plateau miombo woodlands have been extensively used for cultivation and currently about 70 percent of the total cultivated land in Lusaka Province is in the plateau woodlands. The remaining 24 Percent is found in the escarpment and valley regions of the province (Chileshe, 2004). The clearing of forest for agriculture, settlements and charcoal production contributes to soil erosion in the catchment of small dams which leads to siltation of small dam reservoirs (Sichingabula, 1997).

3.3 Socio-Economic Characteristics

This section outlines the socio-economic aspects of the study area.

3.3.1 Population

According to CSO (2012), in Lusaka Province the population in 2010 was 2,191,225 representing an increase of 57.5 percent from the population of 1,391,329 in 2000. The population in rural areas increased from 258,327 in 2000, to 336,318 in 2010, representing an increase of 30.2 percent between the two censuses. The population in urban areas grew by 63.7 percent from 1,133,002 in 2000 to 1,854,907 in the 2010. Overall, the population of Lusaka Province grew at an average rate of 4.6 percent per annum during the period 2000-2010. Lusaka District was the fastest growing district with an annual rate of population growth of 4.9 percent, followed by Kafue District at 4.2 percent and Chongwe District at 3.4 percent. Luangwa District had the lowest annual rate of population growth at 2.5 percent per annum. According to CSO (2016) the projected population in 2016 of Lusaka Province was 2,888,575 representing an increase of 24.14 percent from the population of 2,191,225 in 2010.

3.3.2 Agricultural Production

Agriculture production of both crop (maize, groundnuts and soya beans) and livestock (cattle, chicken, pigs and goats) production is undertaken at subsistence and commercial levels. Agricultural land is able to produce more crops and support livestock over and above the current levels of production (Chileshe, 2004). In many areas, small dams are being used for irrigation, livestock and domestic water supply.

3.3.3 Fishing

Fishing is also another significant part of the economy in Lusaka districts. The major fisheries are in Kafue and Luangwa districts (Chileshe, 2004). The small dams to some extent are also being used for fishing, but their potential is yet to be fully realised in the province.

3.4 Study Sites

Lwiimba dam (Figure 3.2a) is located at latitude 15°46’ 14.68’’ and longitude 28°68’ 54.53’’ at an elevation of 1108. 25 masl. The main source of water that feeds the dam is kalanga stream. Lwiimba dam is mainly used for livestock. Within 50 meters of the dam, Lwiimba had about 45 percent of vegetation cover. Silverest dam (Figure 3.2a) is located at latitude 15°25’ 37.27’’ and Longitude 28°27’ 50. 23’’ at an elevation of 1191.07 masl. The surface runoff is the main source of water that feed the dam. Silverest dam is mainly used for irrigation and livestock. Within 50 meters of the dam, Silverest had about 60 percent of vegetation cover. Morester dam (Figure 3.2c) is located at latitude 15°27’ 40.35’’ and longitude 28°40’ 20.57’’ at an elevation of 1118.06 masl. The main source of water that feeds the dam is a stream called kalanga. Morester dam is mainly used for water livestock. Within 50 meters of the dam, Morester had about 55 percent of vegetation cover. Katondwe dam (Figure 3.2d) is located at latitude 15°24’ 36.12’’ and longitude 30°25’ 27. 25’’ at an elevation of 357 masl. The main source of water that feeds the dam is a Katondwe stream. Katondwe dam is mainly used for water supply for Katondwe hospital and Katondwe School. Within 50 meters of the dam, Katondwe had about 90 percent of vegetation cover.

(a)

(b)

(c)

(d)

Figure 3.2: (a) Lwiimba dam (b) Silverest dam (c) Morester dam (d) Katondwe dam.(Source: Field data,2015).

CHAPTER 4: METHODOLOGY

This chapter describes the methodology used for this study in data collection and analysis.

4.1 Research Design

A case study research design was used for this study. Four (4) case studies of small dam were purposively selected for the study in Lusaka Province because they had the initial storage capacity data required for assessment of loss of reservoir capacity. The dams were Lwiimba, Silverest, Morester and Katondwe. Information on the original reservoir capacity was required as a benchmark against which the water storage capacity loss and sediment volumes can be estimated and computed for bathymetric and sedimentation survey (Rausch & Heinemann, 1984).

4.2 Data Collection

This section highlights the types of data and the methods of data collection used for the bathymetric surveys, sediment control measures and water quality determination.

4.2.1 Types of Data

The types of data collected are grouped into primary and secondary data. The primary data collection methods used were; field observations, bathymetric surveys, key informant interviews as detailed below.

4.2.2 Field Observations.

Field observations included bathymetric measurements of dam reservoir depths, and photographs of dams were also collected (Figure 4.1a).

4.2.2.1 Bathymetric Surveys

Bathymetric surveys were conducted from 24th February, to 12th March, 2015 when the small dams were at full supply level and water was spilling over the crest spillway. These surveys were conducted when dams were at full capacity because that’s when the current storage capacity could be accurately estimated. A hydrographic boat RC-S3 (Figure 4.1b) made by Coden company in Japan was used to conduct the bathymetric surveys for each dam.

During the bathymetric survey, the hydrographic boat was used to measure water depth and water surface elevation. The Universal Transerves Mercator (UTM) coordinates for each measurement along the travel path were automatically recorded. The perimeter and elevation of the water surface for reservoirs were also measured with the hydrographic boat taking several points along the shoreline.

(a) (b)

Figure 4.1: Photographs showing (a) illustration of bathymetric survey of Morester dam (b) hydrographic Remote controlled boat, 8 March, 2015. (Source: Filed data)

The use of Differential Geographical Position System (DGPS) on the hydrographic boat was important for location accuracy because of the OMNISTAR VBS services utilised. The DGPS is an enhancement to the Global Position System that provides improved location accuracy (Shukla, *et al.*, 2012). The location accuracy for the data collected for this study was less than 20 cm of which if DGPS had not been used, the location accuracy would have been between 4 and 20 meters. The actual location accuracy for each dam was 0.09 m, 0.08 m, 0.10 m and 0.13 m for Lwiimba, Silverest, Morester and Katondwe dams, respectively. The observed variability in the location accuracy was due to a number of factors such as existence of big trees and hills, at dam sites. These factors influence the number of satellites used for DGPS values recorded. The larger the number of satellites captured, the more accurate the location of a place and vice versa.

4.2.2. Key Informants Interviews

Since the studied dams are privately owned, data on the effects of sedimentation on dam uses was collected from key informants who included owners of the small dams. Interviews with key informants were conducted using interview guides. The interview guide included questions on the purposes for which the dams were constructed and challenges faced with regard to sedimentation (Appendix I).

In order to collect data on the nature and type of soil erosion/sediment control measures, interviews with Key Informants were conducted. The key informants included the owners of the small dams (one for each dam), the Departments of Water Affairs and the Department of Agriculture representative. The Department of Water Affairs (DWA) and Agriculture were included on the key informants because they are among the key authorities with the mandate of development and maintenance of small dams in Zambia.Interviews with key informants were conducted using the interview guides (Appendices I and II).

4.2.2.4 Water Sampling

Four water samples were collected from each dam using dipping method. The dipping method involved the use of a bottle that was lowered slowly in a reservoir's water until the bottle was full and the bottle was closed on top whilst in water. The sampled water bottles were then taken for laboratory analysis at Environmental Laboratory at the University of Zambia, using standard methods for water quality analysis (World Health Organisation, 2010).

4.2.3 Secondary Data

The secondary data obtained for this study included on sediment control measures, Digital Elevation Model data (DEM), topography and land use information obtained from various published and unpublished sources.

4.2.3.2 Desk Analysis

The Digital Elevation Model data was acquired as secondary data from United States Geological Survey (USGS) for the purpose of calculating the catchment areas of the surveyed small dams.

4.3 Data Analysis

Data analysis under this study included estimation of dam storage capacity, sediment volumes and rate of sedimentation using ArcGIS 10.1 and Microsoft excel 2007 software and assessment of the effects of sedimentation on dam usage and sediment control measures as described in detail below.

4.3.1 Estimation of Dam Storage Capacity

The reservoir water storage capacity and surface area were calculated for each reservoir using bathymetric data from the hydrographic boat for each reservoir with the application of ArcGIS 10.1, 3D, Area and Volume Spatial Analyst tools. The point data in x, y, z were downloaded from the boat software from back data. Then the Z (depth) values were given a minus (-) sign. This is so because water surface was taken as the reference level and if minus sign was not given, the surface volume 3D analyst tool would have calculate Z values as elevations instead of depth. The imputing of recorded measurements from the hydrographic back data to ArcGIS 10.1 was accomplished by using the Tools – Add XY Data option. The x, y coordinates of the reservoir shoreline were also imported, the reservoir boundaries x, y points were given a default values of zero associated with each point. The projection information was specified at this time, World Geodetic System 1984 (WGS 84). Files were displayed as event files in ArcGIS, and were then exported as shape files. The point shape file(s) were visually evaluated for any points with spurious latitude and longitude coordinates. The attribute tables were also examined for any points reporting a value of 0 in the depth file and if found, these points were deleted as errors. The reservoir boundary point data were then merged with x, y, z data set using the merge tool in ArcGIS. Thereafter, ArcGIS Spatial- Analyst was used to produce an interpolated surface using Inverse Distance Weighted (IDW). It is from this raster surface that the volume and surface area of the reservoir were calculated using the Area and Volume tool under ArcGIS 3-D Analyst. Since the reservoir boundary had zero values representing the reservoir surface, the plane height was set at zero and all the reservoir depths were taken to be negative using metres as units of measurement. These methods have recently been applied in Zambia by Sichingabula *et al*. (2014) and Chisola (2015).

4.3.2 Estimation of Sediment Volumes and Rates of Sedimentation

The sediment volumes were computed from the differences between the initial storage capacity and the study measured storage capacity using the following formula by Adwubi *et al*., (2009) given as:

$SV = RSC_i – RSC_{i+n}$..equation 2.

Where: SV = Sedimentation Volume (m^3); RSC_i = reservoir storage capacity at an initial year, i (m^3); RSC_{i+n}= reservoir storage capacity n years after i (m^3).

The initial (i) year is the reservoir storage capacity when the dam was constructed and the storage capacity n years after an initial (i) year is the study measured storage capacity. The difference between the two volumes is assumed to be the volume of sediment accumulated in the reservoir. As such, the rate of sedimentation per year was estimated by dividing the number of years the dam has been in operation by the volume of deposited sediments. The average depth of deposited sediment was calculated as sediment volume divided by surface area.

4.3.3 Effects of sedimentation on small dam uses

Thematic analysis was used to assess the effects of sedimentation on small dams. The themes included effects of sedimentation on uses of dams with regard to livestock watering, irrigation and domestic uses. The idea was to develop themes and to work out how they relate to each other within the data that was collected from different selected dams.

4.3.4 Sediment Control Measures

Thematic analysis was also applied in analysing the existence of sediment control measures in catchments of small dams from the field observation and key informants. Sediment control measures were understood to be synonymous with soil erosion control measures. The themes were based on the nature and types of soil erosion control measures. The themes were assigned to the particular type of sediment control measures for each dam such as vegetation and existence of sediment traps such as ridges in the catchment. This was informed by previous soil erosion conservation measures adopted by government in different parts of the country (Robinson, 1978).

4.2.5 Catchment Area Delineation

Catchment area for each dam was delineated using Digital Elevation Model (DEM) data and several tools from the Spatial Analyst toolbox in ArcGIS as used by Irwin et al, (2014).The first step in catchment area delineation was to determine the flow direction of the study sites from the DEM Model. Direction function of the hydrology toolbox was used to assign a value to each raster cell of DEM indicating the direction of flow leaving that cell; while flow accumulating into each raster cell was computed using the flow Accumulation function of the Hydrology toolbox. Thereafter, the accumulation output raster classes were classified into two classes until the locations of water courses within the study area were visible and defined. After the water courses were defined in the DEM layer the catchment outlet points were located. The location of the centre of the dam crest given in x and y coordinates for each dam site were uploaded from the excel sheet and overlaid on the flow accumulation layer. Catchment areas were delineated upstream from the location coordinates. Delineation of catchment area of small dams was done using the watershed function of the hydrology toolbox of ArcGIS Spatial Analyst. This function calculated the area contributing water to each dam crest centre. The flow direction output layer and dam crest point layers were used as input. The catchment layers were converted from a raster to polygon format for the purpose of calculating catchment area using the calculate area function tool.

CHAPTER 5: FINDINGS AND DISCUSSIONS

5.1 Introduction

This Chapter presents findings on each of the four studied small dams, namely, Lwiimba, Silverest, Morester and Katondwe dams, followed by a discussion of the issues that emerged for the study.

5.2 Findings

The findings of this study from the analysis conducted focused on storage capacities, volumes of deposited sediment, effects of sedimentation on small dams and sediment control measures undertaken the results are presented below for each of the four dams studied.

5.2.1 Storage capacities of studied small dams in reservoirs

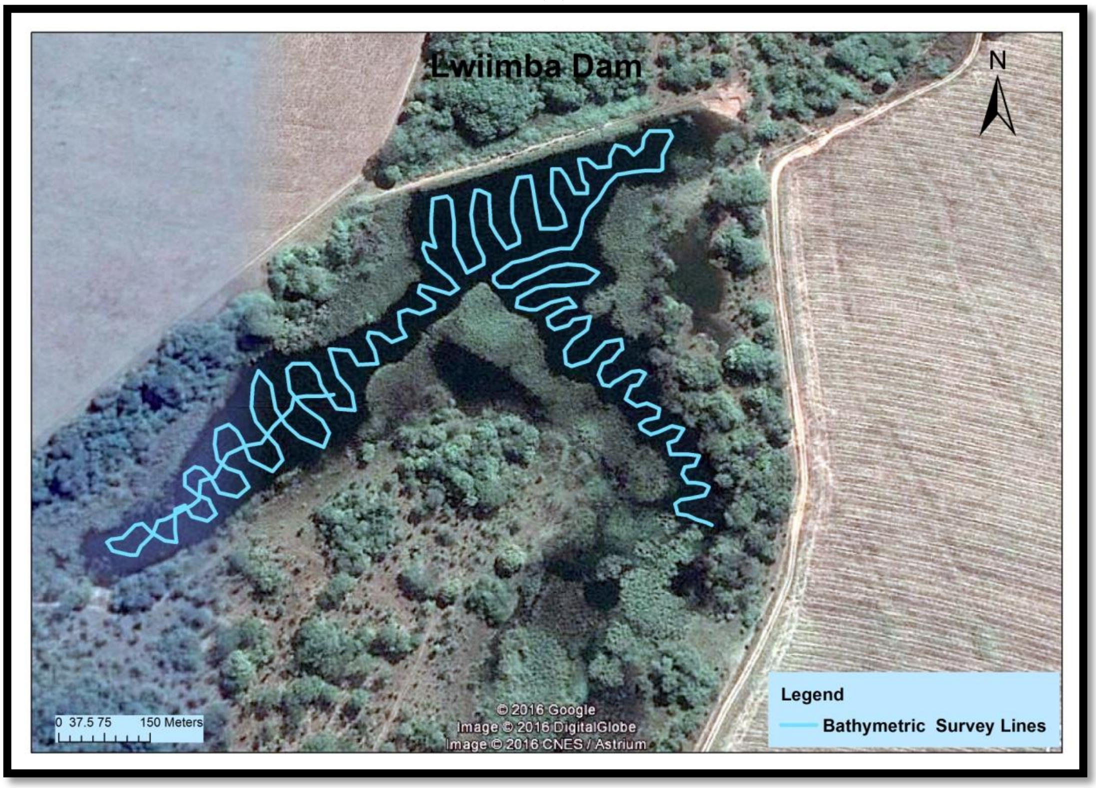
Measured storage capacities of dams are presented in this section including other related aspects.

5.2.1.1 Lwiimba Dam

The owner of Lwiimba dam reported that the dam was constructed in 1970. It has a catchment area of 11.79 km^2. At the time of the bathymetric survey its water surface elevation was at 1106.3 m above sea level. Figure 5.1a shows bathymetric survey path line results recorded during the bathymetric survey. Based on bathymetric map (Figure 5.1b), the water depth of Lwiimba reservoir ranged from -0.6 m to -4.0 m with half of reservoir depth occurring at – 2.3 m.

The reservoir surface area for Lwiimba dam was found to be 43,013 m^2 with a water volume of 101,051.43 m^3 (Table 5.1).The results in Table 5.1 have been plotted to produce hydro-sediment hypsometric curves. Figure 5.2a shows a very close relationship between depth and reservoir area, and so is the relationship between depth and reservoir volume (Figure 5.2b). The reservoir's current storage capacity was found to be 101,051.43 m^3 which was much lower than 200,096 m^3 the storage capacity at construction in 1970. This indicates that sediment deposition between 1970 and 2015 in Lwiimba reservoir has resulted in a loss of approximately 99,044.57 m^3 (43.3%) of the initial storage capacity of 200,096 m^3.

(a)



(b)

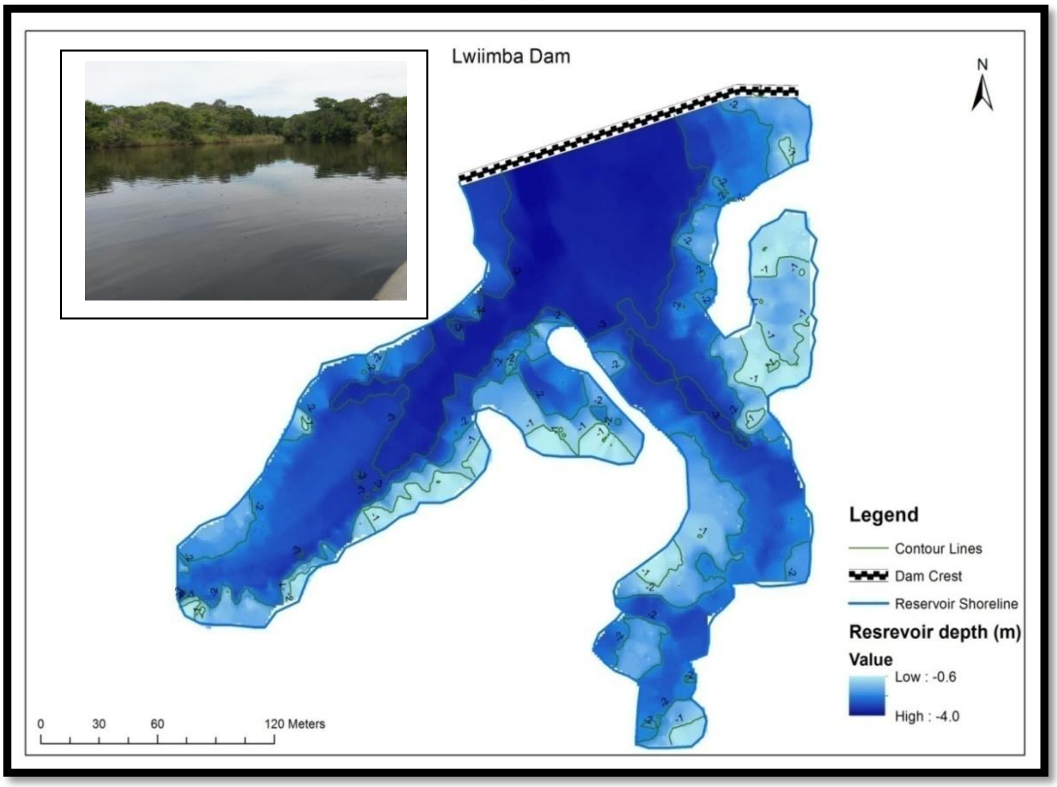


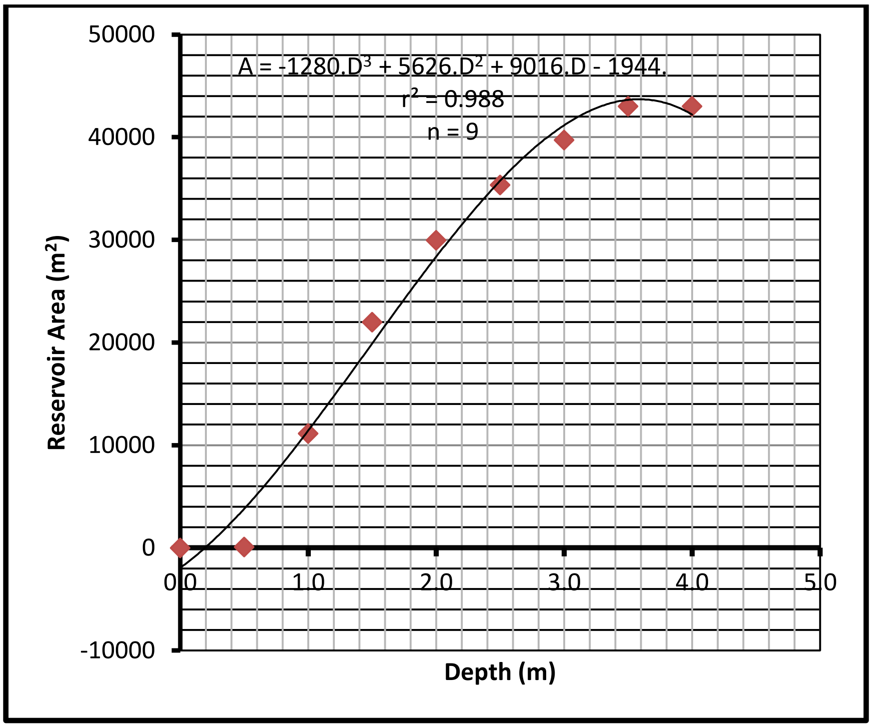
Figure 5.1: (a) Survey Path lines, and (b) Lwiimba reservoir, 7 March, 2015. (Source: Field Data)

Table 5.1: Reservoir Surface Area and Volume at different depths of Lwiimba Dam, 7 March 2015

Water Depth(m)	Water Surface Area (m^2)	Water Volume (m^3)
4.0	43,013.89	101,051.43
3.5	42,136.19	79,669.83
3.0	39,732.06	58,819.22
2.5	35,353.47	4,0077
2.0	29,966.61	23,785.53
1.5	21,991.35	10,813.48
1.0	11,144.54	2,474.66
0.5	91.00	3.76
0.0	0.01	0.00

Source: Field Data, 2015.

(a)



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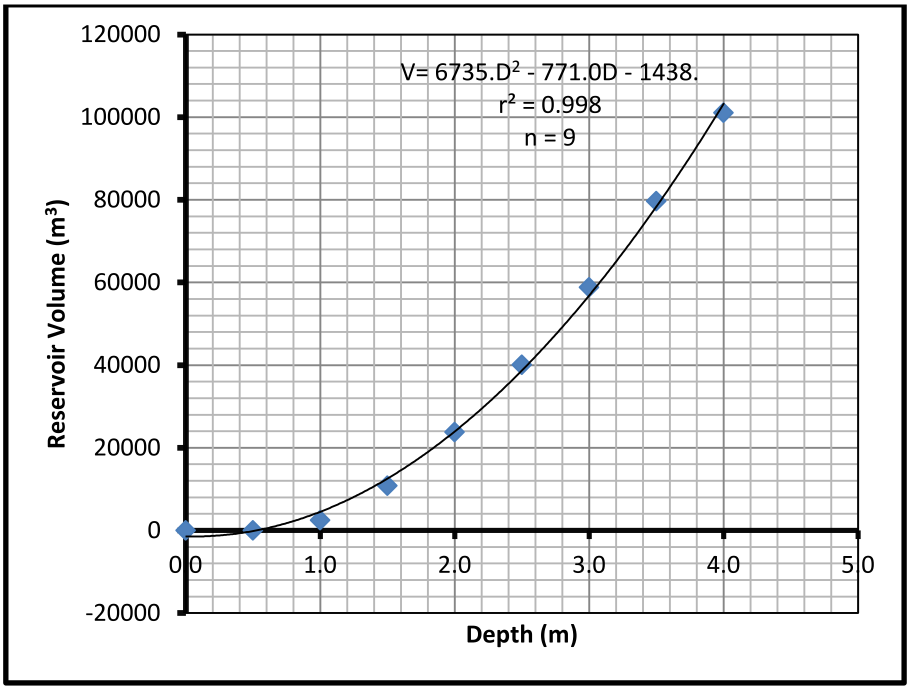


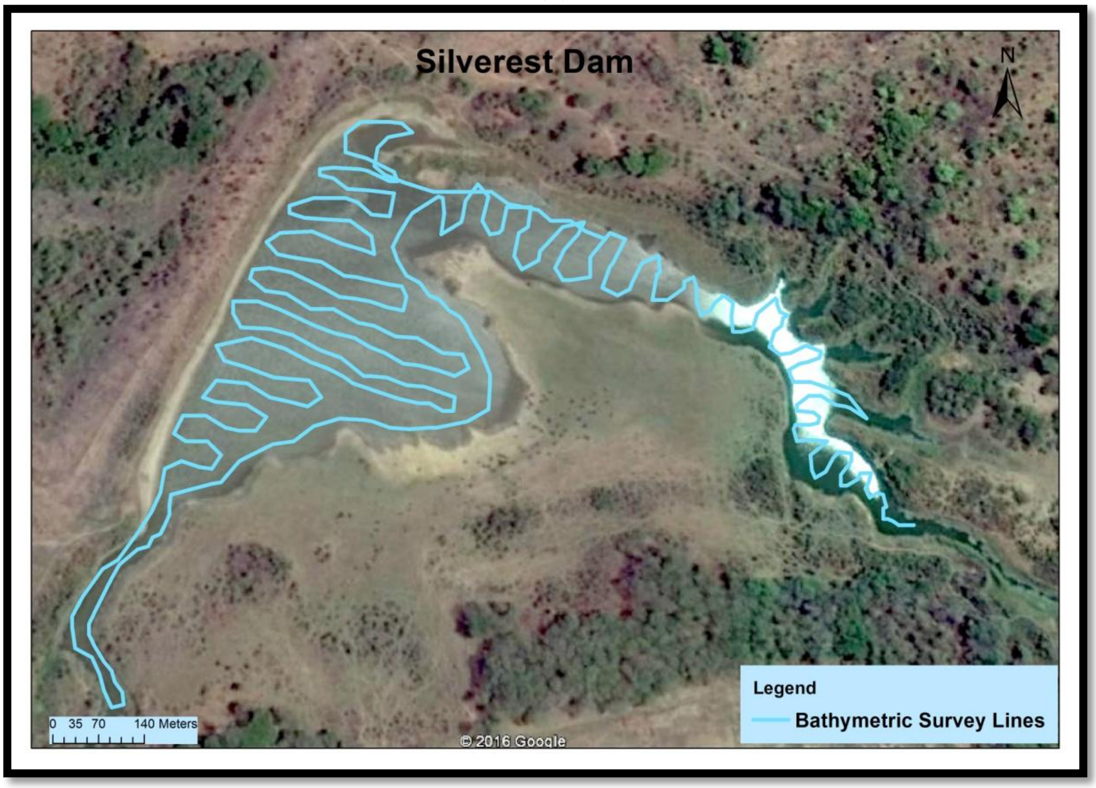
Figure 5.2: Hypsometric graphs showing (a) Depth-Area and (b) Depth-Volume relationships for Lwiimba reservoir, 7 March, 2015.

5.2.1.2 Silverest Dam

According to the owner, Silverest dam was constructed in 1989 for irrigation purposes and livestock watering. The catchment area of Silverest was found to be 28.53 km^2. At the time of the bathymetric survey the water surface elevation for Silverest reservoir was 1189.3 m above sea level. Figure 5.3a shows bathymetric survey path line results recorded during the survey. Based on the bathymetric map (Figure 5.3b),the water depth of Silverest reservoir ranged from 0 m to -9.7 m with half of its reservoir depth occurring at – 4.4 m.

The reservoir surface area of Silverest was found to be 86,082.47 m^2 with water volume of 368,331.5 m^3 (Table 5.2). The generated hypsometric curves between water depth and water surface area (Figures 5.4a) and between depth and reservoir volume (Figure 5.4b) show a very close relationship that exist between depth and reservoir capacity, and depth and reservoir volume. The reservoir current storage capacity was found to be 368,331.5 m^3.The design total storage capacity of Silverest dam in 1989 was 747,812 m^3 indicating that 379,480.5 m^3 (50.7%) storage capacity of the dam has been lost due to deposited sediment resulting from resulting from plant colonisation among other factors.

(a)



(b)

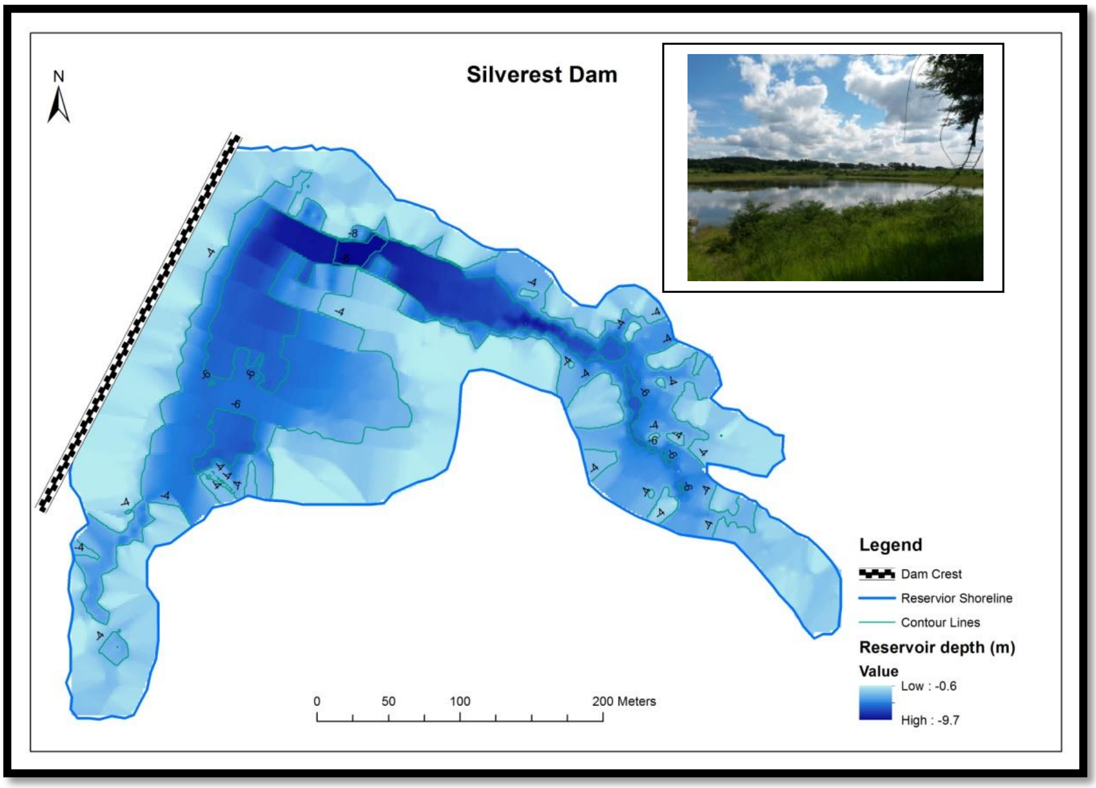


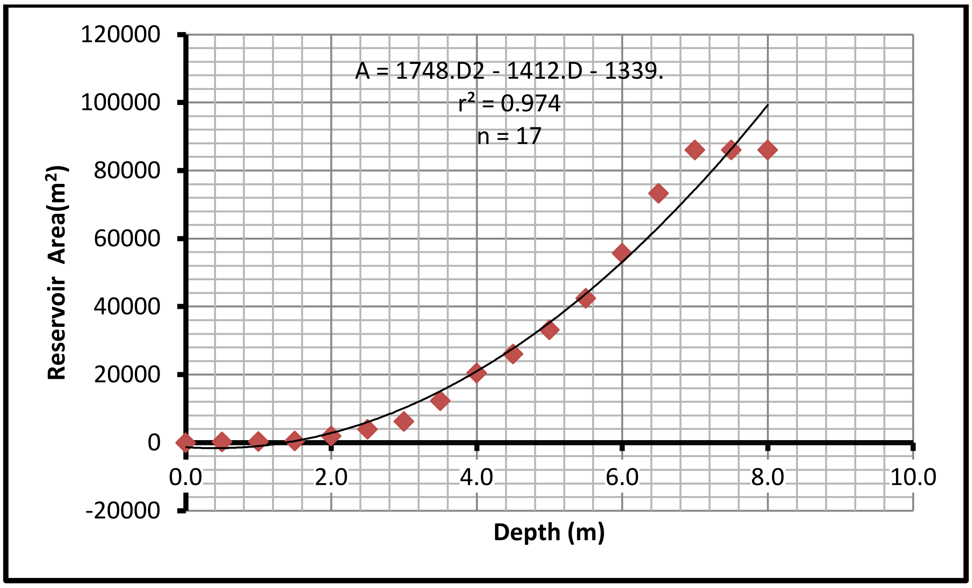
Figure 5.3: (a) Survey Path lines (b) Silverest dam, 27 February,2015. (Source: Field Data).

Table 5.2: Reservoir Surface Area and Water Volume at different depths of Silverest Dam, 27 February, 2015

Water Depth(m)	Water Surface Area (m^2)	Water Volume (m^3)
9.5	86,082.47	368,331.46
9.0	86,080.41	325,983.17
8.5	86,078.38	283,634.88
8.0	86,075.23	241,286.59
7.5	86,070.51	198,937.21
7.0	86,074.36	156,590.12
6.5	73,332.51	116,214.78
6.0	55,720.18	84,846.13
5.5	42,466.40	61,210.64
5.0	33,198.89	42,993.75
4.5	26,097.91	28,528.5
4.0	20,497.44	17,263.45
3.5	12,344.03	9,087.96
3.0	6,266.55	4,916.22
2.5	3,957.96	2,507.75
2	1,979.82	1,099.41
1.5	527.35	433.40
1.0	361.81	233.74
0.5	246.62	89.11
0.0	0.00	0.00

Source: Field Data, 2015

(a)



(b)

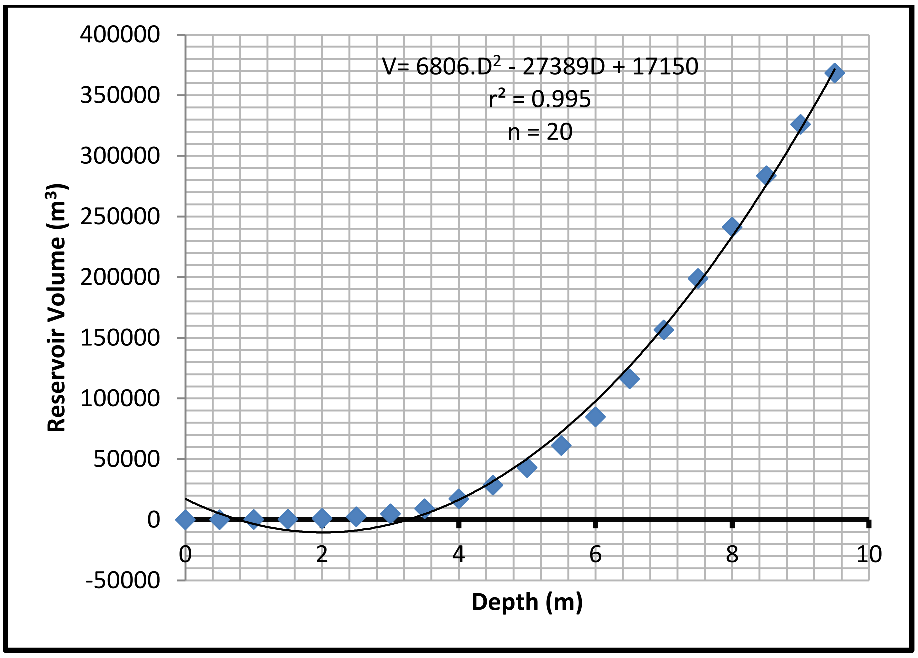


Figure 5.4: Hypsometric graphs showing (a) Depth-Area, and (b) Area-Reservoir Volume for Silverest Reservoir, 27 February, 2015. (Source: Field Data)

5.2.1.3 Morester Dam

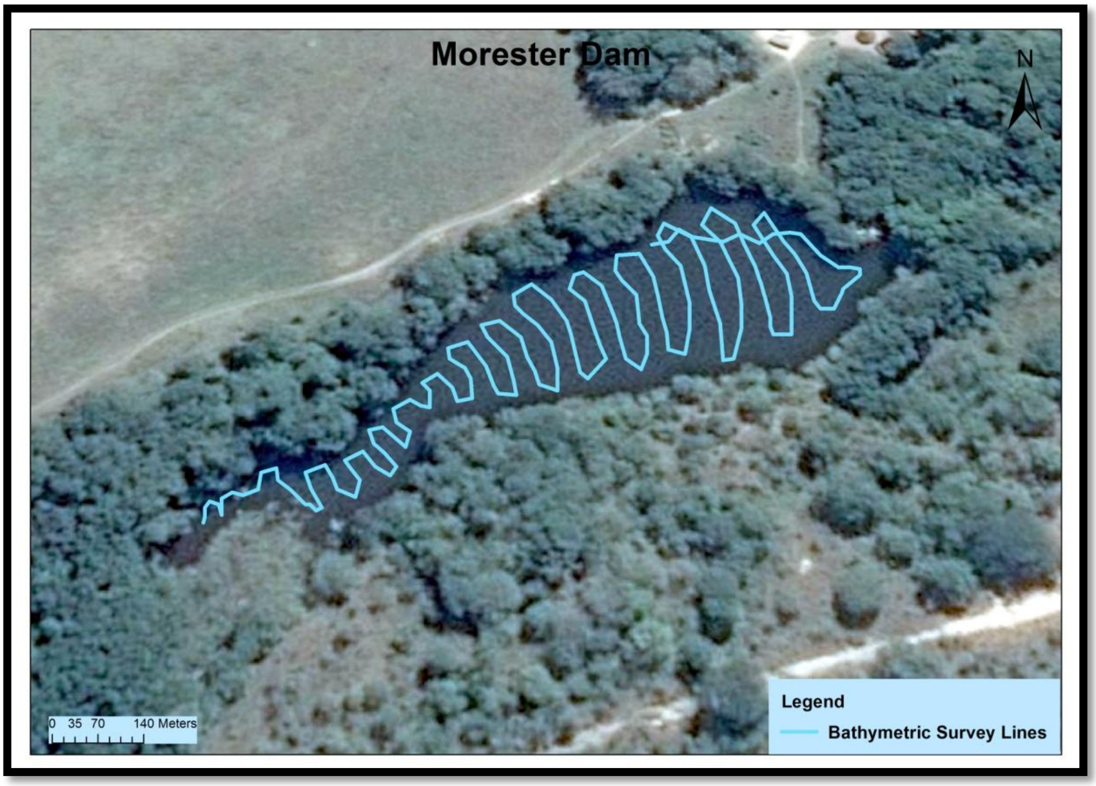
Morester dam was constructed in 1960 as reported by the owner and has a catchment area of 6.30 km^2. At the time of bathymetric survey the water surface elevation for Morester reservoir was at 1119.5 m above sea level. Its water depth ranged from 0 m to -4.0 m with an average depth of -1.9 m based on bathymetric map (Figure 5.5b). Figure 5.5a shows bathymetric survey path results recorded during the survey. The reservoir surface area using an interval of 0.5 m of depth ranged from 0 to 7,479.63 m^2 and the water volume ranged from 0 to 14,724.32 m^3 (Table 5.3). The design for Morester at construction, storage capacity was at 28,530 m^3. The current measured storage capacity was found to be 14,724.32 m^3, indicating that about 13,805.68 m^3 (46.5 %) of storage capacity has been lost in a period of 55 years. The hypsometric curves for this dam between water depth and water surface area (Figures 5.6a) and between depth and reservoir volume (Figure 5.6b) show a very close relationship that exist between depth and reservoir capacity, and depth and reservoir volume.

Table 5.3: Reservoir Surface Area and Water Volume at different depths of Morester dam, 8 March, 2015.

Water Depth(m)	Water Surface Area (m^2)	Water Volume (m^3)
3.5	7,479.63	14,724.32
3.0	7,369.38	11,006.95
2.5	6,680.85	7,418.07
2.0	5,747.73	4,320.90
1.5	4,469.87	1,728.91
1.0	1,464.48	186.87
0.5	2.24	0.26
0.0	0.00	0.00

Source: Field Data, 2015

(a)



(b)

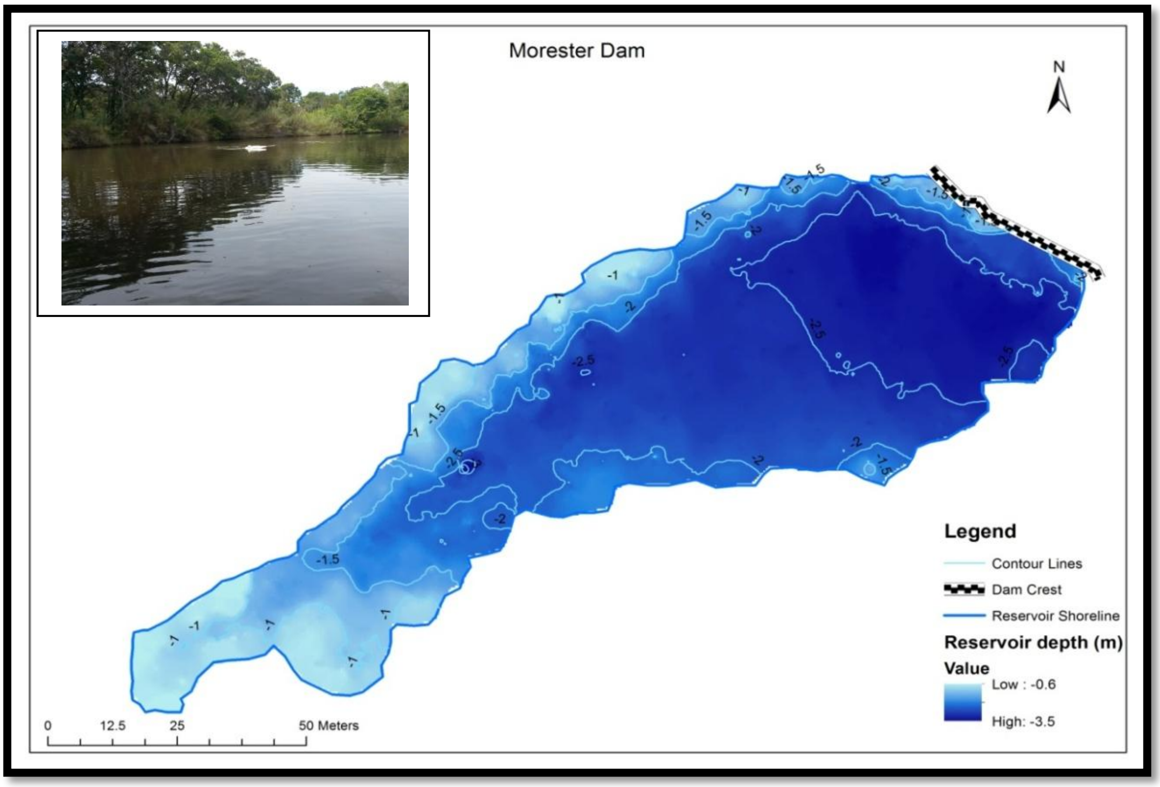
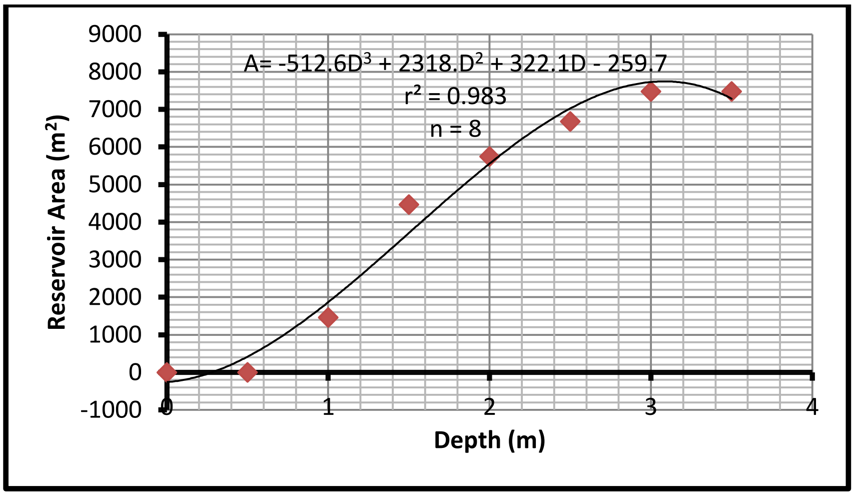


Figure 5.5: (a) Survey Path lines (b) Morester reservoir, 8 March, 2015. (Source: Field Data).

(a)



(b)

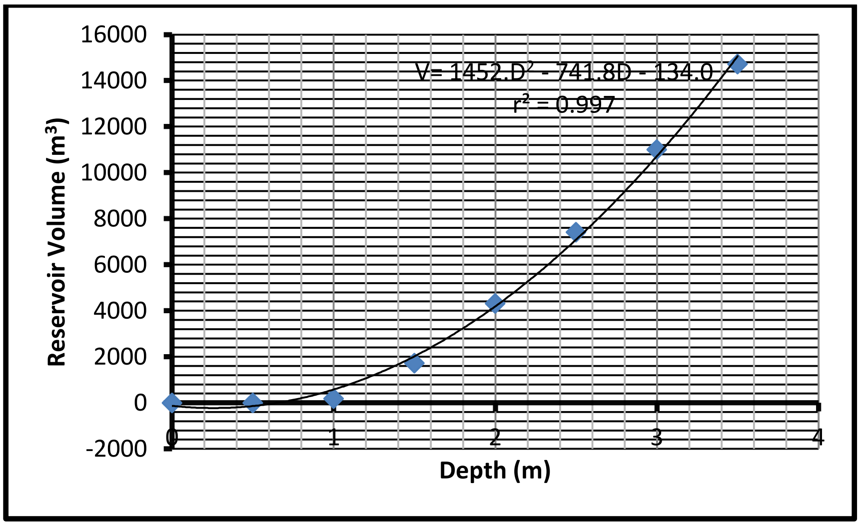
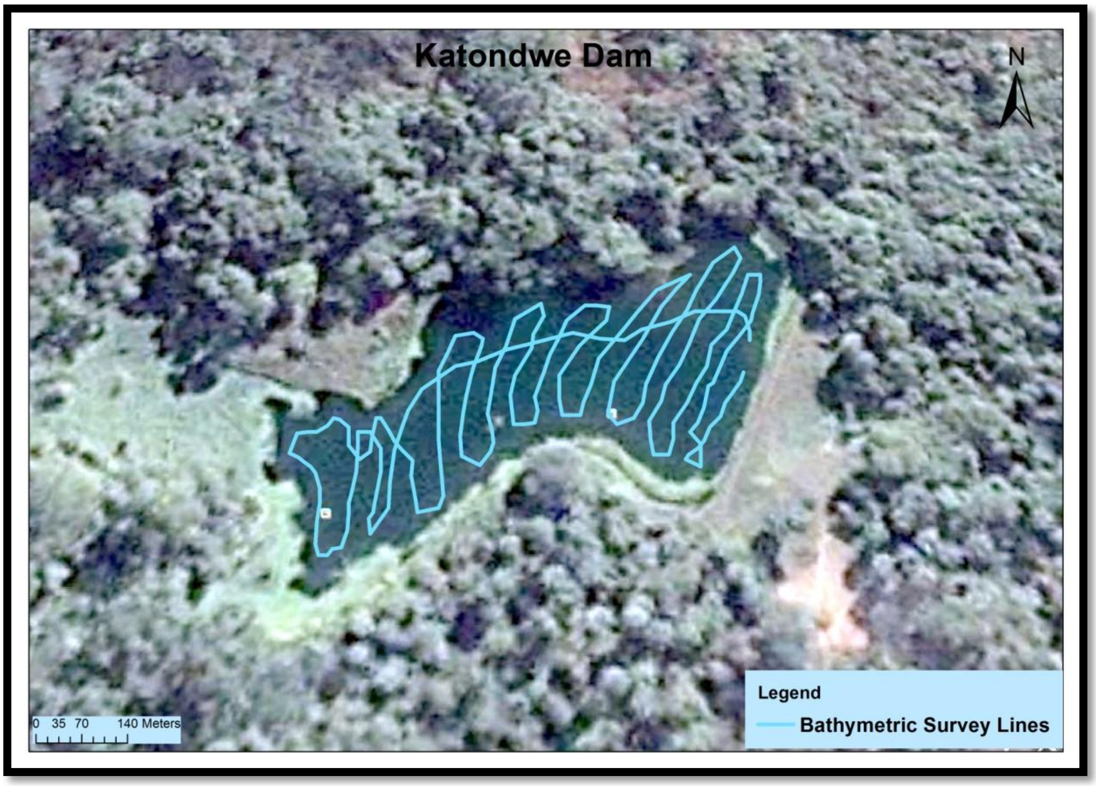


Figure 5.6: Hypsometric graphs showing (a) Depth-Area and (b) Depth Reservoir Volume relationships for Morester Reservoir, 8 March, 2015. (Source: Field Data)

5.2.1.4 Katondwe Dam

Katondwe dam was reported by the owner to have been constructed in 1980 and has a catchment area of 2.15 km^2. Figure 5.7a shows bathymetric survey path line results recorded during the survey. At the time of the bathymetric survey the water surface elevation of Katondwe was at 357.4 m above sea level. The water depth of the reservoir ranged from 0 m to -3.0 m with an average depth of -1.2 m based on bathymetric map (Figure 5.7b).

(a)



(b)

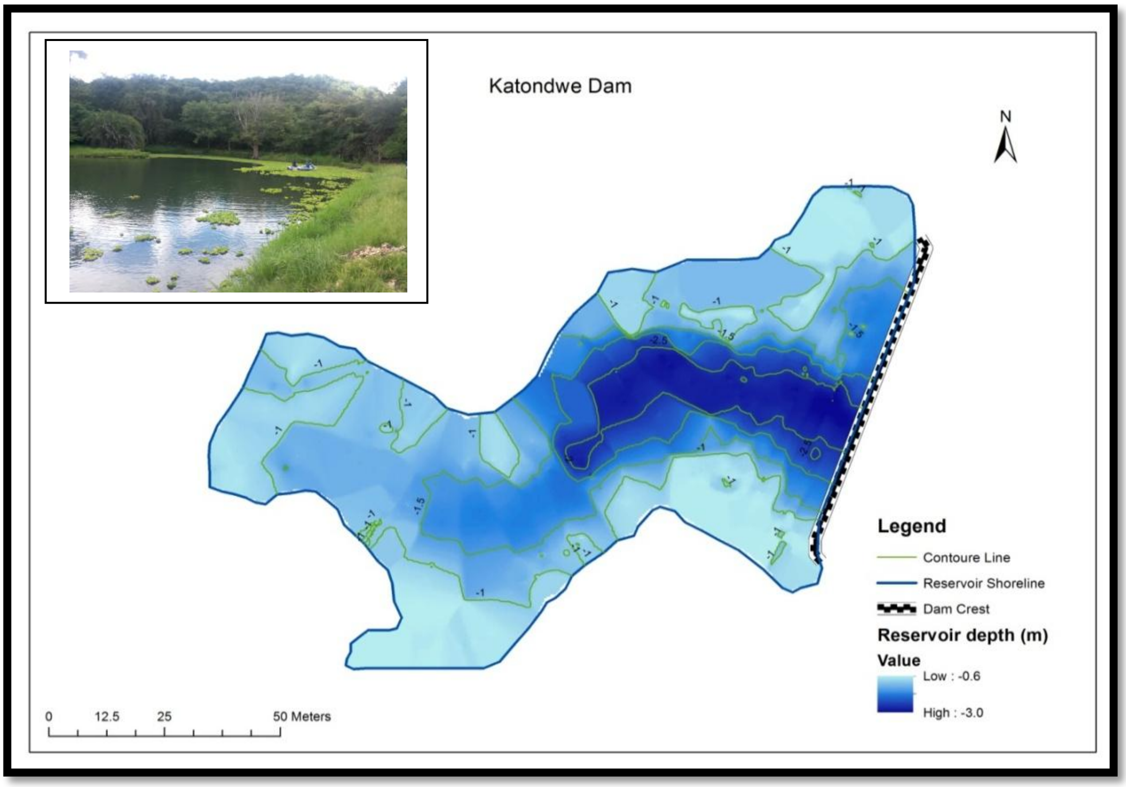


Figure 5.7: (a) Survey Path lines (b) Katondwe Reservoir, 24 February, 2015. (Source: Field Data).

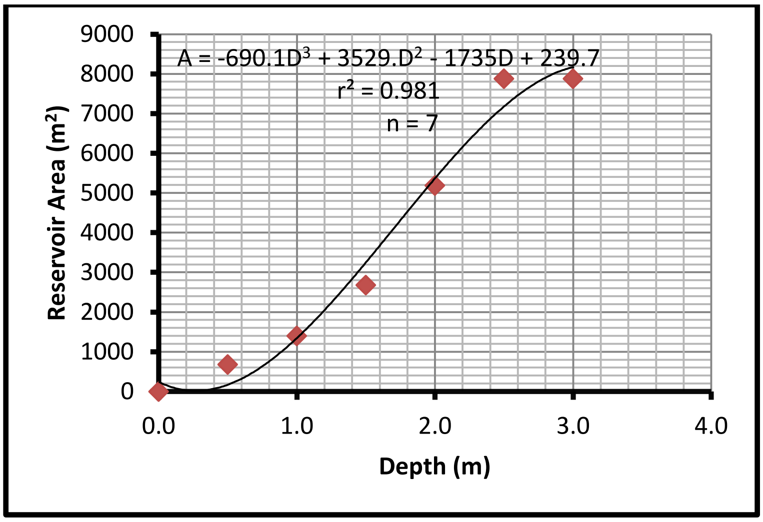
The reservoir surface area was found to be 7,881 m^2 and the water volume was 10,714 m^3 (Table 5.4). The results in Table 5.4 have been plotted to produce hydro and sediment hypsometric curves. Figures 5.8a show a very close relationship between depth and reservoir area, and so is the relationship between depth and reservoir volume (Figure 5.8b). The current total storage capacity of Katondwe dam was found to be 10,714.88m^3 whereas, 35 years ago, the design storage capacity was 20,652 m^3 (Table 5.4). The Sediment deposition between 1980 and 2015 in Katondwe reservoir has resulted in a loss of approximately 9,937.12 m^3 (39.2%) of reservoir storage capacity.

Table 1.4: Reservoir Surface Area and Water Volume at different depth of Katondwe dam

Water Depth(m)	Water Surface Area (m^2)	Water Volume (m^3)
3.0	7,881.63	10,714.88
2.5	70,421.41	6,806.57
2.0	5,189.66	3,423.84
1.5	2,681.85	1,598.29
1.0	1,402.33	628.11
0.5	681.57	113.14
0.0	0.00	0.00

Source: Field Data, 2015

(a)



(b)

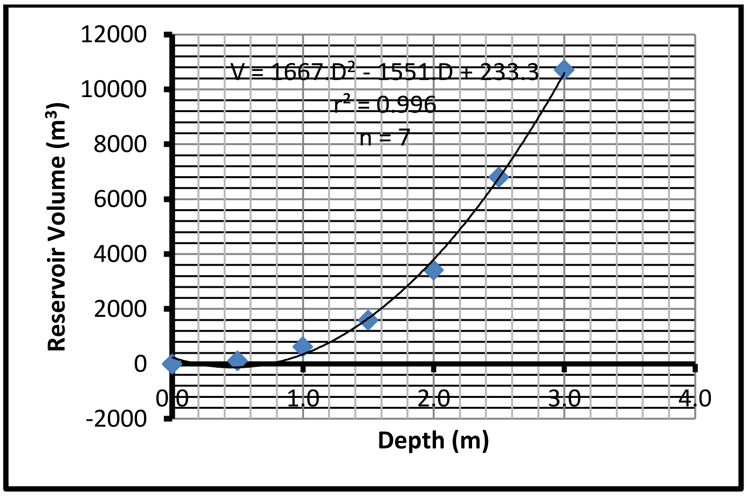


Figure5.8: Hypsometric graphs showing (a) Depth- Area and (b) Depth-Reservoir Volume relationship for Katondwe reservoir, 24 February, 2015. (Source: Field Data)

5.2.2 Estimated volume of deposited sediment in the studied small dam reservoirs

The sediment deposition between 1970 and 2015 in Lwiimba reservoir has resulted in a sediment volume of 99,044.57 m^3. This gives an annual sedimentation rate of 2,200.99 m^3 yr^{-1}. If this rate is divided into the current reservoir storage capacity, the estimated lifespan for Lwiimba dam is 46 years. Meanwhile, Silverest dam in 45 years had an estimated deposited sediment volume of 379,480.5 m^3. This gives an annual sedimentation rate of 14,595.4 $m^3 yr^{-1}$. At this rate Silverest life span is 26 years. While for Morester dam, approximately 13,805.68 m^3 of sediment volume was deposited in 55 years. This gave an annual sedimentation rate of 251.01 m^3 yr^{-1}. At this rate, the lifespan of Morester dam was estimated at 58 years. Whilst at Katondwe, the sediment deposition between 1980 and 2015 in

Katondwe reservoir has resulted in approximately 9,937.12 m^3 sediment volume. This gave an annual sediment rate of 283.92 m^3 yr^{-1}. At this rate the estimated lifespan of Katondwe dam was 38 years. Table 5.5 summarises reservoir capacities, estimated sediment volumes, rates of sedimentation and other statistics for the studied dams.

Table 5.5: Summary of Storage Capacity and Sedimentation Statistics for the Studied Small Dams East of Lusaka.

Name of the Dam	Year Built	Catchment Area (km^2)	Reservoir storage capacity When Built (m^3)	Measured reservoir storage capacity (m^3)	Measured Water mean depth (m)	Estimated Sediment Volume (m^3)	Estimated Mean Sediment Depth (m)	Annual Rate of sedimentation (m^3yr-^{1})
Lwiimba	1970	11.8	200,096	101,051.4	2.30	99,044.6	2.30	2,200.9
Silverest	1989	28.2	747,812	379,480.0	4.41	379,480.5	4.41	14,595.4
Morester	1960	6.3	28,530	14,724.3	1.93	13,805.7	1.84	251.0
Katondwe	1980	2.2	20,652	10,714.9	1.22	9,937.1	1.26	283.9

Source: Field Data, 2015.

5.2.3 Effects of Sedimentation on uses of small dams

During the study respondents reported that sedimentation affected mainly usage of small dams due to reduced water storage capacity. For instance, the loss in storage capacity at Lwiimba dam was negatively affecting irrigation and livestock watering. The dam quickly filled up with water at the onset of the rainy season since the dam bed has been raised due sedimentation. As a result, Lwiimba dam dries up in dry season. It was no longer able to conserve water for both livestock and irrigation throughout the year. This was also the case for Silverest dam where the loss of storage capacity was affecting irrigation. It was revealed that although the dam did not dry out completely in the dry season, the stored water during that time was not enough for pumping to the centre pivots for irrigation. Consequently, towards the dry season, irrigation was suspended so as not to deplete the water completely and reserve some water for livestock watering. Meanwhile, the loss of water storage at Morester dam (Figure 5.9) was said to have contributed to the abandonment of the dam for irrigation. The dam was longer holding enough for irrigation such that it was just used for livestock watering (Malilo Patrick, pers. com, 2015).

Figure 5.9: Morester dam used for livestock drinking, 8 March, 2015

Katondwe dam was exclusively used for domestic water supply through the use of pressure pumps (Figure 5.10a), loss of storage capacity was posing a challenge to Katondwe Mission in the provision of water supply to Katondwe school and the Hospital. It was reported that due to low water storage, especially in dry season, Katondwe management faces challenges of adequately supplying water to these two facilities. As such, boreholes have been sunk to supplement the water supply from the dam (Figure 5.10b).

(a) **(b)**

Figure5.10: (a) Pressure pumps, pumping water from Katondwe dam and (b) Borehole hand pump supplementing water from the dam to Katondwe Mission for water supply, 24 February, 2015.

In addition to the effects of sedimentation on small dams, data on water quality from the water samples were collected and analysed at the environmental laboratory at the University of Zambia. Knowledge of the quality is important because some people drink dam water directly without treatment. The concentration of the measured parameters for Katondwe and Morester dams were all within the World Health Organisation (WHO) permissible limits for drinking water while Silverest dam had concentrations of sulphates beyond the permissible limit. The pH levels for Silverest and Lwiimba dams were all found to be below permissible levels (Figure 5.6).

Table 5.6: The physico-chemical results of analysed water samples for the studied small dams, February to March, 2015

Parameter	**Lwiimba Dam (07.03.2015)**	**Silverest Dam (27.02.2015)**	**Morester Dam (08.03.2015)**	**Katondwe Dam (24.02.2015)**	**WHO Maximum Permissible Limit for Drinking Water**
pH	**6.07**	**6.42**	7.14	7.18	6.5-8.5
Turbidity(NTU)	0.19	0.18	0.19	0.46	5
Total Dissolved Solids(mg/l)	84	174	101	154	1000
Total Suspended Solids(mg/l)	< 1.0	<1.0	<1.0	<1.0	1000
Nitrates(mg/l)	<0.01	<0.01	<0.01	<0.01	10
Sulphates (mg/l)	75.58	**397**	53.65	63.76	250
Iron (m/l)	0.22	0.09	0.23	0.14	0.3

Source: Field Data, 2015

5.2.4 Sediment Control Measures

On sediment control measures in the catchment for the studied small dams, the one theme that emerged strongly is natural vegetation. From the field observations and key informants interviews, the natural vegetation was the main soil erosion/sediment control measure used in the catchment. However, it was revealed that most of the vegetative cover that once was well established in the catchments of the studied dams had been cleared for agriculture, settlements, and for charcoal production. The exceptions are Katondwe and Silverest where natural vegetation had been allowed to grow around the reservoir and cutting of trees was not allowed within the distance of about 50 meters. This allowed natural vegetation to grow and act as a buffers strip and sediment trap around the reservoirs. Unfortunately, for Lwiimba and Morester dams cultivation was done very close to the dams and reservoir water lines.

The Assistant Director from the Department of Water Affairs mentioned that for small dams, sediment control measures were largely dependent on the natural vegetation in the catchment area and pointed out that previously a fence to act as a buffer used to be constructed around small dams within 50 meters of the water. Cultivation was never allowed within 50 meters of the dams. But there was a problem of enforcing the existing regulations. It was reported that for some dams like Lwiimba and Morester, grass called *vetiver* was planted within the buffer zone of 50 meters. This grass was said to reduce runoff and soil erosion. However, at the time of the study, *vetiver* grass had been grazed by livestock. It was further reported that there was no integrated plans and programmes to control soil erosion in catchment areas for small dams. The rehabilitations that were carried out on a very slow pace focused mainly on maintenance of small dam such as rebuilding of breached dam walls.

From the Department of Agriculture, The Irrigation Engineer stated that there were no specific sediment control measures for small dams except the natural vegetation. However, he went on to say that there was a limited soil conservation measure being practised. This measure is minimum tillage conservation farming which was encouraged to reduce the disturbance of soil and sheet erosion that may be susceptible to water erosion by small farmers in catchment area of Katondwe dam.

5.3 Discussion

This section discusses study findings on the current storage capacity, reservoir storage loss, sediment volumes, rate of sedimentation, and effects of sedimentation on uses of small dams and sediment control measures for the studied small dams in relation to similar studies elsewhere.

5.3.1 Reservoir Storage Capacity

The studied small dams have lost a substantial amount of storage capacity. The reservoir storage capacity losses obtained in this study, for Lwiimba, Silverest, Morester and Katondwe ranging from 49 percent to 50 percent are within the same order of magnitude as those observed by Onwuegbunam *et al.,* (2009) in a related sedimentation study in Nigeria in 2009 on a small reservoir constructed in 1987 at the Afaka Forest Reserve in Kaduna State. The study in Nigeria showed that about 35 percent of the reservoir storage capacity was covered with sediments within a period of 26 years, which was a serious problem that was undermining water uses of the dam. It was further ascertained that there were several similar small-dams within Kaduna State, some of which were almost completely silted up (Onwuegbunam *et al.*, 2009). While in another study of Welbeck Reservoir in South Africa completed in 1973, it had lost most of its storage capacity (66 %) within the first 13 years of its existence due to sedimentation (Rooseboom and Lotriet, 1992). Reservoir capacity storage loss is one of many sedimentation problems that are affecting the four studied small dams. As these dams continue to age and sediments continue to accumulate, sediment related problems will continue to negatively affect the storage capacity of these water resources. The results of this study revealed that the loss of reservoir storage capacity on small in Lusaka province was due to sedimentation. However, combinations of other environmental factors that include changes in climate, water seepage and plant colonisation do affect storage capacity of dams.

The derived hypsometric curves, depth-area and depth-volume relationships were very strong for all the studied dams. The generated hypsometric curves can be used for monitoring of reservoir capacities from stage data which can be obtained from gauge plates if available for each dam.

5.3.3 Sediment Volumes and Rate of Sedimentation

The four studied small dams have substantial amounts of deposited sediment. Silverest dam had the greatest amount of deposited sediment of 379,480.50 m^3, followed by Lwiimba 99,044.57m^3, then Morester (13,805.68 m^3) and followed by Katondwe with 9,937.12 m^3. Additionally, the rates of sedimentation for Silverest dam of 14,595.40 m^3yr^{-1} was the highest followed by Lwiimba (2,200.99 m^3yr^{-1}) then Katondwe (283.92 m^3yr^{-1}) and lastly Morester dam with 251.01 m^3yr^{-1}. The results of the rates of sedimentation obtained in this study were within the order of magnitude as those observed by Aynekulu et al, (2007) in the study conducted in Tigray, northern Ethiopia, where the annual rate of sedimentation of Filiglig and Grashito reservoirs were found to be 6,928 m^3 yr^{-1} and 11,987 m^3 yr^{-1}, respectively. The differences in the deposited sediment and sedimentation rates among these dams can be attributed to the differences in catchment characteristics as well as the older the dam, the higher the volume of sediments deposited. Additionally, a number of other environmental factors do affect the sediment yield of the catchment area such as precipitation (with regard to quantity, intensity and frequency), type of soil, vegetation cover, soil management practices (cultivation practices, forest exploitation, building activities and conservation measures) and the nature of the drainage network (density, slope, shape, size and channels configuration) (ICOLD, 1989). Thus, appropriate measures should be put in place, especially for the catchment management in order to reduce the rates of sediment deposition in small dams.

5.3.4 Effects of Sedimentation on uses of small dams

Retained rainfall water in reservoirs can ensure sufficient water availability for households, livestock and agriculture during both wet and dry seasons. Reduced reservoir storage capacities for Lwiimba, Silverest, and Morester and Katondwe dams related to sedimentation was affecting the full utilisation of their intended uses. The increasing demands on water, coupled with their decreasing storage capacity, means that the reservoirs are being used below their intended yields. This implies that the owners of the dams have to stop using the dams, especially in dry season in order to maintain water supplies for other critical uses, such as livestock watering as was the case with Silverest and Morester dams. Thus, these dams are failing to contribute significantly to ensuring all year round reliable water supply for intended use. This is similar to a study by Kamutukule (2008) in Malawi on the impacts of sedimentation on water availability on Chamakala small dam, where sedimentation was found to be a serious problem by undermining the usefulness of Chamakala dam especially during dry season as the dam could not contain enough water for irrigation and livestock watering.

Whilst in Zimbabwe Magnus and Magnus (1999), report that siltation processes, due to large sediment transport in fluvial systems, have rapidly reduced the storage capacity of water reservoirs in several small dams negatively impacting on the usefulness of small reservoirs especially that many of them are built under the irrigation projects with the intention of bringing significant socio-economic benefits to the farming communities. Ainworth (2005) argues that loss of reservoir storage capacity due to sedimentation exacerbates the challenge of providing enough storage for the rising population with its rising aspirations and standards. Apart from reduced storage capacity, sedimentation also does affect reservoir water quality. Hargrove (2008) argue that sedimentation is said to not only reduce water-storage capacity of reservoirs, but deposited sediments containing nutrients, and trace metals significantly pollute and affect reservoir water quality. For this study, the pH for Lwiimba (6.07) and Silverest (6.42) were slightly below the acceptable permissible limits (6.5-8.5) for drinking water based on WHO standards. Meanwhile, sulphate concentration for Silverest was above the acceptable levels. This means that the catchment area contributing water to Silverest dam may have soil and rock formation that contain sulphate minerals. High concentration of sulphates give water a bitter taste and when the water is used for livestock watering, as it is the case with Silverest, it may cause diarrhoea as livestock are also sensitive to high levels of sulphates especially in young animals (Smart, *et al.,* 1986).

5.3.5 Sediment Control Measures

Lack of adequate soil erosion/sediment control measures in the catchment as revealed in this study is one of the factors contributing to reservoir observed sedimentation for the studied dams. The other possible factor that positively is contributing to sedimentation for Lwiimba, Silverest, Morester and Katondwe dams could be the size of the watersheds. Since these dams have small watershed size, the suspended sediment being carried by the runoff do reach the reservoir in a relatively shorter distance without settling somewhere along the way in the watershed. Sediments reaching the reservoir from surface runoff depend on soil erosion in the catchment. Thus, lack of proper implementation of soil control measures in the catchment is one of the major factors accelerating soil erosion and consequently high sedimentation rates for the studied dams. In a study conducted in Ghana to assess the impact of Landuse management on the Burekese catchment, the results showed a loss in reservoir storage capacity of 45 % due to siltation over a period of six years. The causes for the quick silting up of the reservoir were attributed to lack of adequate soil conservation measures, deforestation and lack of proper education of the communities in soil erosion catchment management practises (Mavima *et al.,* 2011). Sichingabula (1999) argued that if the catchments were not protected from activities such as tree clearing for charcoal production, settlement and agriculture, sediment yield in the catchments was likely to increase. Hence, for the studied dams, more attention should be given to concerns in preventing or at least slowing down, the process of soil erosion by applying integrated soil and water conservation techniques on at catchment scale as it was done in the 1970s under the Region and catchment conservation planning which was included in the First and Second National Development Plans (Robinson, 1978). Such measures would help in dealing with the problem of soil erosion from a spatial dimension. Conservation programmes should be done through changes in land use, notably reforestation and altering agricultural practices to emphasise soil conservation and construction of soil erosion control measures such as ridges on steeper slopes in the catchment.

CHAPTER SIX: CONCLUSIONS AND RECOMENDATIONS

This chapter presents conclusions based on the findings of the study on sedimentation and its effects on small dams for Lwiimba, Silverest, Morester and Katondwe dams. The chapter also provides some recommendations that may be useful in dealing with the problem of sedimentation in Lusaka Province.

6.1 Conclusions

Sedimentation is one of the factors that directly affect the performance of reservoirs in Lusaka due to the resultant reduction of storage capacity. This study on the first objective found that that measured reservoir storage capacities in year 2015 for Lwiimba, Silverest, Morester and Katondwe dams were 101,051.43m^3, 379,480.00m^3, 14,724.88m^3 and 10,714.88m^3, respectively. On the second objective, the estimated volumes of deposited sediment for Silverest dam was 14,595.40 m^3yr^{-1}, at this rate the reservoir lifespan was found to be 26 years; Lwiimba (2,200.99 m^3yr^{-1}), the lifespan was 46 years; Katondwe (283.92 m^3yr^{-1}) had a lifespan of 38 years and Morester dam (251.01 m^3yr^{-1}), had a lifespan of 58 years. This amount of sediment deposition has led to reservoir 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 for Lwiimba, Silverest, Morester and Katondwe dam, respectively, with the general consequences of reservoir drying especially in the dry season. For the fourth objective, lack of adequate soil erosion/sediment control measures at the catchment scale is one of the factors contributing to high reservoir sedimentation for studied small dams in Province Lusaka. The annual rates of sedimentation found in this study are in the same order of magnitude with other studies conducted in other parts of Africa. For example, in Ethiopia, the annual rate of sedimentation of Filiglig and Grashito reservoirs were found to be 6,928 m^3 yr^{-1} and 11,987 m^3yr^{-1}, respectively. In Malawi, a study to investigate the impact of sedimentation on water availability in Chamakala small dam revealed that the annual rate of sedimentation in the dam was 2, 250 m^3 yr^{-1} (Kamutukule, 2008).

Overall, this study has also demonstrated the value of bathymetric mapping and the value of sediment monitoring to water resources management for Zambia. Bathymetric maps are important in assessing changes in depth of the reservoir over time in cases where bathymetric surveys are done on separate time intervals as sediment accumulates on the reservoir bed. It is concluded, that as small dams in Lusaka Province age, sediment will continue to accumulate and sediment-related problems will increase in severity with negative effects on their reservoir usefulness. This calls for periodic dredging of deposited sediment in order to maintain high level storage capacities and coupled with good soil erosion control measures in the catchment areas.

6.2 Recommendations

Based on findings of this study, the following recommendations are made for the government, owners of small dams and researchers.

1. A national programme of regular bathymetric surveys and monitoring of sediment accumulation in small dams should be put in place for sustainable management of water resources in reservoirs by the central government.
2. Local rural communities should be educated on the value of soil conservation measures such as tree planting and early bush burning in order to reduce sediment generation, transportation and deposition of sediment into small dams.
3. The government should reintroduce soil conservation works in catchment areas and rehabilitation of small dams in Lusaka Province in particular and the entire nation at large.
4. There is need for enforcement of buffer zones along streams and around small dam reservoirs by the central government in order to allow natural vegetation to grow and act as sediment trap away from reservoirs.
5. Researchers should undertake more studies on siltation rates, sediment yields, sedimentation and area-specific sediment yields on small dam reservoirs in Lusaka and other provinces of Zambia. The information that will be generated will be useful for sediment monitoring and abetment.
6. There is need for the government to build capacity of water resources practitioners in water and sediment monitoring and analysis for them to be able to deal with sediment problems and effects of climate change on water resources.

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Appendix I: Interview guide for the key informants (owners of the Dam)

Place……………………. ………………………….   Date…………………………

I am Innocent Chomba, carrying out a research on ***Sedimentation and its Effects on small dams in Lusaka Province***. This is part of my Master's degree in Environmental and Natural Resources Management at the University of Zambia. You are kindly requested to answer all questions to the best of your knowledge**.** The information provided will be kept anonymous and confidential and will only be used for academic purposes only.

SECTION A: BACKGROUND INFORMATION

1. Sex...
2. Age..
3. How long have you resided in this area...

SECTION B: INFORMATION ON THE DAM

4. What is the name of the dam?...
5. Who is the owner of the dam?...
6. When was the dam constructed?...
7. Who constructed the dam?..
8. What is the name of the stream flowing in the dam?.......................................
9. What was the design water storage capacity at construction?.........................
10. What was the purpose for the construction of the dam?
    ....
    ....
    ....
11. What are other benefitsfrom the dam other than the ones the dam was constructed for?...
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    ....
12. Are you facing any problems with regard to sediments and sedimentation on this dam?...
13. If any, what problems are you facing related to sediment and sedimentation?
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14. How are these problems affecting the purposes of this dam?

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15. Are there any sediment control measures for this dam at the dam site and in the catchment area?

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16. If any, what types of sediment control measures being implemented to protect this dam from sedimentation?

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17. Who is implementing sediment control measures for this dam?

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THANK YOU FOR YOUR TIME AND COOPERATION

Appendix II: Interview guide for the Key informants (Department of Water Affairs and Agriculture)

Name of the Department………………………. Date……………………..

I am Innocent Chomba, carrying out the research on ***Sedimentation and its Effects on small dams in Lusaka Province***. This is part of my Master's degree in Environmental and Natural Resources Management at the University of Zambia. You are kindly requested to answer all questions to the best of your knowledge**.**

SECTION A: BACKGROUND INFORMATION

1. Sex...
2. What is your designation in this Department?...

SECTION B: INFORMATION ON SMALL DAMS

3. What is the purpose for the construction of the small dams in Lusaka Province?
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   ....
   ....
4. Are you facing any problems with regard to sediments and sedimentation on small dams in Lusaka Province especially with respect to Lwiimba, Silverest, Morester and Katondwe dam
   ....
   ....
   ....
5. If any, what problems are you facing related to sediment and sedimentation?
   ....
   ....
   ....
6. How are these problems affecting the purposes of these small dams?
   ....
   ....
   ....
7. Are there any sediment control measures for small dams at the dam site and in the catchment area?..

8. If any, what types of sediment control measures being implemented to protect this dam from sedimentation?

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9. Who is in charge of implementing sediment control measures for small dams?

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THANK YOU FOR YOUR TIME AND COOPERATION