COST BENEFIT ANALYSIS OF SEDIMENT AND SEDIMENTATION IN SELECTED SMALL DAMS IN LUSAKA AND SOUTHERN PROVINCES, ZAMBIA

By

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A Dissertation submitted to the University of Zambia in Partial fulfillment of the Requirements for the award of the Degree of Master of Science in Environmental and Natural Resource Management

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DECLARATION

I, Darliet Mwiinde, do declare that this dissertation represents my own work, and that it has not previously been submitted for a degree, diploma or other qualification at this or any other University. All published work or materials from other sources incorporated in this dissertation have been acknowledged and adequate reference merely given.

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APPROVAL

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ABSTRACT

There are many small dams in Zambia constructed for the purpose of collecting and storing runoff from the catchments. The flow of water into dams is accompanied with sediment resulting from soil erosion within reservoir catchments. The deposition of sediment in reservoirs has implications for their sustainability and thus future water supplies. However, accumulated sediment in reservoirs can be dredged to extend the useful lives of dams. This study aimed at evaluating the burden of sediment and sedimentation in selected small dams in Lusaka and Southern provinces of Zambia. A survey research design was employed to gather data from the sampled dams in Lusaka and Southern provinces of Zambia. A cost-benefit analysis was performed to determine the cost and value of burden of sediment and sedimentation on selected six small dams. A Contingent Valuation of Willingness to Pay was conducted to find out the possibility of local peoples' support of a possible programme of dredging the accumulated sediment in the reservoirs to restore the lost storage capacities. of the dams. The results of the study showed a clear scenario of the burden of sediment to local communities and the potential restoration of lost reservoir storage capacities to sedimentation. The study established that 25 - 52 percent of studied reservoirs initial water holding capacities had been lost to sediment accumulation in 26 – 60 years of dam operations. The rates of sediment accumulation ranged from 283.92 m^3 yr^{-1} to 29,118.63 $m^3 yr^{-1}$, indicating that the surveyed reservoirs had less than 60 years of useful lives beyond the year 2015. Sediment and sedimentation was found to lower the annual benefits from reservoirs intended water uses in monetary terms. The Net Present Value (NPV) for removing and selling the accumulated sediment was found to be high and positive for all the dams while the NPVs for operating reservoirs with sediment in them were found to be low and sometimes negative values were recorded. It is concluded that the studied small dams in Lusaka and Southern Provinces were experiencing severe sedimentation which lowers the benefits from intended dam uses. Because of the high potential benefits that could be derived from sediment, local communities and dam owners should be encouraged to exploit this abundant natural resource in their areas.

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Dedication

To my children Bibusa, Lusekelo, Mapesho and Butemwe.

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ACRONYMS AND ABREVIATIONS

ADSP Agricultural Development Support Project

ASIP Agricultural Sector Investment Program

CBA Cost Benefit Analysis CV

CSO Central Statistical Office

CV Contingent Valuation

DA Department of Agriculture

dBD Dry Bulk Density

DGPS Differential Geographical Positioning System

DWA Department of Water Affairs

FNDP Fifth National Development Plan

GPS Geographical Positioning System

ICOLD International Commission of Large Dams

IDW Inverse Distance Weighted

ITCZ Inter-Tropical Convergence Zone

LE Life Expectancy

NPV Net Present Value

PV Present value

RIF Rural Investment Plan

RSC Reservoir Storage Capacity

SR Sedimentation Rate

SV Sediment Volume

SWASCO Southern Water and Sewerage Company

SY Sediment Yield

TIN Triangulated Irregular Network

UNICEF United Nations International Center for Education Fund

WB Water Board

WTP Willingness to Pay

ZMW Zambian Kwacha

ZAMSF Zambia Social Investment Fund

CHAPTER ONE: INTRODUCTION

1.1 Background

There are many small dams in Zambia constructed for the purpose of collecting and storing runoff from the catchments. They serve as water storage facilities for domestic use, irrigation, stock watering, flood control, fish farming, ground water recharge and climate change adaptation through flood impact attenuation. The flow of water into dams is also accompanied with sediment resulting from soil erosion within reservoir catchments (Erskine *et al*., 2002). Soil erosion is one of the normal aspects of landscape degradation. The terms 'dam' and 'reservoir' are sometimes herein used interchangeably to refer to the body of water held behind a dam wall constructed for the purpose of water storage.

When soils leave their source due to erosion and enter water sheds, they have both positive and negative effects. Soil erosion and deposition have positively contributed to the fertile agricultural lands in the valleys of the Euphrates, Tigris, Nile, Indus and the rivers of China (Hudson, 1986, Wild, 1993). These agricultural lands arose from flood deposits of fertile silt that provide plant nutrients. Negative effects include damage to water reservoirs and pollution of water bodies. Soil particles accumulating in the reservoirs can lead to changes in reservoir water storage capacity and water use potential (Leigh *et al*., 2013 and McBroom *et al*., 2012). Small reservoirs in particular are affected by these storage losses as the maximum water depth is often only a few meters and an accumulated sediment layer of a few decimeters at the bottom of the reservoir causes a comparatively large reduction in water volume (McCully, 1996). However, accumulated sediment can be mined to extend the useful lives of the dams. Policy makers are likely to be concerned with the costs and benefits arising from the sediment and accumulated sediment in dams and well founded estimates of sediment removal or reduction costs. These costs and benefits could serve as basis for funding for construction or rehabilitation as well as the selection and design of sediment control measures. In order to find out the value of sediment and accumulated sediment on economic, environmental and social effects on small dams, this study used a Cost-Benefit-Analysis (CBA) approach.

Everyday decision making starts with comparing the costs and benefits of planned actions especially when the aim of economics is to make a policy recommendation. CBA is a method which systemizes this and it is commonly used for assessing the profitability of various undertakings and to aid in decision making especially in government projects (Heinzerling and Ackerman, 2002). The basic idea is that scarce resources should be allocated to their most valued uses. At the most general and comprehensive level, CBA is an aggregator of all impacts, to all affected parties, at all points in time. The impacts, both positive and negative, are converted into a common monetary unit, and the cost-benefit criterion is simply a test of whether the benefits exceed the costs. The Costs are measured as the value of lost production in the sector from which the factor of production is withdrawn (opportunity cost). Benefits are what members of society receive from the use of the resource.

This research will be undertaken to evaluate the costs of sediment in terms of the lost production from dams and benefits of sediment in terms of the possible increase in production if sediment is removed from the dams as well as possible benefits from the sale of the mined sediment. The results of the CBA will enhance the understanding of the value of sediment and accumulated sediment in the small dams.

1.2 Statement of the Problem

Sediment deposition has both positive and negative effects. It can positively contribute to the fertility of agricultural lands. On the other hand, it can negatively lead to the siltation of reservoirs. The deposition of sediment in dams is extremely important in the management of these water resources because it has significant consequences for the sustainability of the reservoirs and thus for future water supplies. A study was previously done on sedimentation in small dams in Zambia (Sichingabula, 1997) but this was limited to the inventory and analysis of sediment loads into small dams. This study used the CBA method to determine the value of sediment and accumulated sediment in six selected small dams in Lusaka and Southern Provinces of Zambia.

1.3 Aim

The aim of this study was to establish the value of the burden of sediment and sedimentation in six selected small dams in Lusaka and Southern Provinces.

1.4 Objectives

To address the general objective, the following specific objectives were formulated;

(i) To determine the volume of accumulated sediment in the selected dams.

(ii) To determine the rates of sediment accumulation in the selected dams.

(iii) To determine the current economic life spans of the selected small dams.

(iv) To assess the cost and beneficial value of sediment and accumulated sediment in the selected small dams.

(v) To assess local people's perception and value attached to sediment and sedimentation in small dams.

1.5 Research Questions

The research questions were six-fold:

(i) How much sediment has accumulated in the selected small dams?
(ii) What are the rates of sedimentation in small dams?
(iii) What are the current economic life spans of the dams?
(iv) What is the monetary value of the suspended sediment and accumulated sediment in terms of costs and benefits of the uses of the small dams?
(v) What is the value of the costs and benefits of possible removal of the accumulated sediment from the dams?
(vi) How do local people perceive the issue of sediment and sedimentation in the dams?

1.6 Scope of the Study

This study was conducted on four small dams located in Lusaka Province and two dams located in Southern Province used for municipal water supply and agricultural irrigation. The costs and benefits of concern to the study were all those caused by existing sediment, sediment accumulation and possible removal of accumulated sediment from the small dams.

1.7 Rationale

Little has been known about the value of sediment and accumulated sediment to small dams in Zambia. So far, there has been no study carried out on the value of sediment and accumulated sediment in the country based on this methodology. This research therefore was undertaken to investigate the value of sediment and accumulated sediment in selected small dams in Lusaka and Southern Provinces. This study identified and assessed the benefits and costs of remediating sediment and sedimentation. Raising the profile of sediments and sedimentation can help identify possible corporate involvement and generate local support when a decision to intervene has been made. Further, the findings from this research will hopefully be useful in decision making and policy formulation at local and national levels of planning. The study results will also be used as an early warning to dam owners and local communities on the need to reduce soil erosion in catchments that leads to sedimentation in small reservoirs.

1.8 Organisation of the Dissertation

This dissertation is organized into seven chapters. Chapter One gives a background of the study and clearly states the Problem Statement, Aim, Research Objectives, Research Questions related to the objectives and the importance of undertaking this research. The first chapter frames the study effort and gives specific focus to the research. The second chapter explores the existing literature on small dams and sedimentation beginning with other places and later to Zambia. It also looks at the concept of CBA. Chapter Three provides a physical and socio-economic description of the study areas. Chapter Four explains the methodology and methods used in the research. The fifth chapter provides summaries of the collected data according to the research objectives in the form of tables and maps. The sixth chapter discusses the research findings and contextualizes them with other studies. Finally, Chapter Seven summarises the findings of the research according to the research objectives. It also contains the recommendations for future research.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews relevant existing literature on small dams and sedimentation in other places and later to Zambia, the effects of sediment and sedimentation on small dams, and furthermore, concepts related to CBA.

2.1 Dams and Sedimentation

Poff and Hart (2002) defined dams as structures designed by humans to capture water and modify the magnitude and timing of its movement downstream. They are constructed and operated for a wide variety of purposes such as domestic, commercial and agriculture water supply, flood and debris control and hydropower generation (Nilsson *et al*. 2005). Dams are classified differently according to different countries and most are classified based on three parameters of height of dam wall from river bed, storage volume of a dam at full supply level and size of the catchment area. The Technical Guidelines for the Construction and Management of Improved Small Dams (2009) states that in the USA, small dams have a height of not more than 15 m and a capacity at normal water surface of less than 1,233,526 m^3. Large dams have a height of more than 15 m and a capacity at normal water of more than 123,326 m^3. Great Britain considers small dams to be those with a volume below 1,000,000 m^3 and a catchment area below 25,000 km^2 (White *et al*., 1996). In Zimbabwe, they are classified to be those with a capacity of less than 1,000,000 m^3 and a height of less than 10 m (Senzanje and Chimbari, 2002). In the Zambian case, the classification of dams is based on the Manual on Small Earth Dams by Stephens (2010). In the Manual, small dams are considered to have storage capacities of up to 10,000 m^3 and an embarkment of up to 15m height.

2.2 Small Dams in Africa

All dams are sediment traps because of the low velocities of water flowing in them (Kondof, 1997). McCully (1996) observed that the rate of reservoir sedimentation depends mainly on the size of a reservoir relative to the amount of sediment flowing into it and that small reservoirs on extremely muddy rivers or streams can rapidly lose capacity while large reservoirs on very clear rivers may take centuries to lose an appreciable amount of storage. A study done by the

Department for International Development (2004) found that most of the small dams in Africa constructed in semi arid regions fill with sediments after a few years of construction as evidenced by their survey of sedimentation in 17 small dams in Zimbabwe and Tanzania in which they found that small dams on small rivers were silting up more rapidly than big dams on big rivers. They further found that the sedimentation lifetime of these small dams was less than 38 years due to a lot of evaporative losses that occurred as siltation increased. Wang and Kondof (2013) conducted a study on sedimentation in Taiwan and found that in the Dahn river basin, some of the upstream small reservoirs constructed in 1963 had filled with sediment by 1976 while the three largest dams filled by 2007.

2.3 Small Dams in Ethiopia

Studies done to provide quantitative information on small scale reservoir sedimentation rates and the impact on economic lives of the small dams that have been done in Ethiopia, East Africa have found that sediment and sedimentation were serious problems that undermined the economic life times of small dams (Aynekulu *et al*., 2010 and Alemau *et al.*, 2013). They found that intended dam purposes could not be attained with the short projected lives of the dams. In one of the studies, they found that Angered Reservoir in North West Ethiopia had reached almost half of its design life in a very short period of time thereby, could only supply to 45 percent of the intended population in Gondar town.

2.4 Small Dams in Zambia

There are various estimates of the total number of small dams in Zambia. These estimates are given by Department of Agriculture (DOA), Department of Water Affairs (DWA), Water Board (WB), Nordic Consulting Group (NCG) and Sichingabula (1997). The DOA estimated that there are 2000 small dams, defined as those with a storage capacity of mainly less than 1,000,000 m^3. A survey on sedimentation in small dams published in 1997 reports that by about 1991 there were at least 537 small dams in the country (Sichingabula 1997). The WB lists 917 dams but this figure is not exhaustive. According to the Nordic Consulting Group (2010), many more dams are missing from the WB data base since the most recent official national figure estimates 2000 small dams but cautions that the number could go up to 3000.

Over the years, a number of programmes have supported development of the agriculture sector in Zambia, and these have to varying degrees included investments in small dams. These programmes include notably the multi-donor effort such as the Zambia Agricultural Sector Investment Program (ASIP), implemented from December 1995 - 2001, which funded some dams through its Rural Investment Fund (RIF) component; and the World Bank financed the Zambia Social Invest Fund (ZAMSIF) implemented from 2000 – 2005 and the Agricultural Development Support Project (ADSP) from 2007 – 2012. Such programs have financed either the construction or rehabilitation of a number of small dams.

2.5 Sources of Sediments

According to Erskine *et al.* (2002), sediments are a natural part of fluvial processes and the type and amount found in surface runoff, streams and rivers is influenced by the geology of the surrounding area. They are transported hydrologically by runoff, snowmelt and river channel erosion and deposited in reservoirs and lowland areas. Kondof (1997) found that sediment is transported mostly as suspended load in the form of clay, silt and sand held aloft in the water column. He further found that the rate of sediment transport increases as a power function of flow with most sediment transportation occurring during floods. Natural processes that add to sediments in waterways include in-stream scouring of the river bed and banks and erosion of sediments from the surrounding catchment from natural slips and any exposed soils. Sediments can enter reservoirs from alongside a reach or from upstream through the numerous smaller interconnecting streams that form a river network within a catchment area.

Human land use, especially agriculture, emerges as the major cause of sedimentation in reservoirs (Sichingabula, 1997; Erskine *et al*., 2002; Koteen *et al*., 2002 and Alemau *et al*., 2013). According to Moxey (2012), sediments and sedimentation in dams due to agriculture depends on various factors such as the type of agricultural activity, local site conditions, prevailing weather conditions, management of the surrounding land and past land management practices. Sediment accumulation is highly dependent on the slope factor and rainfall intensity (Alemau *et al*. 2013). Dams located in high rainfall areas experience more sediment accumulation than those found in low rainfall areas. Steep slopes erode more contributing to sediment in moving water than gentle slopes.

2.6 Sediment Control and Management

Sediment management is cardinal in sustainable reservoir management (Bureau of Reclamation, 2012). The methods of dam capacity preservation fall into three broad categories of measures to; reduce the entry of sediment, reduce deposition of sediment and recovery of lost storage.

Measures to reduce entry of sediment into reservoirs involve watershed management which means controlling soil erosion through watershed management. McCully (1996) observed that watershed management of afforestation and promotion of good farming practices such as contour farming, terracing, and conservation tillage to reduce soil erosion in the dam catchment areas are the best way of cutting sediment deposition in reservoirs. However, this is rarely implemented because of the high cost of land management and the need for cooperation by a large number of landowners and farmers in the watershed, making this alternative difficult to implement in most cases. Sichingabula (1997) found that lack of maintenance of conservation works was contributing to the silting up of many small dams in Southern Province of Zambia.

The deposition of sediment cannot be prevented completely by watershed management. Therefore, reduction of deposition of sediment in dams provides protection beyond that afforded by reduction of entry of sediment (McCully, 1996). A large part of particles can however be evacuated by the application of appropriate techniques such as sediment flushing, dredging, hydrosuction, sluicing, density current venting and mechanical removal. Benard and Webb (2010) contend that such structural measures are costly in the short term but may be very beneficial in the long run.

2.7 Sediment Volume Determination

The estimation of sediment volumes in small reservoirs can be done using direct and indirect methods. Indirect methods include measurement of suspended sediment fluxes (Alemau *et al.*, 2013), sediment traps (Gharekhani, 2011; Chitata *et al.*, 2014; Lambert and Walling, 1987) radionuclides dating (Walling and He, 1994) or runoff/sediment yield estimations. Direct methods comprise bathymetric eco-sounding surveys (Sekellick *et al*. 2013), sediment coring of deposited bottom sediments and digging pits in dry dams (Kouhpeima *et al*., 2010) .

Bathymetric survey refer to the determination of water depths. They are based on a simple comparison of reservoir morphology at two different time periods, first at the time of construction of the dam and second at the time of the survey (ICOLD, 1989). In general, bathymetric surveys are seen as more accurate than alternative methods for assessments of sediment export at the basin scale, since they provide direct measurements instead of indirect estimates (Strand and Pemberton, 1987). Another advantage of reservoir surveys is that they often provide information over long time spans and represent both the effect of frequent and rare events

Bathymetric surveys though being considered to be more reliable than other methods, still has some uncertainties related it. For example, errors can be made in the bathymetric survey, in volume calculations, in the conversion from sediment volume to mass and in the trap efficiency calculations. The latter two are expected to be the most uncertain. As Verstraeten and Poesen (2001) demonstrated, the empirical relations to determine bulk density based on fractions of sand, silt and clay did not provide accurate estimates of sediment mass in small ponds in Belgium, suggesting that it might be more reliable to use sediment volume than sediment mass in sediment yield assessments. However, Salas and Shin (1999) suggested that the uncertainty related to estimation of the sediment type and the trap efficiency are small compared to the estimation of annual stream flow and sediment inflow, required for application of sediment rating curves. Furthermore, though uncertainty in trap efficiency can be relatively high for small reservoirs and ponds, for larger reservoirs, the error normally is much lower (Verstraeten and Poesen, 2000; Verstraeten and Poesen, 2002). Altogether, bathymetric surveys seem the most suited available method to make assessments of short and long term average sedimentation in reservoirs.

Sediment volume determination is important in studies such as this one because the lost water volumes can be recovered by application of sediment management techniques such as dredging. Such methods require determination of the accumulated volumes of sediment and the costs of removing it. Such relations of volumes of sediment in the dams, the costs of removing the sediment and the benefits that can be realized from increased water volumes in the dams form part of the CBA that is used in this study.

2.8 Effects of Sediment and Accumulated Sediment

Alemu *et al.* (2013) states that sedimentation reduces the storage capacity and life span of the reservoirs. The reduction in storage capacity reduces the usefulness of dams to their intended purposes. Chemical reactions occurring within sediment due to long term storage cause serious problems of water quality. Furthermore, the likelihood of dam failure increases with the presence of sediments (Sherman, 2013) as sedimentation might cause structural damage to dams and increase costs of operating the dam and possibly lead to costly decommissioning at earlier dates.

According to Poff and Hart (2002), sediments modify biogeochemical cycles as well as the structure and dynamics of aquatic and riparian habitats. Sediment in nutrient rich waters can increase the rate of evapotranspiration by stimulating the growth of water consuming vegetation in dam boarders. (Kondof, 1997) observed that Silt and clay can be deleterious to aquatic habitats and water quality. Further he states that when sediments come from agricultural fields, it can be a source of chemical contamination as it often carries with it fertilizer, pesticides and other chemicals from agricultural activities. However, Hudson (1986) contends that there are also positive impacts of sediment such as; generation of valuable habitat with biological diversity, reduction of fine sediment discharge and hence improved water quality and the opportunity for uses of sediment deposits in substitution of other peat based composite.

2.9 Beneficial Uses of sediment

Stanley and Doyle (2002) argue that sediment deposition in dams promotes the retention of phosphorus and nitrates which are essential to plant growth. Further, Kunz *et al.* (2013) found that dams trap plant nutrients coming in the form of sediment when they observed that the fertility of the Kafue Flats in Zambia declined with the complete construction of the Itezhi- tezhi dam in 1977. A study done in the United States of America by Lembke *et al.* (1983) on the possible use of dredged lake sediment on agriculture output found that there was a significant yield increase of corn yields on plots where hauled lake sediment were applied compared to the original farmlands. Malino *et al.* (2014) considered the possibility of reusing sediment for engineering and agriculture uses and for environmental enhancements and found that use of sediment offers a sustainable way of recycling a natural resource with potential value. Koropchak *et al.* (2015) came up with three classes of beneficial uses of dredged sediment, namely, engineered, agricultural and product as well as environmental enhancement uses.

Sediment can be used for engineering purposes in the construction industry in the manufacture of bricks, ceramics and concrete (Great Lakes Commission, 2013). Beneficial utilization projects in environmental enhancement where there was need for land creation and improvement or as a replacement fill have been documented in literature (Darmody and Martin 2002; Darmody *et al.*, 2004; Ebbs *et al.*, 2006) in the United States of America (USA). Similar findings and potential applications have been reported for Ireland (Sheehan *et al.*, 2010; Sheehan and Harrington, 2012). The sediment material was applied to areas where the quality of existing land was poor such as mineland or brownfields reclamation. The material was also used to replace soils or other materials moved or removed for construction and landscaping projects. Despite the positive potential use of the sediment, Koropchak *et al.* (2015) warn of the importance of undertaking laboratory testing of the sediment samples to evaluate the presence of possible contaminants to the intended uses.

2.10 Cost Benefit Analysis Concept

Cost Benefit Analysis (CBA) has its theoretical foundations in welfare economics. Welfare economics is largely guided by Pareto efficient optimal condition and Kaldor-Hicks criterion (Kniivila, 2004). Pareto optimal decision rule states that a policy change or a new project is socially desirable if everyone or at least some people in society are made better off without making anybody worse off. Kaldor-Hicks criterion states that a policy or project should be adopted if and only if those who gain could fully compensate those who will lose and still be better off. These same two principles could be applied in CBA of sediment and sedimentation in small dams. In this case, there is need for comparing the gains or losses from allowing sediment to enter or accumulate behind small dams or those of not allowing such a situation to occur.

CBA is done by accounting and comparing the cost of an action and its benefits by assigning values to social and environmental effects of a given undertaking together with the value of the resources consumed or produced (Cunningham and Cunningham, 2006). This makes CBA an important economic evaluation technique for use as a planning tool for self assessment, cost projections, assessing efficiency, assessing priorities, accountability and assessing equity. Thus, it has been used as a decision making tool for developing and justifying policy actions and determining the level of funding changes necessary to achieve a desired goal (Anderson, 1987; Newcombe, 1987; Lutz *et al.* 1994; Tilahun *et al*. 2007, Gelaye, 2012). Convery (2013) argues that the method can provide an analytical framework and a body of evidence that enables scholars to look back and judge whether past investments have been effective thereafter allowing for an examination of history which can yield important lessons for the future.

However, applying CBA in environmental conservation involves a variety of challenges. One major challenge arises from the fact that many environmental goods and services are not traded directly in the market and thus do not have market prices. Hence, attaching economic values to them becomes a difficult task. Another major controversy in applying CBA to environmental conservation is the choice of the discount rate for discounting the future flows of benefits and costs (Hanley, 1995). From an economic point of view the discount rate should reflect the social time preference as some environmental changes are irreversible; the choice of the discount rate is not as simple as for private business investment decisions. Choosing a relevant time horizon from the perspective of local people is another important consideration in CBA application. Despite the challenges, CBA remains an important analytical tool in environmental decision.

Auckland Council (2013) identified five steps in conducting Cost Benefit Analysis as follows;

1. Develop and articulate a scenario for the situation at hand for each contemplated action.

2. Develop scenarios of likely effects with each action or alternative scenario. It is recommended that at least two alternative scenarios to the situation at hand should be created, but it may be prudent to develop more to show various options and to compare the relative effects of different approaches.
3. Identify the costs and benefits of each alternative or action undertaken in the scenario.
4. Measure the costs and benefits. Given that some benefits and costs can only be realized at a future date, a discount rate is used to convert the flows of costs and benefits over time into present values that is the current values of the costs and benefits that occur in the future. According to Grafton *et al.* (2004) the discount rate influences the present value of costs and benefits especially those that occur many years in the future. The higher the discount rate, the lower the present value of the future benefits and costs, and the less the emphasis that is placed on future costs and benefits by project developers. Dasgupta (1982) argues that after discounting, the net present value of a project is socially acceptable if it is greater than zero.

5. State the method and assumptions made in the analysis. This should include the timeframes under which the assumptions are relevant and the social discount rate used to express the costs and benefits in constant terms. At this stage, sensitivity analysis should also be undertaken to show the uncertainties associated with the different alternative actions as some values of the benefit and/or cost items and the economic parameters used in the analysis may undergo changes over time (Balana *et al.* 2012). Such uncertainties of future circumstances affect the results of the CBA.

Cunninghum and Cunninghum (2006) state that a good Cost Benefit Analysis must consider both tangible and intangible values of an action. Water is one of the commodities that can be traded in the market where buyers and sellers can reveal their preferences directly through their actions, thus creating the price of water. Such a valuation of water can easily give the tangible value of sediment found in the water. However, the valuation of environmental resources has to cover the intangible part of the resource as well. Intangible values of resources are not traded on the market thus, the market price does not exist. Several methods exist for the estimation of prices of non market resources. These can be divided into two categories; Revealed Preference Methods such as Hedonic Pricing and Travel Cost Analysis and Stated Preference Methods (Grafton *et al*., 2004).

2.10.1 Contingent Valuation Method

A Contingent Valuation Method is a survey or questionnaire-based approach to the valuation of non-market goods and services. The basic assumption underlying a CV survey is that individuals know approximately how much they would be willing to pay to acquire an environmental good, and given an optimal design of a survey, they would report this value (Perman *et al.*, 2003). CVM enables economic values to be estimated for a wide range of commodities not traded in markets. It works by directly soliciting from a sample of consumers based on their willingness to pay or willingness to accept compensation (Hanley and Spash, 1993). The monetary values obtained for the good or service are said to be contingent upon the nature of the constructed (hypothetical or simulated) market and the good or service described in the survey scenario. The contingent valuation technique has great flexibility, allowing valuation of a wider variety of non-market goods and services. Application of soil conservation measures around the dams and in the catchment areas reduce sediment accumulation in the dams. Therefore, application of sediment control structures or measures are indispensible for assuring a continuous and reliable water supply from the dams. These require the participation and coordination of water users from the dams. One way of finding out how much the users perceive and value the problem of sediment is by finding out how much they would be willing to pay to come up with sediment control measures through a Contingent Valuation (CV) method.

Contingent valuation studies are conducted as face-to-face interviews, telephone interviews, or mail surveys.

Grafton *et al.* (2004) formulated the following steps for conducting a Contingent Valuation:

1. Identification of the issue in general.
2. Specific description of the current situation and the proposed alternatives regarding the public good or environmental quality change in question. This is done by pre-testing of

the survey on the relevant population until a survey that people seem to understand and answer in a way that makes sense and reveals their values for the service or services is developed. This includes determining exactly what services are being valued, and who the relevant population is. In the present study, the resources to be valued were the small dams and the water in them. The relevant population was all households that use dam water for domestic purposes or for watering crops.

3. Description of the payment mechanism. Include the possibilities of payment mechanisms.
4. Elicitation of respondents' willingness to pay in a discrete choice framework. Ideally, the sample should be a randomly selected sample of the relevant population, using standard statistical sampling methods. Also to be considered here is the method of implementing the survey as by mail, phone or in person.
5. Debriefing questions on respondents' certainty choice.
6. Elicitation of demographic characteristics and attitudinal information from the individual. This estimates the average value for each of the services of the site, for an individual or household in the sample. The results can be extrapolated to the relevant population in order to calculate the total benefits from the resource under different policy scenarios. The average value for a specific action and its outcomes can also be estimated.

Some controversy surrounds this method such that some observers question its validity (Hanemann, 1994). They argue that CVM fails to measure preferences accurately because the willingness to pay may exceed true feelings, respondents may fail to take questions seriously because the financial implications of their responses are not binding, respondents may express a value for the satisfaction of giving rather than the value of the goods or service in question (Hanley, 1995). Estimates of non-use values can be difficult to validate externally, results may appear inconsistent with tenets of rational choice and respondents may be unfamiliar with the good or service being valued and not have an adequate basis for articulating their true value (Kahneman and Knetsch, 1992). Even practitioners accept that poorly designed or badly implemented Contingent Valuation surveys can influence and distort responses leading to results that bear no resemblance to the relevant population's true WTP (Carson, 2001).

Despite these criticisms, proponents of Contingent Valuation method argue that its theoretical foundations are firmer than those of other non-use valuation techniques because it is based on economic utility theory by measuring directly true willingness to pay; it can produce reliable estimates and most biases can be eliminated by careful survey design and implementation (Carson *et al*., 2001). Currently Contingent Valuation method has been used successfully in a variety of situations (Kniivila, 2004; Gelaye, 2012).

Although the connections linking the fertility of sediment to agricultural lands appear obvious (Hudson, 1986, Wild, 1993), this problem has received relatively little scientific attention in Zambia despite the huge economic value of silt in agriculture. Agriculturists, environmentalists and geographers in Zambia have failed to look beyond the adverse effects of sediment and sedimentation to the affected dams (Sichingabula, 1997; Nordic Consulting Group, 2011; Chomba and Sichingabula, 2015). In the few cases where sediment and sedimentation of small dams have been studied, the beneficial use of accumulated sediment in dams have not been documented. This study used CBA to determine negative and possible positive effects of sediment and sedimentation in small dams in Zambia.

CHAPTER THREE: DESCRIPTION OF THE STUDY AREAS

The study was conducted in Lusaka and Southern Provinces. The location of Lusaka and Southern Provinces in Zambia is given in Figure 3.1 .

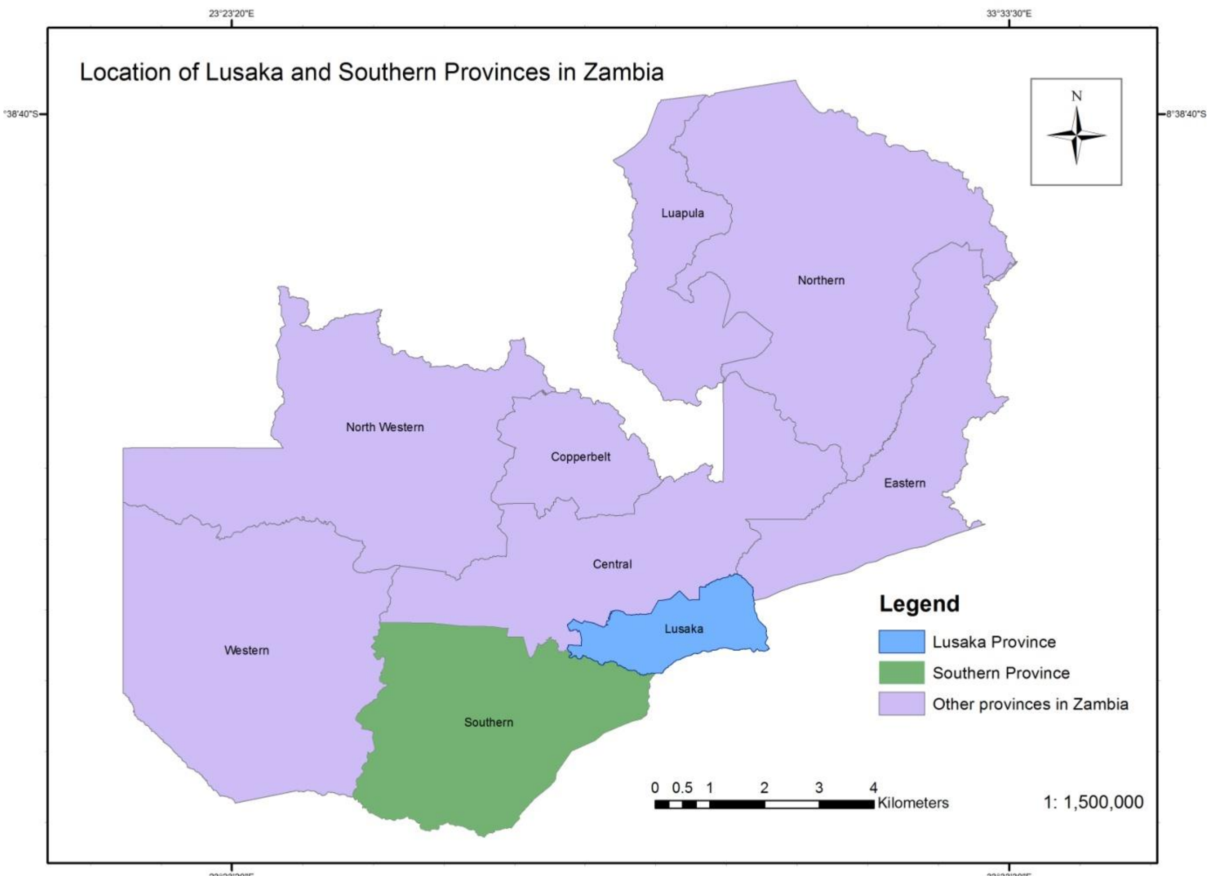

Figure 3.1: Location of the Study Provinces in Zambia

3.1 Location and Physical Characteristics of Lusaka Province

Lusaka Province is located in central Zambia on the central African plateau 1300m above sea level. It is situated between latitude 14^0 40’’ South to 16^0 00’’ South and between longitudes 27^0 45’’ East and 30^0 26’’ East. It is one of Zambia’s ten provinces. The Province is the smallest of all of Zambia’s Provinces with an area of 21,896 km^2. It shares international borders with Mozambique in the east and Zimbabwe in the south. Besides, it shares provincial administrative boundaries with Central Province in the north, Southern Province in the south and Eastern Province in the east.

The province has a humid sub tropical climate in the plateau areas and semi arid climate in Luangwa, Siavonga and Chirundu districts. Relief influences climate in the province. Plateau areas have higher rainfall and lower temperatures than the valley areas. Plateau areas experience average annual temperatures of 20.3^0 c and average rainfall of 831mm while valley areas experience average annual temperatures of 30^0 c and average rainfall of 650mm. December to May are the peak of the rainy season.

The relief is characterized by a flat plateau to the south west at an elevation of 1200 m and some hills to the north-east of the province at a elevation of 1,300 m above sea level. This topography has been greatly influenced by the underlying geology.

Lusaka Province is drained by three major rivers namely; Zambezi is the south, Kafue in the south west and Luangwa in the east. Other smaller rivers are Chongwe, Chalimaba and Ngwerere. The Underlying geomorphology in Lusaka influences the sitting of dams (Chomba and Sichingabula, 2015).

Much of Lusaka has moderately leached Ferrasols soils having a pH of 4.5 - 6.0. The soils are suitable for flowers and vegetable production. The valley floor areas of Luangwa has Vertisols, Luvisols and Fluvisols which are loamy to clayey and are slightly acidic to alkaline with pH of 5.0-7.5 These soils are suitable for the production of drought resistant crops like millet. The flood areas of Kafue plains have Vertisols that are slightly acid to alkaline with pH of 5.0 - 7.5. (Brammer, 1976).

3.1.1 Socio Economic Activities in Lusaka Province

Lusaka Province is the most populous of all the ten provinces of Zambia with a population of 2.2 million people (CSO, 2010). The distribution of the population at district level is as follows; Chongwe 187,969, Kafue 242,754, Luangwa 25,294 and Lusaka 1,742,979. At district level, Lusaka and Kafue have population growth rates of 4.9 percent and 4.6 percent, respectively. The province has the highest average population growth rate of 4.7 percent. in the country (CSO, 2010).

Being the province where the Capital City of Zambia is found, it offers employment to various occupational groups. Almost half the people in the manufacturing industry in Zambia are employed in Lusaka. Out of the total population, 65.7 percent depend on the informal sector for employment while the remaining 34.3% are engaged in the formal sector. Of the population in the informal sector, 10.7 percent are engaged in agriculture while 89.3 percent depend on non-agriculture activities for livelihoods such as fishing in Kafue's Chanyanya Fishing Camp (CSO, 2010).

The common land use in the outskirts of Lusaka is commercial and subsistence farming especially in the western direction. The major crops grown include maize, wheat, groundnuts and sweet potatoes. Livestock reared are cattle, sheep, goats, pigs, poultry rearing and fish farming. Large and small scale quarrying are the most significant mining activity for construction purposes. Lusaka Water and Sewerage Company provide water and sanitation services in the provincial districts. Other sources of water include private boreholes and shallow wells. Figure 3.2 shows the location of study dams in Lusaka Province.

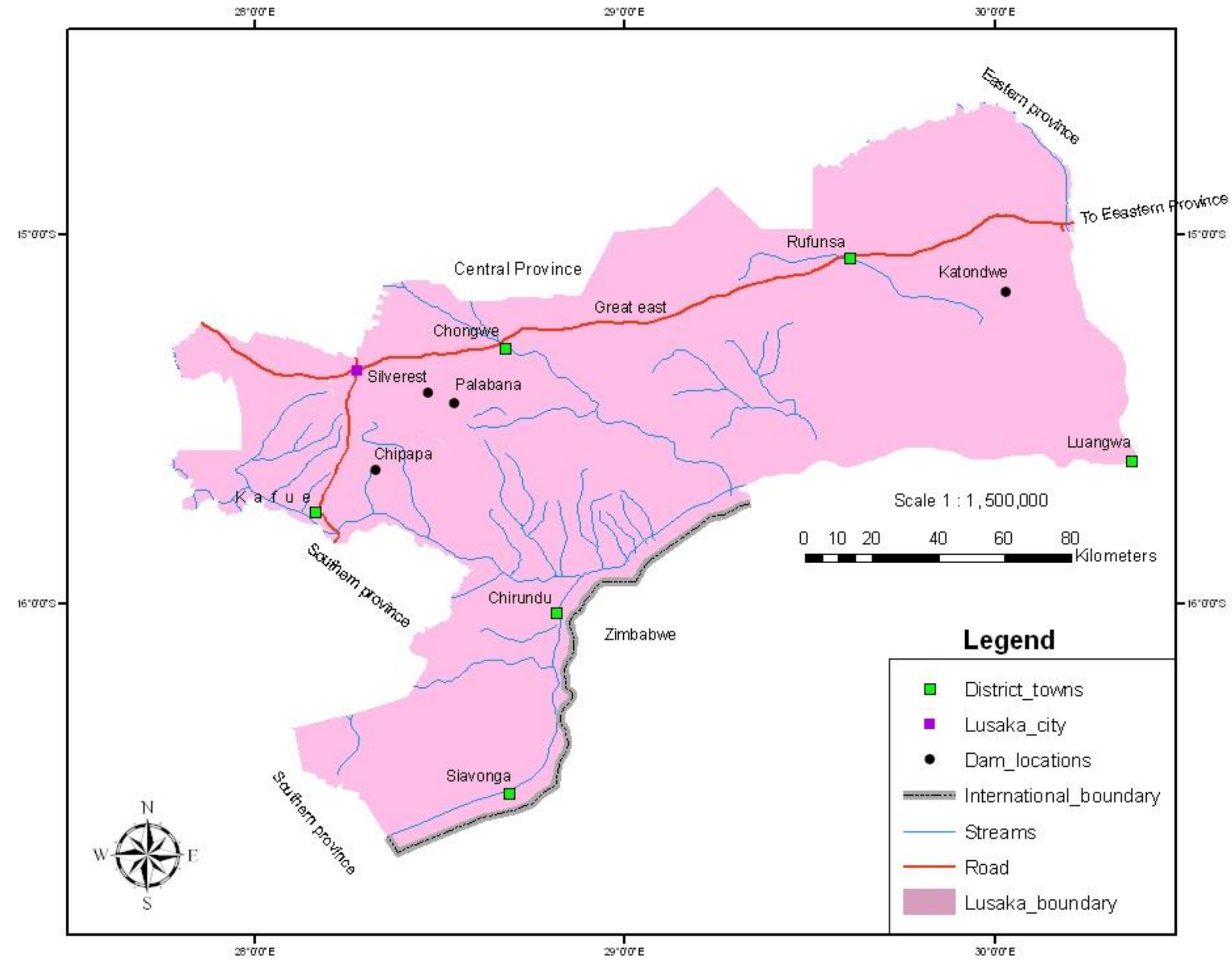

Figure 3.2: Location of the study dams in Lusaka Province.

A total of 41 small dams were found during the pre-survey of the province. The small dams of Lusaka Province have various uses such as irrigation purposes, domestic water supply, watering of animals, beautifying of areas, fishing and many more. The uses of dams are multiple and single in some cases.

3.2 Location and Physical Characteristics of Southern Province

Southern Province is located in the southern part of Zambia. It lies between latitudes 14.5° S and 18.5° S and between longitudes 24.4° E and 30.0° E. Southern Province covers a total area of approximately 85,500 km^2.

The relief of Southern Province rises from 400m in the Zambezi valley to almost 1400m above sea level on the central plateau. The relief can be categorized into four which are valley, plateau, escarpment and Kafue flats.

The area has a humid sub tropical climate with dry winters and hot summers. Three seasons are distinguished namely; rainy (a warm wet season from November to April), Cold season (a mild to cool dry season from April to August) and a hot and dry season (a hot and dry season from September to November) (Monley, 1986). The rains in the area are brought by the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is an area of pronounced convective activity and is therefore associated with heavy tropical rains. The total rainfall and intra-seasonal distribution vary a lot from year to year. The annual precipitation is between 700mm- 800mm with less than 650mm in the south western parts. The mean annual temperatures range from 19.3^0C to 22.1^0C.

The province lies in the watershed between the Congo and the Zambezi river systems and is part of two major river systems namely Zambezi and Kafue rivers. These three major rivers together with three tributaries namely Nanzhila, Magoye and Kaleya are the only perennial water courses in the province. The rest of the tributaries are characterized by seasonal or intermittent runoff during the year.

The common soils are sandy loam on the plateau areas with some Kalahari sands in the western parts of the province.

3.2.1 Socio Economic Activities in Southern Province

The population of Southern province is estimated at 1,589,926 with a mean growth rate of 2.8 percent between 2000 and 2010 and the majority of the people living in rural areas(CSO, 2010). Agriculture is the primary economic activity in the province with a mix of small holder and commercial farms. Drinking water for the district centers and smaller towns is provided by Southern Water and Sewerage Company (SWASCO). The district centers tap surface water sources like Zambezi, Kariba dam and other smaller dams. Figure 3.3 shows the location of Choma and Munzuma dams in Southern Province.

3.2.2 Choma District

Choma District is the provincial capital of Southern Province. Located on the main road and railway from Lusaka to Livingstone it is a market town bordering six districts namely; Monze, Pemba, Gwembe, Kalomo and Sinazongwe. It has an approximate area of 21,896 km^2 with a population of about 180,673 (CSO, 2010). Agriculture is the main economic activity in the area with some of it being supported by a number of small dams that have been constructed. Southern Water and Sewerage Company (SWSC) is the major Municipal Water supplier in Choma District town and the water is from two local dams namely Choma and Munzum.

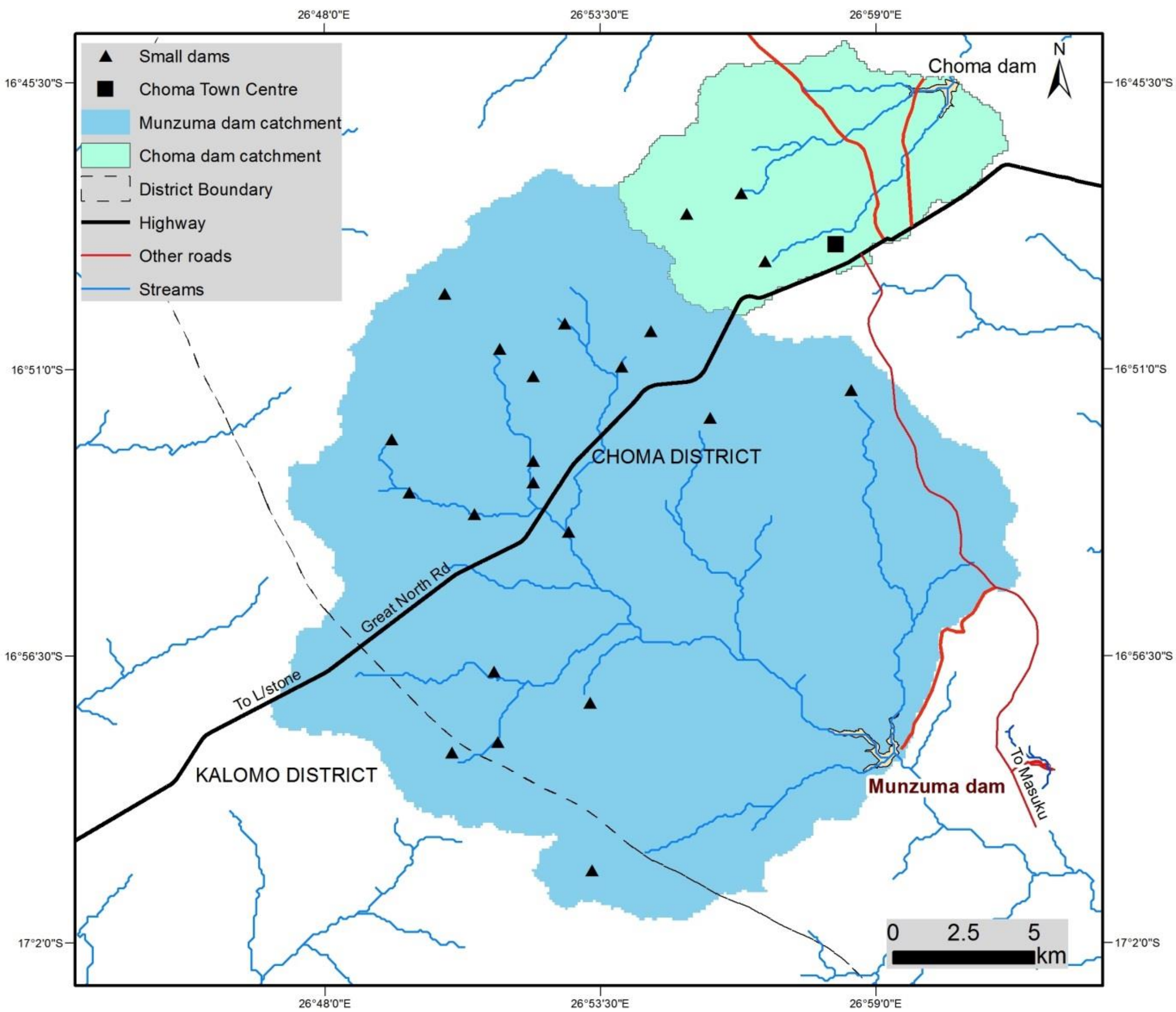

Figure 3.3: Location of the study dams in Choma District, Southern Province.

CHAPTER FOUR: METHODOLOGY

This chapter describes the research design and the research methods used in the study.

4.1 Study Design

A survey research design used in this study is described by Rea and Parcker (2005) as a type of study that gives an overview of an aspect in detail for a whole population. Further, Fowler (2009) states that survey research can be used to acquire quantitative descriptions of aspects in study populations.

The survey research design was used because it helped to provide an overview of the sediment problem in selected small dams in Southern and Lusaka Provinces. It was relevant to the collection of quantitative data on sedimentation and valuing of the costs and benefits of sediment and sedimentation on reservoirs. It was further applicable in conducting and interpreting results of a contingent valuation survey on dam owners and users on the possibility of undertaking a programme of sediment mining which can diminish the burden of sedimentation on the dams.

4.2 Data collection

In order to achieve the study objectives, secondary and primary data gathering methods and techniques were used. The materials and methods used in data collection were as presented in the forth subsections.

4.2.1 Materials

The equipment used during the surveys included boats (Inflatable and Hydrographic Remote Controlled Boat), a computer, protective clothing, measuring tape, ArcGIS software, a Geographical Positioning System (GPS).

4.2.2 Secondary data

A desk study was conducted on secondary data collection. This involved reviewing literature on the situation of sediment, sedimentation, dams and the use and application of the CBA method. Some of the literature reviewed are Lutz *et al*. (1994), Chancellor *et al*. (1996), Sichingabula, (1997), Balana *et al*. (2012), Alemau *et al*. (2013). The other secondary data was from published data such as Chiata *et al.* (2014) and many more other authors as well as unpublished reports from the Water Affairs Department under the Ministry of Energy and Water Development, Ministry of Agriculture, Southern Water and Sewerage Company and University of Zambia.

4.2.3 Primary data

Primary data was collected us described below.

4.2.3.1 Bathymetric Surveys

Bathymetric surveys were done on each of the reservoirs in order to determine the depth and volume of water while present dam storage capacity. Transect survey path lines followed during data collection were made at 10 to 20 meter sampling interval as recommended by Wilson and Richards, (2006) depending on the size of the dam. A Hydrographic Survey Remote Controlled Boat (RC–S2) was used to carry out bathymetric surveys over water surfaces collecting depth data. The boat was connected to a PC receiver (laptop) where the collection of data was recovered in real time. Each depth measurement included DGPS coordinates for locating its position on the reservoir surface and the elevation of each point was simultaneously taken along the survey lines.

4.2.3.2 Interviews

Semi-structured interview guides were used to collect information on the costs and benefits of having and removing sediments, purifying water from the small dams for municipal water supplies as well as concerned people’s perception of the value and problem of sediment in the selected dams. Semi-structured interviews used a list of questions answered by respondents. Interviews with key informants included technocrats from Southern Water and Sewerage Company, Ministry of Agriculture and dam committee members, private dam owners and concerned water users.

A Contingent Valuation Survey was done on local dam users to show the possibility of local peoples’ support to a project such as the one of mining the accumulated sediment and buying it from gravel miners for use as a fertilizer in their fields. A Contingent Valuation Survey was applied on a total of 97 respondents. The target population for the study comprised people who obtained their water from the small dams for either agricultural irrigation or domestic water use under a Municipal water supply. All the interviews were conducted by the researcher. The interview guide had three parts. The first part dealt with the socio-economic characteristics of the respondents like gender, age, level of education, income, household size, etc. The second part focused on the awareness of the problem of sediment in the dams and any possible known uses for it. The third and final part focused on the monetary valuation of the sediment by giving the Contingent Valuation question of Willingness to Pay.

4.3 Sampling Method and Sample Size

Purposive sampling was used when selecting dams for the study. This was done by choosing dams used for water supply to municipalities and irrigation schemes. The dams were six in total, namely, Choma and Munzuma in Southern Province, Katondwe, Silverest, Palabana and Chipapa dams in Lusaka Province. Three key informants per dam were interviewed and 97 household heads from all the dams were interviewed in a contingent valuation survey following a snowball selection method. Of these, 30 were from Chipapa area, 10 were from Katondwe area, 6 from Palabana, 6 from Silverest and 45 were from Choma. The number of people interviewed in Choma was combined for the two dams because the water from both dams is treated at the same plant for supply to Choma town.

4.4 Data analysis

Data was analyzed depending on the aspect of interest as follows:

4.4.1 Determination of the Current Dam Capacities

Current dam capacities were found by inputing and processing of the collected water-depth points and the corresponding DGPS coordinates (Selellick *et al*. 2013). The quality of the collected data was improved by checking for possible outliers in the data and removing duplicate data values from the dataset. The depth values were then assigned negative numbers for the software to interpret them as depth instead of a hill. The collected XYZ point data was then imported into ArcGIS 10.1for further processing. This involved performing Topo to raster interpolation of the survey XYZ data under different interpolation techniques available in the 3-D analyst in ArcGIS to create dam models using TIN, Kriging, Natural Neighbour and IDW. Contour and reservoir bathymetry maps were created from the XYZ data. Different methods gave slightly different areas and volumes. The volumes of the dams were determined by averaging the results of the different interpolation methods. Based on measurement data bathymetric maps of the dams were produced.

4.4.2 Determination of Deposited Sediment in the Dams

Deposited sediment in the dams was found by subtracting the current reservoir capacities from the initial reservoir capacities at the time of dam construction obtained from the construction plans (ICOLD, 1989).

4.4.3 Calculation of Sedimentation Rates

Sedimentation rates were found by dividing the sediment volume by the age of the dam (in years) as indicated in Equation 1. Age of the dam referred to the time period that had elapsed from the time the dam was constructed if no dredging had ever taken place. If dredging had been done before, age referred to the time period from the last desilting works.

$$SR = SV \div y \qquad \text{Equation 1}$$

Where, SR is the sedimentation rate, SV is the sediment volume that has accumulated in the dam and y is the age of the reservoir.

The actual mass of sediment contained in the dams was found as shown in Equation 2

$$SY = SV*dBD \qquad \text{Equation 2}$$

Where SY is sediment yield (ty^{-1}); dBD is dry bulk density (tm^{-3}).

The dry bulk density value used was 1.00 adopted from the report by JICA in 1995 which had an average value for small dams in Zambia. This bulk density value was used because it was not possible to collect sediment cores from the dams at the time of the study since they had water in them. None of the dams dried during the study period. The economic life expectancy of the dams were found by dividing the sediment volume (SV) in Equation (1) above by the rate of sedimentation as shown in equation (3).

$$LE = SV \div SR \qquad \text{Equation 3}$$

Where LE is the life expectancy, SV is the accumulated sediment volume and SR is the rate of sedimentation.

The expected lifespan of dams were based on realistic assessment of the expected operational circumstances considering the amount of sediments entering the dams.

4.4.4 Valuation of the Costs and Benefits of Sediment and Sedimentation

The value of sediment and sedimentation was analyzed using the CBA method based on a comparative basis of either continuing using the dams in the current conditions (Do-nothing alternative) or removing all the accumulated sediment (Without sediment alternative) and to continue doing so every time 10 percent of the original reservoir volume gets filled with sediment using equations (4), (5) and (6).

The Do-nothing alternative estimated the costs and benefits of sediment and sedimentation at the time of this study and the future loss of the productive potential of the small dams.

The Without sediment alternative estimated the costs and benefits of sediment and sedimentation based on sustaining intended irrigation and water supply while preventing future reductions to dam capacities and incomes from water supply.

The effects of continued sedimentation on the productivity of the dams were estimated for the time horizon of interest. These were then used to estimate returns at required points in time. This was to compare the expected difference in costs and benefits between what was being incurred with sediment present in the dams and what would be incurred if no sediment was present.

The no-sediment scenario was assessed by the value of sediment in the earnings that would occur to mining contractors during sediment mining operations. The average pricing used by gravel miners in Zambia for excavating and transporting was used and this was ZMW 50,000.00 for every excavated 1,000m^3 of sediment to be transported and deposited within a radius of 10 km.

These were according to the estimates from excavation mining company prices given to the researcher during the study. The benefits from using sediment were found by equating the monetary value of the mass of the excavated sediment to the price of the equivalent quantity of black soil on the Zambian market in Lusaka. To do this, knowledge of the weight of a cubic meter of sediment in each dam was required. The accumulated volumes of sediment in individual dams were converted to their weight equivalents in tonnes as shown in Equation 2. The monetary value from the sale of excavated sediment was assumed to be ZMW 200.00 equivalent to the current market cost of buying a tonne of black soil used in soil enrichment following a market survey during the research period. It was assumed that the excavated sediment could be used for landscaping, as an agricultural conditioner, as a potting composite, garden use or any other peat based composites.

Benefits from agriculture were obtained from farm gate prices of agricultural produce. Benefits from water supply were estimated from the user fees customers paid for water service provision. The other benefits were considered to be the money that can be earned from selling the accumulated sediment to local people for the purpose of improving their agricultural soils.

Costs were considered to be the forgone productive potential of the dams due to lost water storage space and high costs of water treatment due to the presence of sediment and sedimentation. Others included the costs of sinking boreholes and the cost of electricity to run the boreholes as water supply alternatives to the silted small dams.

A discount rate of 10 percent was used.

Present Value Costs or Benefits at individual time periods were calculated as shown in equation 4.

$$PV = 1 \div (1 + p)^t \qquad \text{Equation 4}$$

Where PV is the present value, p is the discount rate and t is the time in years.

Present Value Costs or Benefits after specified time periods were calculated as shown in equation 5.

$$PV = [(1+p)^t - 1] / [p(1+p)^t] \quad \text{Equation 5}$$

Where PV is the present value after a specified time period, p is the discount rate and t is the time period.

Where investments in alternative sources of water had been made such as sinking of boreholes, the present values were compounded to find the value of the investment at the time of this study as shown in equation 6.

$$PV = P(1+r)^t \quad \text{Equation 6}$$

Where PV is the present value after a specified time period, p is the principle investment amount r is the annual interest rate and t is the number of years the money had been invested.

The Net Present Value was calculated using equation 7. NPV is a way of evaluating the costs and benefits of an action over time in terms of their worth in the present.

Net Present Value (NPV) = Present Value Benefits (PVB) – Present Value Costs (PVC)

$$NPV = PVB - PVC \quad \text{Equation 7}$$

Due to lack of credible data in previous years on dam productivity and related annual sediment yields, the CBA was conducted based on the NPV in the year 2015 of dam operation under the two alternatives of ‘operating the dams with sediment’ and ‘operating the dams without sediment’ with consideration on what was being incurred as a result of sediment accumulation.

Results of the CV survey were used in the CBA to find out the feasibility of an undertaking such as the one of mining the sediment and reselling it to local people. Linear and binary regression analyses at 95 % confidence Interval were used to determine significant variables influencing the willingness to pay for sediment removal by the dam users. Independent variables used in the statistical analysis were gender, age, marital status, ownership of residence or land under cultivation, education level, household size and household income.

4.4.5 Respondents Perception and Value of Sediment

The Respondents perception and Value of sediment and sedimentation were analyzed using descriptive and regression analysis. Data was coded using Microsoft excel and transferred to SPSS (version 16.0). Frequency tables were generated and used in the analysis and interpretation of the findings.

CHAPTER FIVE: FINDINGS OF THE STUDY

This Chapter provides summaries of collected data according to the research objectives. The data is presented in the form of tables and maps.

5.1 Characteristics of Individual Reservoirs

Characteristics of the individual dams included in this study are presented based on location, ownership, management, bathymetric surveys and the valuation of sediment and sedimentation in individual dams.

5.1.1 Chipapa Dam

Chipapa dam is a communal dam found in Kafue district south/west of Lusaka Province. An agricultural irrigation scheme exists at this dam with a total of 120 member farmers from the surrounding community. A dam management committee is in place. According to the Dam Committee Secretary, the committee charges members a levy of ZMW5.00 per cultivatable portion of land per year. The cultivatable portions of land are small parcels of land used for crop cultivation with an area of $165m^2$ each. A total of 455 land parcels totaling 7.5 hectares of land were under cultivation at the time of the study. According to the District Agricultural Officer, the cultivatable land serviced by the dam can be increased to 10 hectares if the dam could hold the originally intended quantity of water. The Dam Committee Secretary stated that a ZMW5.00 fee per parcel of land is charged on every member who uses the water from the dam. The levy is used for maintaining the fence around the land used for growing irrigation crops to prevent livestock from entering irrigated areas. He noted that according to the recorded information, the current dam capacity allows for dry season cultivation of crops worth ZMW 40,000 for the entire agricultural scheme per year. If the dam was to supply water at its intended capacity, the entire scheme would have been producing crops worth ZMW80,000 per year, which is double the current value. Chipapa farmers have not put up a cost recovery system to self finance the operations of the dam. All the interviewed respondents (100%) using water from this dam stated that they were aware of the siltation problem in the reservoir but could not deal with it on their own but needed the government to assist them. At the time of this study, it was observed that some people were cultivating their crops in areas very close to the reservoir waterline while others were making bricks within the peripheries of the dam and no sediment management measures were in place for the dam.

5.1.1.1 Bathymetry and Sedimentation

The bathymetric map of Chipapa dam in 2015 was constructed and is given in Figure 5.1. The depth of the dam increases with increasing colour texture. The deep blue areas (3.5m- 4.0m) show the deepest regions in the dam and the light blue areas show where the dam was shallow. Depth decreased with distance from dam crest (Figure.5.1).

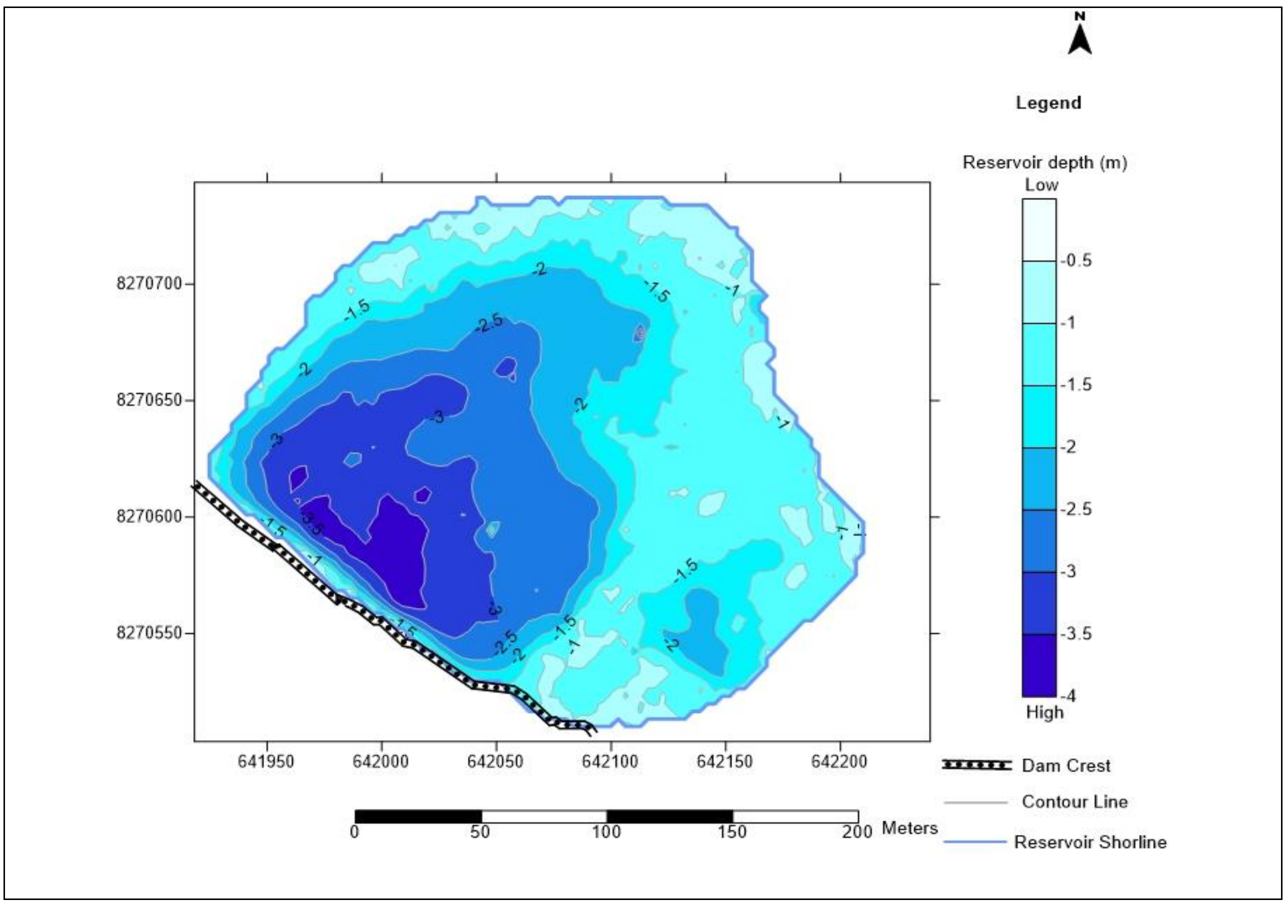

Figure 5.1: Bathymetric map of Chipapa Dam, Kafue District in Lusaka Province, January, 2015.

Area and volume of Chipapa dam at various depths are given in Table 5.5. The analysis of the bathymetric data for Chipapa dam in 3-D analysis of ArcGIS 10.1 the dam gave a total surface area of 44,336.51m^2 and the volume was 95,750.01m^3. The deepest point was found to be 4.0m and this was near the dam crest. Bathymetric results for Chipapa dam are as presented in Table 5.1.

Table 5.1: Bathymetric Survey results for Chipapa Dam

Water Depth(m)	Water Surface Area(m^2)	Water Volume (m^3)
4.0	44,336.51	89,087.75
3.5	44,322.25	66,212.57
3.0	40,009.97	43,336.63
2.5	26,480.63	20,461.07
2.0	20,431.67	15,887.77
1.5	13,968.39	73,55.61
1.0	6,830.06	21,52.93
0.5	1,344.48	123.16
0.0	0	0

Source: Field data,2015

From the results of the bathymetric survey, it was found that sediment volume in the reservoir amounted to 104,249.99 m^3 or 52.0 percent of the designed storage capacity. The sediment was estimated to have a mass of 104,249.99 tonnes. The reduced useful dam capacity was found to have negatively affected the water holding capacity of the dam leading to reduced irrigatable area and irrigated crop yields. From 1958 to 2015 the dam volume decreased from 200,000 m^3 to 95,750.01 m^3 corresponding to an annal sediment yield of 1,828.95 m^3. The Projected life of the dam was 57 years from the year 2015 (Table 5.2). Without any interventions on the sedimentation process such as effective catchment conservation measures or sediment excavation, Chipapa dam is projected to fill up with sediment by the year 2072. The resultant loss of productive water could adversely impact on the sustainability of the water dependent agricultural livelihoods.

Table 5.2: Calculated Sediment Yield Parameters for Chipapa Dam

Variable	Value
Design dam capacity (m^3)	200,000
Current dam capacity (m^3)	95,750.01
Sediment volume (m^3)	104,249.99
Percentage loss of volume (%)	52.0
Period of dam operation from construction (yrs)	57
Maximum depth (m)	3.7
Rate of sedimentation (m^3/yr)	1,828.95
Dam life expectancy (yrs)	57
Dry bulk density	1.0
Sediment yield (tonnes/yr)	1,828.95
Mass of accumulated sediment (tonnes)	104,249.99

Source: Field data,2015

5.1.1.2 Costs and Benefits

The costs and benefits of sediment on Chipapa dam are summarized in Table 5.3. The costs of sediment in Chipapa dam were estimated to be the reduced agricultural irrigation output and the excavation and transportation of the mined sediment to people who would be willing to buy it. The benefits of sedimentation were the earnings from the sale of the excavated sediment and the increased revenue from irrigated crop production owing to the increased dam volume. Removal of accumulated sediment would benefit farmers from the increased water volumes as well as benefit gravel miners by earning them an income once the sediment is sold. This must be done every 11 years when 10% of the dams' design capacity is expected to be filled with sediment.

Table 5.3: Costs and Benefits of Sediment to Chipapa Dam

Parameter	Value Amount (ZMW)
Excavation and transportation of accumulated sediment at onset of the programme	5,212,499.50
Sale of the accumulated sediment	20,849,998.00
Excavation and transportation in the 11th year	1,005,922.50
Sale of the excavated sediment in the 11th year	4,023,690.00
Gross annual income with accumulated sediment in the dam	40,000.00
Gross annual income after removing accumulated sediment in the dam	80,000.00

Source: Field data

The amount of accumulated sediment in the dam would cost ZMW 5,212,499.50 to mine and transport to any place within a radius of 10Km. Benefits of ZMW 20,849,998.00 could be realized from the sale of this mined sediment. If the sediment is removed from the dam, an extra income of ZMW 40,000.00 other than to the current (ZMW 40,000.00) would be realized from increased agricultural output owing to the increased water volumes in the dam used in irrigating crops. In 11 years time, it would cost ZMW 1,005,922.50 to mine and transport the accumulated sediment at the current rate of sedimentation. The net value of sediment was found by subtracting costs from benefits of sediment in Chipapa dam under the two alternatives of with and without sediment. The value of benefits and costs of the alternative of operating the dam with sediment in it were the same giving a value of ZMW 0.00 while the alternative of removing the sediment gave an outright positive value of ZMW 17,214,812.78 (Table 5.4).

Table 5.4: Present Values and Net Present Values of Sedimentation to Chipapa Dam

Alternative	**Present Value Benefits (ZMW)**	**Present Value Costs (ZMW)**	**Net Present Value (ZMW)**
With Sediment (Do-nothing alternative)	259,802.44 (gross annual income)	259,802.44 (Forgone production due to reduced dam capacity)	0.00
Without Sediment	20,849,998 (sale of excavated sediment in year 0) 4,023,690.00 (sale of excavated sediment in year 11) 519,604.88 (Gross annual income)	5,212,499.5 (Excavation and transportation at the start of the programme) 1,005,922.50 (Excavation and transportation in year 11)	17,214,812.78

Source: Field data,2015

Note: The Present Values for both alternatives (Do-nothing and Without Sediment) were estimated by discounting the costs and benefits of sedimentation under the two alternatives except for those that occur at the onset of the sediment removal programme. A discount rate of 10% was used assuming constant crop production income in the next 11 years at current farm gate prices.

5.1.2 Katondwe Dam

Katondwe dam is located in Luangwa District of Lusaka Province. It is a private dam owned by Katondwe Mission. The dam is an earth filling dam which was constructed in 1980.The water from this dam originates from a natural spring 200 meters away from the dam. Currently this water is supplied to the mission school, hospital and staff houses. A report of analysis of water from the dam done in 2002 by the Norwegian Agency for International Development (NAID) revealed that water from this dam was contaminated with colifom bacteria and therefore unsafe for domestic use if supplied untreated to the users (NAID, 2002). Because of the bacteria contamination, 6 boreholes were sunk in 2002 to provide clean water to the mission center. This is one dam where sediment control was being undertaken by prohibition of any form of cultivation in the upper spring catchment. According to one of the interviewed key informants, desilting was done in the dam once in 1995 but there was no record of how much sediment was removed or how much money was spent on this activity.

5.1.2.1 Bathymetry and Sedimentation

The bathymetric map of Katondwe dam created from the study data collected in January 2015 was calculated and is presented in Figure 5.2. The deepest regions in the dam are represented with a darker shade of blue mainly around the center of the dam and in the area near the dam crest. Shallow areas are shown with a lighter shade of blue mainly in the areas away from the center of the dam. The contour lines distinguish the various depth shades. The deepest point in this dam was 3.2m.

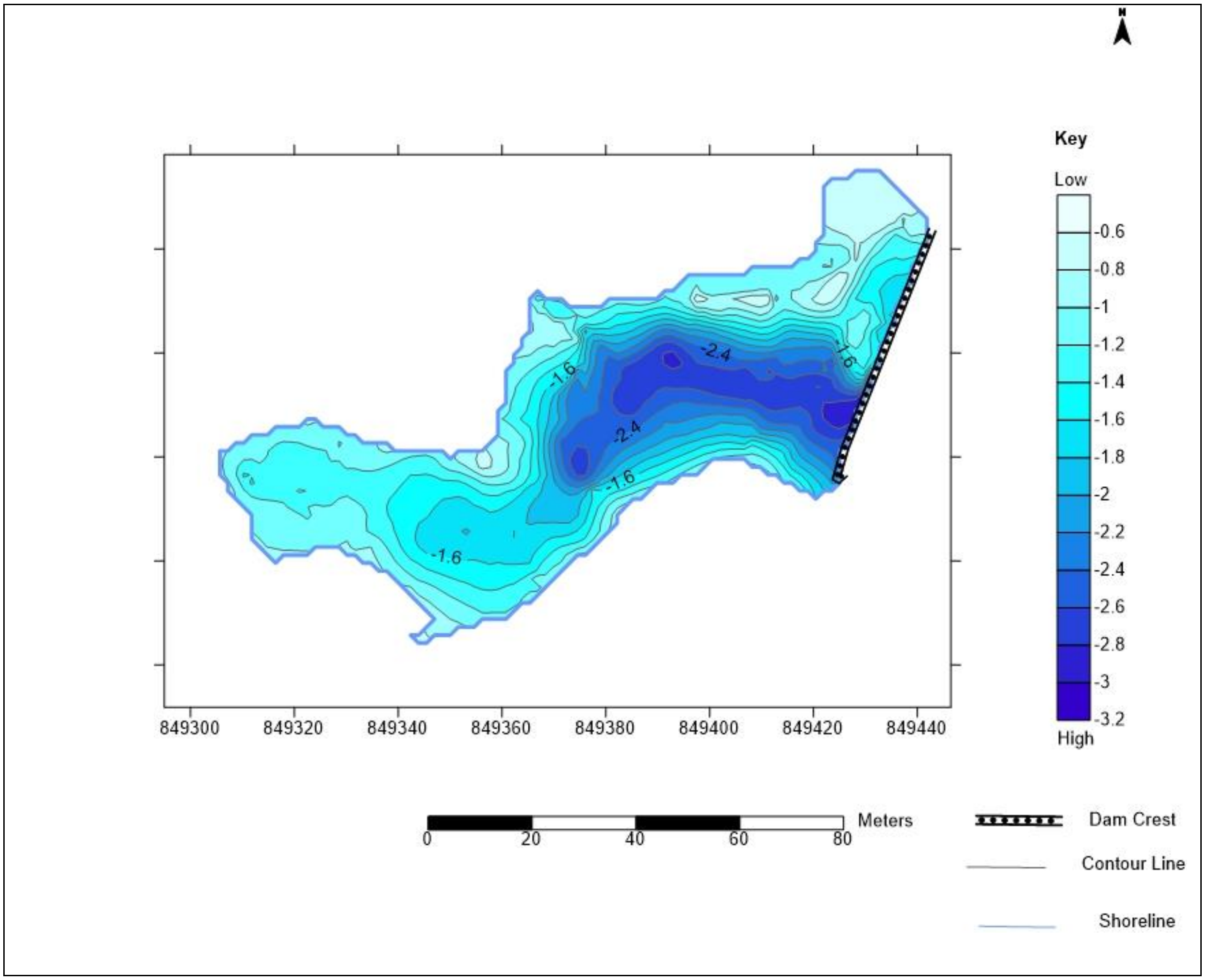

Figure 5.2: Bathymetric Map of Katondwe Dam, Luangwa District in Lusaka Province, January, 2015.

The areas and volumes of the dam at various depths found are given in Table 5.5. The dam had an estimated surface area of 7,881.63 m^2 while the volume was 10,714.88m^3.

Table 5.5: Bathymetric Survey results for Katondwe Dam

Water Depth (m)	Surface Area (m^2)	Water Volume (m^3)
3.2	7881.63	10714.88
2.5	70421.41	6806.57
2.0	5189.66	3423.84
1.5	2681.85	1598.29
1.0	1402.33	628.11
0.5	681.57	113.14
0.0	0.00	0.00

Source: Field data,2015

The results of the bathymetric survey indicate that sediment volume in the dam amounted to 9,937.12m^3 or 39.2 percent of the designed storage capacity (Table 5.6). The rate of reservoir sedimentation was estimated to be 283.92 m^3/year from 1995. The useful life of the dam is expected to be 37.7 years. Without any interventions on the sedimentation process such as through effective catchment conservation measures or accumulating sediment excavation, Katondwe dam is projected to fill up with sediment by the year 2053.

Table 5.6: Calculated Sediment yield Parameters for Katondwe Dam

Variable	Value
Design dam capacity (m^3)	20,652
Current dam capacity (m^3)	10,714.88
Sediment volume (m^3)	9,937.12
Percentage loss of volume (%)	39.2
Period of dam operation from construction (yrs)	35
Maximum depth (m)	3.0
Rate of sedimentation (m^3/yr)	283.92
Dam life expectancy (yrs)	37.7
Dry bulk density	1.0
Sediment yield (tonnes/yr)	283.92
Mass of accumulated sediment (tonnes)	9,927.12

Source: Field data,20

5.1.2.2 Costs and Benefits

The costs of sediment to Katondwe dam were the excavation and transportation fees of mined sediment due to loss in storage capacity of the dam, the sinking of boreholes and the electricity that is bought annually to pump water from the boreholes. The benefits were the earnings from the sale of the excavated sediment. Removal of accumulated sediment would benefit the Katondwe mission community from the increased water volumes in the dam, reduced costs of water abstraction using boreholes as well as earning them an extra income once the sediment is sold. A summary of the costs and benefits on this dam are given in Table 5.7.

Table 5.7: Costs and Benefits of Sediment and Sedimentation on Katondwe Dam

Parameter	Amount (ZMW)
Excavation and transportation of accumulated sediment at onset of programme	496,356.00
Sale of excavated sediment	1,985,424.00
Excavation and transportation in the 7th year	99,372.00
Sale of excavated sediment in the 7th year	397,488.00
Sinking of three boreholes 13 years ago due to sediment accumulation	42,000.00
Annual payments for electricity to run the boreholes	3,000.00

Source: Field data,2015

The amount of accumulated sediment in the dam would cost ZMW 495,356.00 to mine and transport to any place within a radius of 10Km. Benefits of ZMW 1,985,424.00 would be realized from the sale of this mined sediment. In seven years time, it would cost ZMW 99,37200 to mine and transport the accumulated sediment at the current rate of sedimentation.

The total net value of sediment was found by subtracting costs from benefits of sediment in Katondwe dam under the two alternatives of with and without sediment. The alternative of operating the dam with sediment in it gave a negative value ZMW – 159,550.26 for sediment while the alternative of removing the sediment gave a positive value ZMW – 630,140.27 (Table 5.8).

Table 5.8: Present Values and Net Present Values of Sediment and Sedimentation on Katondwe Dam

Alternative	Present Value Benefits (ZMW)	Present Value Costs (ZMW)	Net Present Value (ZMW)
With Sediment (Do-nothing alternative)	0.00	144,984.00 (Sinking of boreholes) 14,566.26 (Payments for electricity annually)	- 159,550.26
Without Sediment	1,985,424.00 (sale of excavated sediment in year 0) 187,430.93 (sale of excavated sediment in year 7) 159,550.26 (Avoided costs from sinking of boreholes and electricity for pumping the water)	496,356.00 (Excavation and Transportation at the start of the programme) 46,357.73 (Excavation and transportation in year 7)	1,789,691.46

Note: The Present Values for both alternatives (Do-nothing and Without Sediment) were estimated by discounting the costs and benefits of sedimentation under the two alternatives except for those that occur at the onset of the sediment removal programme. The cost of sinking boreholes was compounded to give its PV. A discount rate of 10 percent was used assuming the boreholes would remain to be the only alternative source of water to the dam in the next 7 years.

5.1.3 Palabana Dam

Palabana dam is found in Chongwe District in Lusaka Province. It's owned by the Zambia Livestock Development Trust. Constructed in 1965, it was desilted once in 1995 though there was no recorded information on how much this desilting had costed. Similar to Katondwe dam, water into this dam originates from a natural spring a few meters away from where the dam is located. This dam is being used for watering dairy cows, few other farm animals and fodder crop irrigation for feeding mainly cattle and goats. A lot of sedimentation has affected this dam by raising it's reservoir bed. As a result, less water is stored in the reservoir. According to the farm manager of the Livestock Development Trust, the reduction in water storage capacity resulted in the sinking of 3 boreholes in 2006 to supplement for the shortfall in the required water to irrigate the fodder crops for the animals kept at the Institute. He further stated that the institute has 156 dairy cows that provide 700 litres of milk daily. This milk is sold to either Pamalat or Valun at a price of ZMW3.40 per litre. If the dam was operational at full capacity without sediment, the institute would have been able to keep 260 dairy cows giving between 1,000 – 1,200 litres of milk per day all year round.

5.1.3.1 Bathymetry and Sedimentation

The bathymetric map of Palabana dam created from the field survey data collected in January 2015 is given in Figure 5.3. The deepest regions in the dam are represented with a darker shade of blue mainly around the center of the dam. Shallow areas are shown with a lighter shade of blue mainly in the areas away from the center of the dam. The contour lines distinguish the various depth shades. The deepest point recoded in this dam was 3.8m.

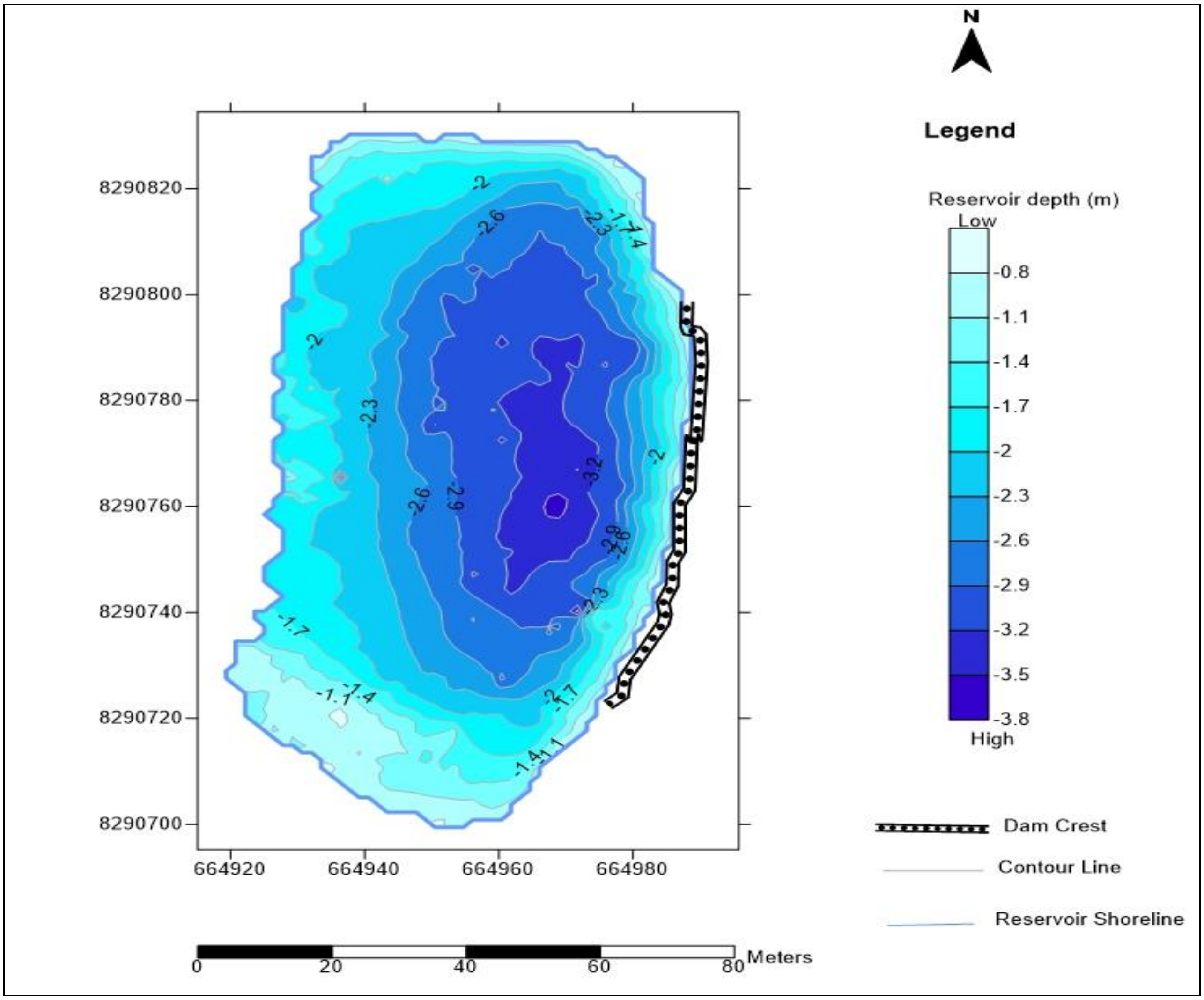

Figure 5.3: Bathymetric Map of Palabana Dam, Chongwe District in Lusaka Province January, 2015.

The areas and their corresponding volumes in the dam at various depths are given in Table 5.9. The estimated dam surface area was 6,771.1m^2 and the volume was 16,163.81m^3.

Table 5.9: Bathymetric Survey results for Palabana Dam

Water Depth	Water Surface Area (m^2)	Water Volume (m^3)
3.8	6,771.1	15,424.23
3.5	6,652.67	11,904.33
3.0	6,447.55	8,427.88
2.5	5,559.23	5,393.378
2.0	4,206.85	2,877.68
1.5	2,680.07	1,203.66
1.0	1,164.31	200.84
0.5	12.23	1.05
0.0	0	0

Source: Field data,2015

From the results of the bathymetric survey, it was determined that sediment volume in Palabana dam amounted to 7,835.19m^3 representing 32.7% of the designed storage capacity. Reservoir capacity change for the years 1995 to 2015 are presented in Table 5.10. The rate of reservoir sedimentation was estimated at about 391.75 m^3/year resulting in the dam's life span of 61 years. Without any interventions on the sedimentation situation, Palabana dam is projected to fill up with sediment by the year 2076.

Table 5.10: Calculated Sediment Yield Parameters for Palabana Dam

Variable	Value
Design dam capacity (m^3)	24,000
Current dam capacity (m^3)	16,163,81
Sediment volume (m^3)	7,835.19
Percentage loss of volume (%)	32.7
Period of dam operation from construction (yrs)	50
Maximum depth (m)	4.2
Rate of sedimentation (m^3/yr)	391.75
Dam life expectancy (yrs)	61
Dry bulk density	1.0
Sediment yield (tonnes/yr)	391.75
Mass of accumulated sediment (tonnes)	7,835.19

Source: Field data,2015

5.1.3.2 Costs and Benefits

A summary of the costs and benefits of sedimentation to Palabana dam is as given in Table 5.11. The costs of sediment to Palabana dam were the loss in storage capacity of the dam, the cost of sinking the three boreholes, the price of electricity for pumping water using the boreholes and the price of conducting excavation and transportation of the mined sediment. The time period of excavating sediment when 10 percent of original dam capacity fills with sediment was found to be six years and this was used as the time periods of carrying out the excavation works. The benefits were the earnings from the sale of the mined sediment and the possible increased revenues from the increased stock of animals owing to the enlarged dam capacity.

Table 5.11: Costs and Benefits of Sedimentation on Palabana Dam

Parameter	Amount (ZMW)
Excavation and transportation of accumulated sediment at onset of program	391,759.50
Sale of excavated sediment	1,565,038.00
Excavation and transportation in the 6th year	12,525.00
Sale of excavated sediment in the 6th year	470,100.00
Sinking of three boreholes 9 years ago due to sediment accumulation	21,000.00
Annual payments for electricity to run the boreholes	2,500.00
Gross annual income with the accumulated sediment	868,700.00
Gross annual income with removing accumulated sediment	1,365,100.00

Source: Field data,2015

The amount of accumulated sediment in the dam would cost ZMW 391,759.50 to mine and transport to any place within a radius of 10Km. Benefits of ZMW 1,565,038.00 would be realized from the sale of this mined sediment. If the sediment is removed from the dam, an extra income of ZMW 496,400.00 in comparison to the current (ZMW 868,700.00) would be realized from increased milk production owing to the increased water volumes in the dam used in fodder irrigation that the cows eat. In six years time, it would cost ZMW 12,525.00 to mine and transport the accumulated sediment at the current rate of sedimentation.

The total net value of sediment was found by subtracting costs from benefits of sediment in Palabana dam under the two alternatives of with and without sediment. The alternative of operating the dam with sediment in it gave a lower value of ZMW – 1,561,057.52 for sediment while the alternative of removing the sediment gave a higher value of ZMW – 7,378,934.48 (Table 5.12).

Table 5.12: Present Values and Net Present Values of Sedimentation on Palabana Dam

Alternative	Present Value Benefits (ZMW)	Present Value Costs (ZMW)	Net Present Value (ZMW)
With Sediment (Do-nothing alternative)	3,783,415.23 (gross annual income from the sale of milk from dairy cows)	49,518.00 (Sinking of boreholes) 10,888.15 (Annual electricity payments) 2,161,951.56 (Forgone production due to reduced number of dairy cows)	1,561,057.52
Without Sediment	1,567,038.00 (sale of excavated sediment) 265,359.23 (sale of excavated sediment in year 6) 5,945,366.79 (Gross annual income)	391,759.5 (Excavation and Transportation at the start of the program) 7,070.04 (Excavation and transportation in year 6)	7,378,934.48

Source: Field data,2015

Note: The Present Values for both alternatives (Do-nothing and Without Sediment) were estimated by discounting the costs and benefits of sedimentation under the two alternatives except for those that occur at the onset of the sediment removal programme. The cost of sinking the boreholes 9 years ago was compounded to get its current Present Value. A discount rate of 10% was used assuming constant crop production income in the next 6 years at current farm gate prices.

5.1.4 Silverest Dam.

Silverest dam is located in Chongwe District in Lusaka province. It is a private dam owned by one farmer. The dam has been in operation since 1989. The water that collects in it comes from a perennial stream called Kapako. At the time of construction, the dam was designed to provide water for irrigation of 75 - 85 hectares of land, but during the time of the survey, only 20 hectares of land was under irrigation. The reduced land under irrigation was not caused by the sediment accumulated in the dam but by the inability of the dam owner to utilize the water in the dam to the maximum. The dam is used for growing winter wheat. The wheat is sold at ZMW40,000.00 annually.

5.1.4.1 Bathymetry and Sedimentataion

The bathymetric map of Silverest dam created from the field survey data collected in January 2015 is as shown in Figure 5.4.

The deepest regions in the dam are represented with a darkest shade of blue mainly around the center of the dam. Shallow areas are shown with a lighter shade of blue mainly in the areas away from the center of the dam. The contour lines distinguish the various depth shades. The deepest point recoded in this dam was 9.7m.

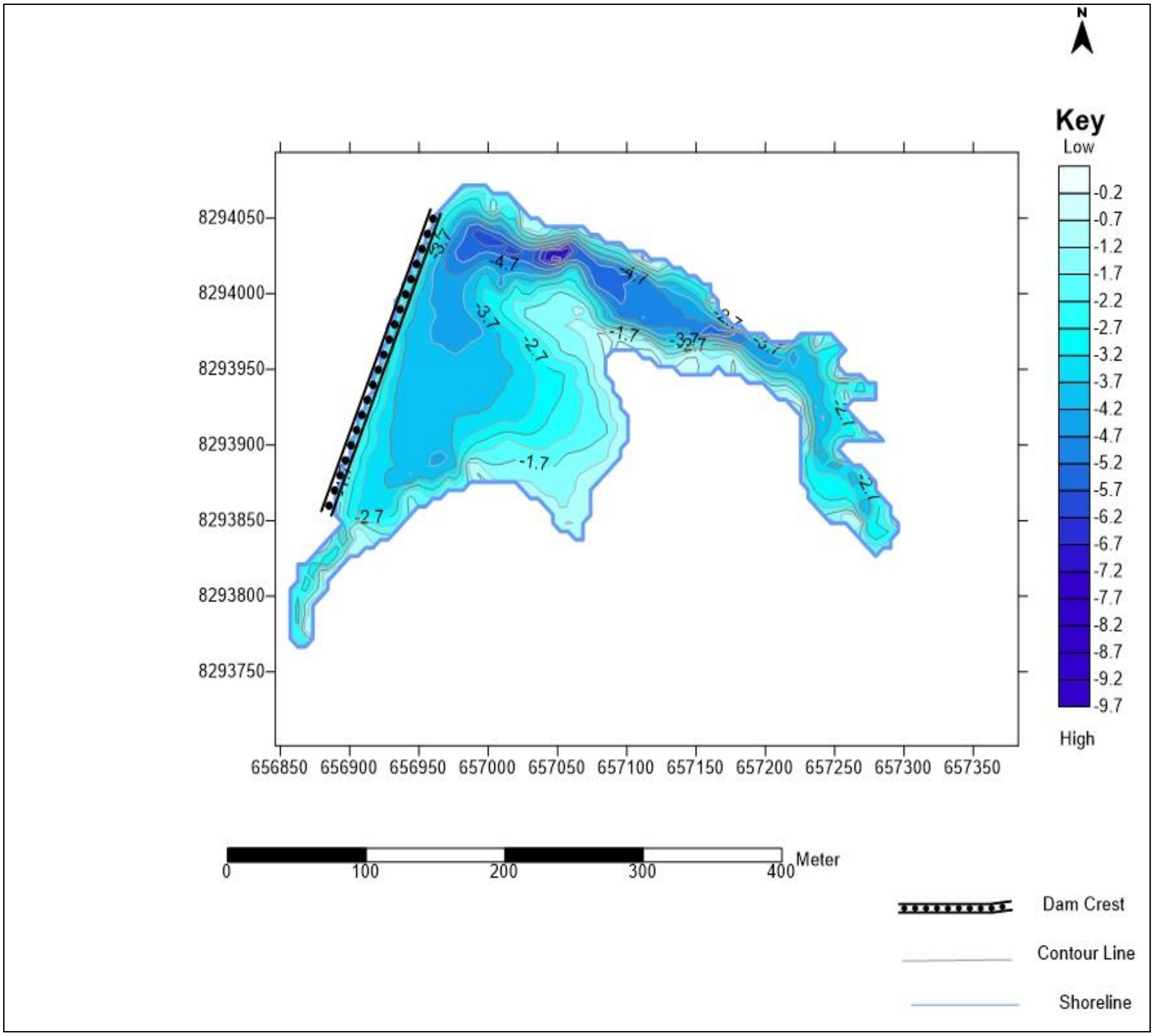

Figure 5.4: Bathymetric Map of Silverest Dam, Chongwe District in Lusaka Province, January, 2015.

The areas and volumes of Silverest dam at various depths are given in Table 5.13. The estimated dam surface area of the dam was 86,082.47m^2; the volume was 368,331.46m^3.

Table 5.13: Bathymetric Survey results for Silverest Dam

Water Depth(m)	Water Surface Area (m^2)	Water Volume (m^3)
9.5	86082.47	368331.46
9.0	86080.41	325983.17
8.5	86078.38	283634.88
8.0	86075.23	241286.59
7.5	86070.51	198937.21
7.0	86074.36	156590.12
6.5	73332.51	116214.78
6.0	55720.18	84846.13
5.5	42466.40	61210.64
5.0	33198.89	42993.75
4.5	26097.91	28528.5
4.0	20497.44	17263.45
3.5	12344.03	9087.96
3.0	6266.55	4916.22
2.5	3957.96	2507.75
2	1979.82	1099.41
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 summary of the sediment yield data for the dam is given in Table 5.18. The results of the bathymetric survey showed that the sediment volume in Silverest dam was 379,480.0m^3 or 50.7% of the designed water storage capacity. The weight of this sediment was estimated to be 379,480 tonnes. The rate of reservoir sedimentation was therefore 14,595.41 m^3/year giving the dam a useful life of 51 years. Without any interventions on the sedimentation process say through effective catchment conservation measures, Silverst dam is projected to fill up with sediment by the year 2066.

Table 5.14: Calculated Sediment Yield Parameters for Silverest Dam

Variable	Value
Design dam capacity (m^3)	747,812.00
Current dam capacity (m^3)	368,331.46
Sediment volume (m^3)	379,480
Percentage loss of volume (%)	50.7
Period of dam operation from construction (yrs)	26
Maximum depth (m)	9.7
Rate of sedimentation (m^3/yr)	14,595.41
Dam life expectancy (yrs)	51
Dry bulk density	1.0
Sediment yield (tonnes/yr)	14,595.41
Mass of accumulated sediment (tonnes)	379,480

Source: Field data,2015

5.1.4.2 Costs and Benefits

The costs and benefits of sediment to Silverest dam are given in Table 5.15. The costs of sediment in Silverest dam were the loss in annual incomes due to loss in storage capacity of the dam and the excavation and transportation costs of the mined sediment. The benefits were the incomes from the sale of the mined sediment and the increased incomes due to the increased dam capacity. Removal of accumulated sediment would benefit the farmer from the increased water volumes and earn her an income from the sale of the sediment.

Table 5.15: Costs and Benefits of Sedimentation on Silverest Dam

Parameter	Amount (ZMW)
Excavation and transportation of accumulated sediment at onset of the programme	18,794,000.00
Sale of the accumulated sediment in year 0	75,896,000.00
Excavation and transportation in the 5th year	3,648,852.50
Sale of the excavated sediment in the 5th year	14,595,410.00
Gross annual income with accumulated sediment in the dam	40,000.00
Gross annual income from removing accumulated sediment in the dam	40,000.00

Source: Field data, 2015.

The amount of accumulated sediment in the dam would cost ZMW 5,212,499.50 to mine and transport to any place within a radius of 10Km. Benefits of ZMW 20,849,998.00 could be realized from the sale of this mined sediment. If the sediment is removed from the dam, an extra income of ZMW 40,000.00 other than to the current (ZMW 40,000.00) would be realized from increased agricultural output owing to the increased water volumes in the dam used in irrigating crops. In 11 years time, it would cost ZMW 1,005,922.50 to mine and transport the accumulated sediment at the current rate of sedimentation.

The total net value of sediment was found by subtracting costs from benefits of sediment in Silverst dam under the two alternatives of with and without sediment. The alternative of operating the dam with sediment in it gave a lower value of ZMW – 151,631.48 for sediment while the alternative of removing the sediment gave a positive value of 75,499,893.98 (Table 5.16).

Table 5.16: Present Values and Net Present Values of Sedimentation on Silverst Dam

Alternative	**Present Value Benefits (ZMW)**	**Present Value Costs (ZMW)**	**Net Present Value (ZMW)**
With Sediment (Do-nothing alternative)	151,631.48 (gross annual income)	0.00	151,631.48
Without Sediment	75,896,000 (sale of excavated sediment at onset of the programme) 9,062,596.57 (sale of excavated sediment in year 5) 151,631.48 (Gross annual income)	18,794,000.00 (Excavation and Transportation at the start of the programme) 2,265,649.14 (Excavation and transportation in year 5)	75,499,893.98

Source: Field data,2015

Note: The Present Values for both alternatives (Do-nothing and Without Sediment) were estimated by discounting the costs and benefits of sedimentation under the two alternatives except for those that occur at the onset of the sediment removal programme. A discount rate of 10% was used assuming constant crop production income in the next 5 years at current farm gate prices.

5.1.5 Choma and Munzuma Dams

5.1.5.1 Choma Dam

Choma dam is found north of Choma town in Southern Province. The dam is owned by Southern Water and Sewerage Company (SWASCO). It was constructed in 1955 for agricultural purposes but its use was later changed to municipal water supply for Choma town. It is one of the two dams operated by SWASCO for municipal supply of water to Choma town. Information from the operations manager for SWASCO was that Choma dam provides 1,600 – 1800 m^3 of water per day though it is capable of supplying 2,000 m^3 of water per day. The company has 7,119 houses connected to its' water supply under four categories of water supply namely; high, medium, and low cost and communal taps. The Operations Manager, further revealed that Choma dam had a water holding capacity of around 1.3 million m^3 at construction. However, this study found that the dam now holds approximately 713,945.41 m^3 of water. Some of the interviewed people complained of a bad odour from the water that is supplied from Choma dam. The Operations Manager stated that sediment flashing is done once or twice during each rainy season to get rid of some of the sediment and possible bad odour in the water from this dam. It was observed during data collection that some people were making bricks very close to the dam using the soil near the dam.

5.1.5.1.1 Bathymetry and Sedimentation

The bathymetric map of Choma dam created from the field survey data collected in December, 2014 is given in Figure 5.5. The deepest regions in the dam are represented with a darkest shade of blue mainly around the center of the dam. Shallow areas are shown with a lighter shade of blue mainly in the areas away from the center of the dam. The results presented in this study were for the full generalized areal extent due to the inaccessibility of the other parts of the dam. The deepest point recoded in this dam was 5.07m. The estimated dam surface area was 324,040.71m^2; the volume was 713,954.41m^3 (Table 5.17).

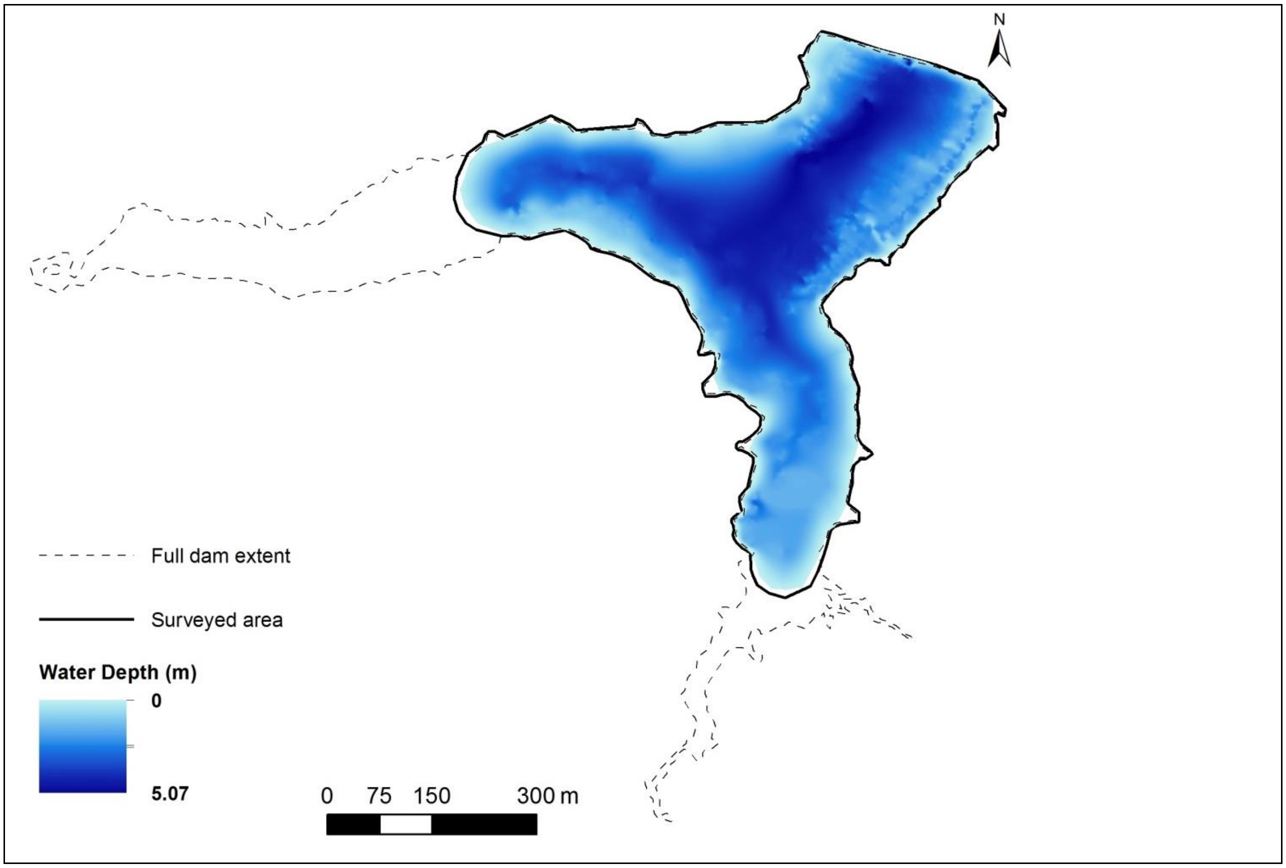

Figure 5.5: Bathymetric map of Choma Dam in Choma District in Southern Province, December, 2014.

Table 5.17: Bathymetric Survey results for Choma Dam

Water Depth (m)	Surface Area (m^2)	Cumulative Volume (m^3)
5.0	324,040.71	713,954.41
4.5	255,626.21	312,847.28
4.0	199,107.55	139,327.89
3.5	157,747.21	107,647.28
3.0	123,335.96	70,275.81
2.5	94,459.82	54,453.94
2.0	67,396.28	40,464.04
1.5	39,770.32	26,859.17
1.0	9,322.81	12,340.79
0.5	34.18	2,339.25
0.0	0.00	0.00

Source: Field data,2015

The volume of sediment trapped in Choma dam was determined on the basis of siltation that had been occurring from 1955 to 2015 and was found to be 586,054.59m^3 (Table 5.18). This lost volume was 45.1 percent of the original dam capacity. The weight of this sediment was estimated at 586,054.59 tonnes.

Table 5.18: Calculated Sediment Yield Parameters for Choma Dam

Variable	Value
Design dam capacity (m^3)	1,300,000
Current dam capacity (m^3)	713,954.41
Sediment volume (m^3)	586,054.59
Percentage loss of volume (%)	45.1
Period of dam operation from construction (yrs)	60
Maximum depth (m)	4.5
Rate of sedimentation (m^3/yr)	9,767.58
Dam life expectancy (yrs)	60
Dry bulk density	1.0
Sediment yield (tonnes/yr)	9,767.58
Mass of accumulated sediment (tonnes)	586,054.59

Source: Field data,2015

The rate of reservoir sedimentation was estimated at around 9,767.58 m^3/year resulting in the dam's useful life of 60 years. Without any interventions on the sedimentation process say through effective catchment conservation measures or sediment removal from the dam, Choma dam is projected to fill up with sediment by the year 2075.

5.2.5.2 Munzuma Dam

Munzuma dam is found in the southern part of Choma district in Southern Province. The dam belongs to Southern Water and Sewerage Company. The dam concrete wall was constructed in 1971 for the supply of water to Choma town together with Choma dam presented in the previous section. Munzuma dam was constructed by excavating and blocking the confluence of two small streams. At construction, the dam was capable of holding around 15 million m^3 of water when water levels reach the upper spillway level. During this study, water was observed spilling from the lowest spillway which was supposed to have a volume of 5 million m^3. Munzuma dam provides 5,000 – 6,000 m^3 of water per day and is still capable of supplying 14,000 m^3 of water per day. Figure 5.6 shows the bathymetric map of Munzuma dam in April 2015.

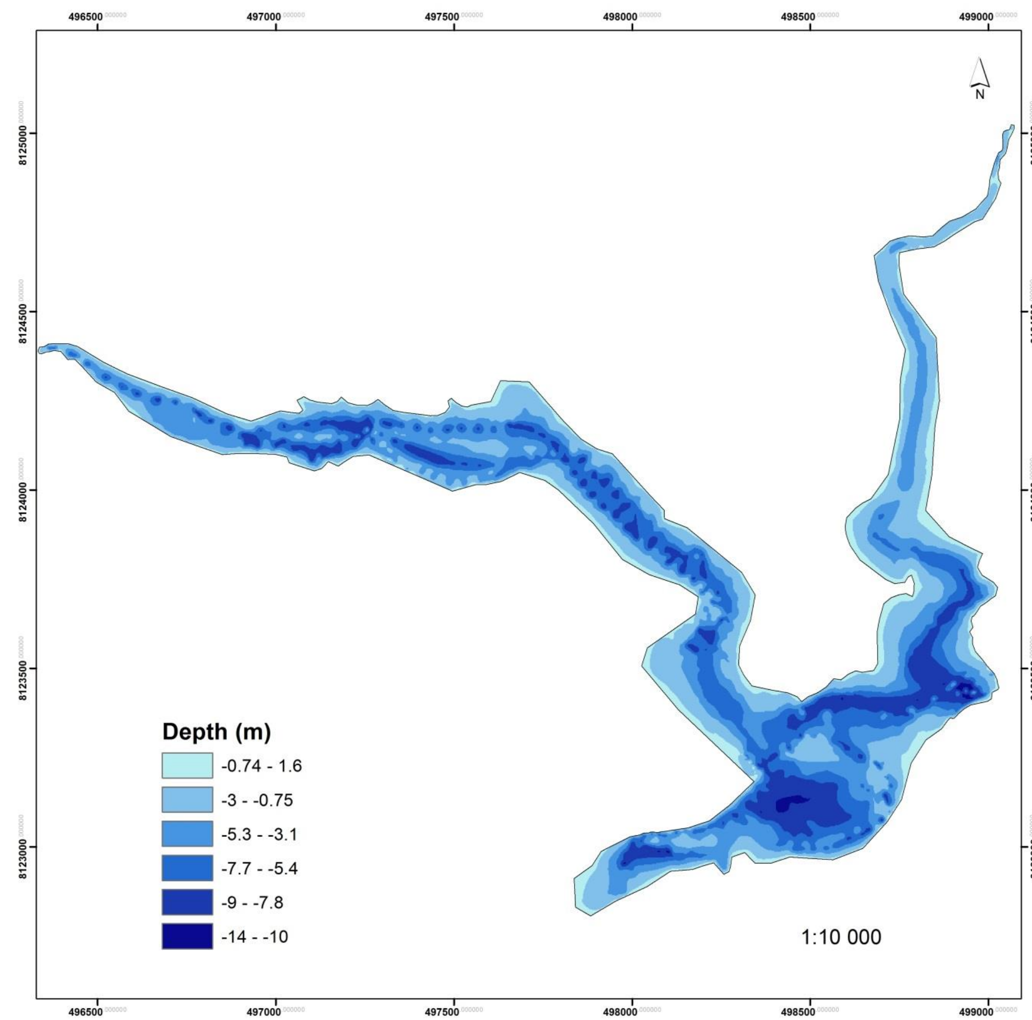

Figure 5.6: Bathymetric map of Munzuma Dam in Choma District Southern Province, April, 2015.

5.2.5.2.1 Bathymetry and Sedimentation

The bathymetric map of Munzuma dam created from the field survey data collected in April, 2015. The deepest regions in the dam are represented with a darkest shade of blue mainly around the confluence of the two streams that join into the dam and the stream that joins the dam from the right. Shallow areas are shown with a lighter shade of blue mainly in the stream joining from the left and the outer areas of the dam. The deepest point recoded in this dam was 14.00m. The estimated dam surface area was 940,051.77m^2, and the volume was 3,718,780.21m^3 (Table 5.19).

Table 5.19: Bathymetric Survey results for Munzuma Dam

Water depth (m)	**Surface Area (m2)**	**Cumulative Volume (m^3)**
14.0	940,051.77	3,718,780.21
13.5	879,178.92	3,290,003.30
13.0	810,554.52	2,867,456.58
12.5	740,111.43	2,479,890.10
12.0	672,716.04	2,126,781.71
11.5	596,529.67	1,809,552.56
11.0	523,933.32	1,529,539.95
10.5	458,213.75	1,284,880.40
10.0	401,787.12	1,070,272.96
9.5	355,994.27	881,331.45
9.0	316,442.86	713,326.40
8.5	278,984.74	564,543.56
8.0	242,727.19	434,215.87
7.5	206,304.95	321,970.06
7.0	168,680.65	228,239.95
6.5	133,147.05	153,048.99
6.0	96,030.22	94,768.99
5.5	64,891.19	55,570.36
5.0	43,023.07	28,691.17
4.5	23,846.68	12,114.93
4.0	2,626.32	1,462.39
3.5	781.47	686.79
3.0	460.10	404.89
2.5	302.32	215.66
2.0	177.55	97.06
1.5	85.79	32.60
1.0	27.04	5.77
0.5	1.29	0.06
0.0	0.00	0.00

Source: Field data, 2015

The volume of sediment trapped in Munzuma dam was determined on the basis of silting measurement from 1971 to 2015 and was found to be 1,281,219.79m^3 (Table 5.20). This lost volume was 25 percent of the original dam capacity at the first water spillway level. The calculated rate of silting in the dam was 29,118.63m^3/year in its forty fourth year of operation. The weight of this sediment was estimated at 1,281,219.79 tonnes. The rate of reservoir sedimentation was estimated at around 29,118.63m^3/year resulting in the dam's useful life of 44 years at the first spillway level. Without any interventions on the sedimentation process say through effective catchment conservation measures or sediment removal from the dam, Munzuma dam is projected to fill up with sediment by the year 2059.

Table 5.20: Calculated Sediment Yield Parameters for Munzuma Dam

Variable	Value
Design dam capacity (m^3)	5,000,000
Current dam capacity (m^3)	3,718,780.21
Sediment volume (m^3)	1,281,219.79
Percentage loss of volume (%)	25.0
Period of dam operation from construction (yrs)	44
Maximum depth (m)	14.0
Rate of sedimentation (m^3/yr)	29,118.63
Dam life expectancy (yrs)	44
Dry bulk density	1.0
Sediment yield (tonnes/yr)	29,118.63
Mass of accumulated sediment (tonnes)	1,281,219.79

Source: Field data, 2015

Valuations of the impacts of sediment and sedimentation on these physical changes required data on relevant variables namely the production cost and price of treated water. These data were solicited from an interview with the marketing manager for the water utility company. The Operations Manager revealed that the current water demand from both Choma and Munzuma dams is at 7,000 m^3 of water per day. Currently, SWASCO earns ZMW1.1million per month from water supply to Choma Town. It has employed 9 people to purify water of sediment and other impurities and pays them a total of ZMW30,000 per month. The average cost of treating water which has sediment is ZMW 60,880 per month but if the sediment was not present in the water, the cost of treating water would have been ZMW18,800 per month.

5.1.5.3 Costs and Benefits of Sediment and Sedimentation for Choma and Munzuma Dams

The costs and benefits of sediment to Choma and Munzuma dams were combined because water from these two dams is treated at one point and could not be considered individually. They were as shown in Table 5.21. The costs of sediment to Choma and Munzuma dams were the expenditure by SWASCO on employees recruited specifically to purify the water; and the chemicals bought to purify the water due to the presence of sediment. The benefits of sediment and sedimentation to the two dams were the annual incomes from providing the water and the income from the sale of the mined sediment. Removal of accumulated sediment would benefit the water utility company as it would spend less money (no need for extra employees and extra purification chemicals) as well as benefits from the sale of mined sediment. The total cost to remove the accumulated sediment from both dams was found to be ZMW 93,363,719.00.

Table 5.21: Costs and Benefits of Sediment and Sedimentation on Choma and Munzuma Dams

Parameter	Amount (ZMW)
Excavation and transportation of accumulated sediment at onset of the programme	93,363,719.00
Sale of the mined accumulated sediment in year 0	373,454,676.00
Excavation and transportation in the 10th year	19,443,105.00
Sale of the excavated sediment in the 10th year	77,772,420.00
Gross annual income with accumulated sediment in the dam in year 10	13,200,000.00
Gross annual income with removing accumulated sediment in the dam in year 10	13,200,000.00
Annual water treatment with sediment	1,090,560.00
Annual water treatment without sediment	18,800.00

Source: Field data, 2015

The amount of accumulated sediment in the dams would cost ZMW 93,363,719.00 to mine and transport to any place within a radius of 10Km. Benefits of ZMW 373,454,676.00 could be realized from the sale of this mined sediment. In 10 years time, it would cost ZMW 1,005,922.50 to mine and transport the accumulated sediment at the current rate of sedimentation.

The total net value of sediment was found by subtracting costs from benefits of sediment in Choma and Munzuma dams under the two alternatives of with and without sediment. Despite the positive values for both alternatives of operating the dams, operating the dams with sediment gave a lower value ZMW – 74,407,265.41for sediment and sedimentation while the alternative of removing the sediment gave a higher value of ZMW 384,155,467.90 (Table 5.22).

Table 5.22: Present Values and Net Present Values of Sediment and Sedimentation on Choma and Munzuma Dams

Alternative	**Present Value Benefits (ZMW)**	**Present Value Costs (ZMW)**	**Net Present Value (ZMW)**
With Sediment (Do-nothing alternative	81,108,284.40 (gross annual income)	6,701,018.99 (Water treatment)	74,407,265.41
Without Sediment	373,454,676.00 (sale of excavated sediment at start of programme) 30,762,328.41 (sale of excavated sediment in year 10) 81,108,284.40 (Gross annual income)	93,363,719.00 (Excavation and transportation at the start of the programme) 7,690,584.08 (Excavation and transportation in year 10) 115,517.86 (Water treatment)	384,155,467.9

Source: Field data, 2015

Note: The Present Values for both alternatives (Do-nothing and Without Sediment) were estimated by discounting the costs and benefits of sedimentation under the two alternatives except for those that occur at the onset of the sediment removal programme. A discount rate of 10 percent was used assuming constant current revenues from water supply in the next 10 years.

5.1.6 Summary of the Bathymetric Surveys and the Value of the Costs and Benefits of Sediment and Sedimentation for the dams

A summary of the Bathymetric Surveys for the dams in this study are given in Table 5.23.

Table 5.23: Summary of Storage Capacities and Sediment Yield Information of the Surveyed Dams

Variable	Chipapa Dam	Katondwe Dam	Palabana Dam	Silverest Dam	Choma Dam	Munzuma Dam
Year of Construction	1958	1980	1965	1989	1955	1971
Design dam capacity (m^3)	200,000	20,652	24,000	747,812	1,300,000	5,000,000
Current dam capacity (m^3)	95,750.01	10,714.88	16,163,81	368,331.46	713,954.41	3,718,780.21
Sediment volume (m^3)	104,249.99	9,937.12	7,835.19	379,480	586,054.59	1,281,219.79
Percentage volume lost (%)	52.0	39.2	32.7	50.7	45.1	25.0
Percentage annual loss of Volume (%)	0.90	0.01	0.02	0.02	0.75	5.80
Period of dam operation from construction (yrs)	57	35	50	26	60	44
Maximum depth (m)	3.7	3.0	4.2	9.7	4.5	14.0
Rate of sedimentation (m^3/yr)	1,828.95	283.92	391.75	14,595.41	9,767.58	29,118.63
Dam life expectancy (yrs)	57	37.7	61	51	60	44
Dry bulk density	1.0	1.0	1.0	1.0	1.0	1.0
Sediment yield (tonnes/yr)	1,828.95	283.92	391.75	14,595.41	9,767.58	29,118.63
Mass of accumulated sediment (tonnes)	104,249.99	9,927.12	7,835.19	379,480	586,054.59	1,281,219.79

Source: Field data, 2015

The rates of sediment accumulation ranged from 283.92 m^3 $year^{-1}$ – 29,118.63 m^3 $year^{-1}$, indicating that all the surveyed dams would be completely full with sediment in less than 60 years beyond the year 2015 if no control measures are undertaken for the reservoirs.

A summary of the costs and benefits of sediment and sedimentation linked to the calculated present values and net present values of the costs and benefits of sediment and sedimentation for the surveyed dams is given Table 5.24.

Table 5.24: Summary of Calculated Present Values and Net Present Values of Costs and Benefits of Sediment and Sedimentation for the Surveyed Dams

Name of Dam	**Alternative of Operating Dam with Sediment**			**Alternative of Operating Dam without Sediment**		
	PVB (ZMW)	**PVC (ZMW)**	**NPV (ZMW)**	**PVB (ZMW)**	**PVC (ZMW)**	**NPV (ZMW)**
Chipapa Dam	259,802.44	259,802.44	0.00	47,503,714.88	11746,027.50	35,757,687.38
Katondwe Dam	0.00	159,550.26	-159,550.26	2,332,405.19	542,713.73	1,789,691.46
Palabana Dam	3,783,415.23	2,222,357.71	1,561,057.52	7,777,764.02	398,829.54	7,378,934.48
Silverest Dam	151,631.48	0.00	151,631.48	90,643,041.48	15,145,147.50	75,499,893.98
Choma and Munzuma Dams	81,108,284.40	6,701,018.99	151,631.48	485,325,288.80	102,440,517.4	382,884,771.40

Source: Field data,2015

The accumulation of sediment on dam beds has reduced the water storage capacities of dams consequently lowering the benefits from dams' intended water uses. Ultimately, the irrigated area of land is bound to reduce and the number of people that can be supplied with water under the municipality of Choma will reduce too due to loss of dam storage capacity. Further, the presence of sediment in water increases the cost of water treatment as water with sediment was found to be more expensive to purify than water without sediment when the water was supplied for domestic uses. The results of the CBA indicate that the NPVs for removing and selling the accumulated sediment in monetary terms were higher and positive for all the dams and ranged between ZMW 630,140.27 and ZMW 384,155,467.90. The NPVs for operating dams with sediment in them were lower and ranged from ZMW –159,550.26 to ZMW 74,407,265.41 (Table. 24).

5.2 Local People's Perception and Value Attached to Sediment and Sedimentation

More than half (59.8%) of the interviewed people were females. The majority ((91.8%) of the respondents were married while very few (8.2%) were single. More than two thirds (69.1%) of the respondents owned the pieces of land they were cultivating or the houses they were living in while few (30.9%) of them did not. A summary of some of the social economic characteristics of the respondents is given in Table 5.25.

Table 5.25: Summary of the Socio Economic Characteristics of the Respondents

	N	Minimum	Maximum	Mean	Std. Deviation
Age (Years)	97	20.0	68.0	42.4	11.7
Household Size	97	1.0	17.0	8.0	3.0
Length of Residency (Years)	97	1.0	60.0	19.1	15.8

Source: Field data, 2015

The levels of education for the respondents are presented in the Table 5.26.

Table 5.26: Respondents Levels of Education

Education Level	Frequency	Percent	Cumulative Percent
Primary (Grades 1-7)	31	32.0	32.0
Junior Secondary (Grades 8-9)	31	32.0	63.9
Senior Secondary (Grades 10-12)	22	22.7	86.6
Tertiary (College or University)	13	13.4	100.0
	97	100.0	

Source: Field data, 2015

All the respondents had attended schooling at various levels of education (Table 5.26). About one third (32%) of the respondents had attained primary level of education. A similar number (32%) of the respondents had attained junior level of education and less than a quarter (13.4%) of the respondents had attained tertiary level of education. To elicit their attitudes on sediment, respondents were asked to state their willingness to pay for sediment removal or buying of desilted sediment from the dams. Most (87.6%) of the respondents were willing to pay while very few (12.4%) were not willing to pay.

5.2.1 Willingness to Pay for Sediment free Dams and Water

To measure water users' value of sediment and sedimentation, the maximum amount of money an individual would be willing to forgo of their annual income to obtain the preferred quantity or quality of water was determined using CVM. Most (87.6%) of the respondents were willing to pay an average of ZMW 268.35 annually for the control and recycling of sediment in the environment. The minimum one was willing to pay was a ZMW 10.00 while the maximum was ZMW 10,000.00. All (100%) the respondents reported that they were aware of the problems and some costs of sediment and sedimentation in the small dams. No respondent showed any knowledge of any beneficial use of sediment. To show the relationships between willingness to pay and the independent variables, binary and linear regression were done

Table 5.27: Binary Regression Analysis of Willingness to Pay

							95.0% C.I.for EXP(B)	
	B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Gender	-1.670	.717	5.424	1	.020	.188	.046	.768
Marital Status	-19.373	1.393E4	.000	1	.999	.000	.000	.
Own Residency	.753	.661	1.297	1	.255	2.123	.581	7.759
	17.225	1.393E4	.000	1	.999	3.026E7		

It was found that WTP was significantly influenced by gender (Table 5.27). The odds ratio of men to women was 0.188 indicating that men were more likely (18.8%) to be willing to pay compared to women at 95.0% confidence interval. Marital Status and Ownership of residence or land under cultivation had no effect on WTP at 95% confidence interval. Age and household size had an influence on WTP with p-values of 0.004 and 0.038, respectively, at 95% confidence interval (Table 5.28). The older ones were more likely willing to pay. The bigger the household size, the less likely was the WTP. The level of education and the amount of income one earned did not influence their WTP at 95% confidence interval.

Table 5.28: Linear Regression Analysis of Factors that Influence Willingness to Pay

	Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	Beta			Lower Bound	Upper Bound
(Constant)		-.569	.571	-1332.741	739.092
Age (years)	.309	2.989	.004	9.195	45.600
Education Level	.026	.228	.820	-204.730	257.734
Household Size	-.261	-2.108	.038	-173.782	-5.170
Household Income	.042	.328	.744	-.005	.007

CHAPTER SIX: DISCUSSION

This chapter discusses the research findings and contextualizes them with other studies. The study findings are discussed in relation to the study objectives. The chapter consists: (i) the current small dam capacities by looking at the amount of accumulated sediment, the rates of accumulation and the current useful economic lives of the dams; (ii) the impact of sediment and sedimentation on the dams; (iii) the economic value of the accumulated sediment by considering the missed hydrological outputs, the costs incurred to come up with other sources of water when dam water holding capacities are replaced with sediment and the costs of purifying water with sediment when water is intended for municipal supply to households; (iv) it considers the potential benefits that can be realized if sediment was removed from the dams and sold at the price of black soil assuming it be used for improving soil fertility in agriculture and landscaping and (v) the results of the CVM and give respondents' valuation of the sediment in the dams surveyed and possibility of supporting a sediment removal programme;.

6.1 Sediment and Sedimentation in Small Dams

Small dams in Zambia are seriously threatened in their performance due to losing their capacity to sedimentation process. The analysis performed on 6 small dams in Zambia established that sedimentation is severe and a burden to dams owners and local communities. The study has shown that a significant loss of storage capacity due to the deposition of sediment has occurred with a consequent decrease of overall storage capacity. It was generally found that 25 percent to 52 percent of dams' initial water holding capacities had been lost to sediment accumulation in 26 to 60 years of dam operations (Table 5.23). This figure could have been higher had some dams not been desilted before as the case was for Katondwe and Palabana dams where sediment that had accumulated in the dams was once removed.

The rates of sedimentation ranged from 283.92 – 29,118.63 m^3/yr among the studied six dams. Similar studies conducted in other countries in Southern Africa have been documented. Similar results were found in Zimbabwe by Chitata *et al.* (2014) who reported sedimentation rates of

8,539 m^3 /yr for Mutangi reservoir in Zimbabwe. On the other hand, Alemau (2013) reported that the average rates for 22 dams in Lotsane catchment in Botswana was 132,886 m^3/yr indicating that the sedimentation problem in this study were less severe compared to those in his study. However, Munzuma dam in Choma had a very high (5.8%) annual volume loss to sedimentation compared to the world average annual rate of storage loss for large dams that is 0.5 – 1% (WCD, 2000). The high sedimentation rate could be attributed to the high sediment yield load accumulating in the dam most likely due to lack of soil erosion conservation measures being undertaken in the catchments for Munzuma dam as observed by Sichingabula , (1997).

The study found that there were variations in the sedimentation rates in individual studied dams. The difference may be attributed to conditions within individual drainage areas which were not assessed by this study and include slope, vegetative cover, grazing use, soils, availability of erodible material in the catchment areas and other features that admittedly have a direct influence on erosion (Alemau *et al*., 2013; Chitata *et al.* 2014). Another cause of the variations to the sedimentation rates could be the differences in sediment yield due to siting of the dams and the presence or absence of soil erosion control measures. In Zambia, dams have typically been sited based principally on engineering, economic, political considerations and commonly on land already owned by the dam proponent or otherwise convenient for the purpose (Nordic Consulting Group, 2010). This shows that the important problem of loss of reservoir storage capacities by sedimentation has not received enough consideration in the development and maintenance of small dams in Zambia despite the many projects and programs of small dam construction in the country. Private dam owners on the other hand recognize that deforestation and cultivation of steep slopes and other unwise practices greatly accelerate soil erosion and result in large increases in the sediment loads of dams as was found in Katondwe and Palabana dams. For sustainability motive, dam siting decisions and erosion control should account for the larger spatial and temporal context as they largely determine future reservoir performance. Future sedimentation rates would be based on the likelihood of climate change and its potential impacts on the small reservoirs. In a country like Zambia, one of the negative impacts of climate change would be increased flush floods (Zambia National Climate Change Response Strategy, 2010). With increased flush floods which carry large amounts of sediment in water courses, the rates of sediment accumulation would be expected to be higher than what was found in this study hence most of the reservoirs might not reach expected useful lives.

In the case of Chipapa Dam, the observed cultivation of crops during the rainy season and making of mud building blocks in the periphery of the dam could be the cause the accelerated sediment load in this dam. Other causes of high sediment loads in the dams could be the stream bank cultivation observed on streams draining into Choma and Munzuma Dams. Stream bank cultivation results in unstable stream banks collapsing during high flow periods causing increased deposition of silt into the dams. Another reason could be due to the small catchment sizes of the dams which makes the suspended sediment being carried in the runoff to reach reservoirs in relatively short distances without settling anywhere in the catchment areas (Michalec, 2014). In other cases, allowing of domestic animals to over graze in catchment areas and drink water direct from the dams could have been the cause of the high sediment loads. Animal tramping loosen the soil which is carried by running water and ends up into the reservoirs. Of concern is the fact that most of the people interviewed feel that it is government responsibility to protect reservoirs from sedimentation. This suggests that there is urgent need for finding solutions to the sedimentation problem that involve community participation.

It is clear from the study findings that the rates of sedimentation could cause all studied dams to be completely full with sediment in less than seventy years from 2015 if no remedial measures area taken.

The useful lives of the dams were found to be shorter and different from the ones done by Sichingabula (1997) who estimated the useful lives of Small Dams in Zambia to be between 200 to 5100 years based on the regression method but this study estimated using the bathymetric survey method useful lives to be ranging from 44 to 61 years. Apart from the differences in the methods used, other differences could be due to the social economic activities happening in the upper catchments of the dams as the human population in the country has increased by 3.7 million from the time he did his study to the time this study was conducted with the Zambian population standing at around 13 million people (CSO, 2014). The other reason could be that this study was conducted on fewer dams compared to the ones done before by Sichingabula who made the estimation on the whole of Southern Province.

6.2 Consequences of Sediment and Sedimentation to Small Dams

Studied Small dams are losing their capacities due to sedimentation process and are therefore seriously threatened in their performance. Dam loss of storage capacities to sedimentation was found to range from 25 percent to 52 percent of their original design water storage volumes. This had restricted the proper utilization of the small dams because the raised dam beds reduce the water storage capacities of dams and thereby reduced the economic benefits from dam use. These findings are similar to those of Palmieri *et al.* (2001), Great Lakes Commission, (2008) and Kondof *et al.* (2014) who reported a decline in benefits from dams around the world due to accumulating sediment in the reservoirs. This study found that where small dams were being used for agriculture production, the dependence on them was most apparent during the annual dry season from April to November when there are no rains to water the crops. In the case of Chipapa Dam, the reduced water storage prevents sufficient watering of crops as water is rationed to allow for everyone to perform their irrigation activities. This in turn reduces crop growth as the crops do not get sufficient water needed to allow their maximum growth. For example, from June to July, irrigation of crops is only done three or four times a week. Further, no irrigation is allowed after September due to the low water levels in the dam. Irrigation of crops comes to an end early before October. This negatively affects agricultural output. On the contrary, in some dams, the accumulated sediment had not yet nagatively affecting the water quantity output from the dams. This was observed for Silverest, Choma and Munzuma dams. Despite the accumulated volume of sediment in Silverest dam, sedimentation appeared not particularly burdensome to the dam use. This was because less water was being obtained from the dam as less (20 hacters) land is being cultivated under irrigation than what was originally intended (75 – 85 hacters).

The high volumes of accumulated sediment in Choma and Munzuma dams had not been affecting the supply of water to households in Choma urban by SWASCO. This was due to the fact that the available useful volumes of the two dams are sufficient to cater for the current human population in Choma. However, the domestic water demand in Choma is expected to increase due to the increasing population for each year from high influx of people coming to settle in Choma town owing to its being the new Provincial Capital of Southern province. In addition, more areas are being opened up by the local authority for residential development in Choma urban. This is expected to put more pressure on water demand which might render the current volumes of the two dams insufficient to providing the required quantities of water. Sufficient good quality water for households is an important basic necessity for good health and wellbeing of people. It appears in future, the support given by the two dams in Choma will no longer be met with the increasing population. It is expected that the period of water supply in a day will be reducing with the current decrease in dam capacities such that in future, the percentage of areas/households not being covered by water supply will be increasing on a daily basis owing to accumulating sediment in the two dams. Since Choma area is recorded to have poor ground water recharge (Baumle *et al*., 2007), the only way to consider for continued supply of water to the area would be to desilt the two dams as the alternative source of water to the urban area would be Zambezi River and this would cost a lot of money to abstract water from the Zambezi River and later provide it to the people of Choma urban. According to the Operations Manager for SWASCO, a project is on-going to construct another small dam in the same catchment area as to Munzuma dam. Other dams could be constructed to replace silted ones if economics was the only major consideration. However, Annandale (2013) contends that there are fewer feasible and economically justifiable sites available for new reservoirs.

Sediment and accumulated sediment in small dams was found to be a problem that compromises water quality when water is meant for municipal use. The quality of consumed water was found to be lowered by the brown colour in water meant for domestic use especially in the rainy season, bad odor and harmful bacteria present in accumulated sediment. Koteen *et al.* (2002) contends that sediment contains pathogens and bacteria and is a source of mineral fertilizer, pesticides and other chemicals which are undesired in water intended for human domestic use. Getting rid of such pathogens, chemicals and bacteria requires chemicals to purify the water and this drives up the cost of water treatment thereby lowering the earnings from water supply. In the case of Choma and Munzuma dams, the costs of sediment and sedimentation were reflected primarily in higher costs arising from the need to put more purification chemicals in the water due to contaminants concealed in the sediments and from the labor required to conduct the water purification. In other cases, alternative sources of water are found when the costs of water treatment become too high due to the long residence periods of sediment in the water. For example, the presence of accumulated sediment in Katondwe dam could be the cause of the permanent contamination of the water in Katondwe dam by corliform bacteria (NAID, 2002). This has resulted in the sinking of boreholes which are a source of safe domestic water to Katondwe mission community.

6.3 Value of Sediment and Sedimentation on Small Dams

The study has established that sediment trapped behind dams reduces reservoir capacities impairing the functions of the dams. It also lowers the quality of domestic and municipal water creating a need to apply more and expensive chemicals for purifying such water. These stated negative impacts of sediment and sedimentation reduce the economic returns from dam operation as the lost dam storage to sedimentation is no longer available for use in the future. The results of this study are unambiguous indicating that sediment mining and reuse is economically the best management alternative with sedimentation. The NPV for the alternative of removing sediment from the dams were always positive for all the dams.

6.3.1 Costs of Sediment and Sedimentation

The costs of sedimentation in dams were primarily in the lost water volumes. In dams used for irrigation agriculture, the main constraint of sedimentation was the reduction in dam capacities caused by sediment deposits as the areas that could be irrigated using water from dams was restricted by the amount of water available in the dams. If no sediment removal is undertaken, returns to agricultural production would decline as shown for Chipapa and Palabana dams. Eventually, production would become uneconomic and cease although exactly when would vary depending on the rate of reduction in dam storage volume, the cost of production and the price of agricultural output. The lack of data on the annual productivity of the dams and the related sediment accumulation hinders the determination of a relationship to show the rate of reservoir decrease and a decrease in benefits to intended reservoir use.

From the study results, it is clear that an intervention is needed since the sediment deposits were putting the operations of the dams at losses. Evaluation of the feasibility of sediment excavation using machines established that about ZMW 391,759.50 to ZMW 93,363,719.00 would be required to remove and transport the sediment to areas within the radius of 10 km from the dams.

The study also found that sediment in water cause organizational and operation costs accredited to sediment due to the work needed to provide good and quality water to households. In the case of Choma and Munzuma dams, a total of ZMW 846,160 which is 6.42 percent of gross annual revenues is spent on paying employees to purify the water as well as on buying extra chemicals for purifying water. The costs of sediment and sedimentation are expected to persist in the remaining useful lives of the dams until the dams eventually fill up with sediment if no remedial measures to stop sediment accumulation in the dams are put in place.

6.3.2 Benefits of Sediment and Sedimentation

The benefits of sediment and sedimentation considered in this study were the monetary values from sediment reduction costs through desilting, increased revenues from increased capacities and fees that could be generated from the sale of the mined sediment. The economic returns from operation of dams without sediment were positive for all the dams. Operation of the dams without sediment was based on the fact that the volumes of reservoirs at construction must be treated as renewable resources that have to be restored regularly using sediment mining. When treated as renewable resources, there are more positive implications for the future sustainability of water supply from the dams. Sediment mining means that the usable lives of dams could be extended to long periods in the future. The high costs of sediment excavation and transportation are more than offset by the benefits from the sale of the excavated sediment. This is contrary to the findings of Chancellor *et al*. (1996), Sichingabula *et al*. (2000) and Palmieri *et al.* (2001) that sediment removal is more expensive than constructing new dams. This can be explained by the fact that these studies were conducted based upon the necessity to remove sediment only without considering the profitability of reusing it. Further, they did not use the NPV to determine the costs and benefit of sediment removal. Mining and reuse of accumulated sediment has been proposed and conducted in other parts of the world (Lembke *et al.*, 1983; Stanley and Doyle, 2002; Haregeweyn, 2011; Malino *et al*., 2014). No such ventures have been undertaken in Zambia most likely due to lack of knowledge by the people on the beneficial reuse of sediment. Other than that, it may be that dam developers and operators are not aware of the range of potential reuse nor have they been demonstrated to be effective. Thus, collectively dam users and gravel miners are missing opportunities to sustain reservoir functions into the future, and to minimize impacts of sedimentation. With more new dams planned for Zambia (African Water Facility, 2012) it is timely that a lesson be learned from reservoir sediment management which can be used in the management of accumulating sediment in dams and to establish policies for sustainable reservoir and sediment management.

Besides extending the reservoir useful lives and increased benefits from restored reservoir dead storage volumes, sediment removal from dams would generate additional incomes to dam owners and operators from the possible sales of sediment for agriculture soil enrichment and landscaping. Therefore, local people where dams are located can be encouraged to use the mined sediment from dams to add or retain much needed crop and plant nutrients in their fields as well as landscaping to beautify their homes and degraded lands. If accumulated sediment could be dredged and be sold as soil conditioner, it would prevent the construction of new dams where desirable dam sites are somewhat limited and environmental impacts of these dams must also be considered. Implementing sediment removal from dams and reuse of sediment in agriculture can greatly reduce the burden of sediment on intended dam uses and prolong the lives of the dams. Even if sediment mining was possible, its' feasibility would likely depend on local peoples ability and willingness to buy the sediment.

The problem of sedimentation is very important to both dam users as well as for the development perspectives of the Zambian society that attempts to put up new dams. Nevertheless, the study has confirmed the large benefits that can be realized by removing accumulated sediment and using it in agriculture as these generate large and continuing benefits to society. This shows that although sediments accumulating in reservoirs can be considered with negative consequences, they can still be regarded as resources out of place because the same sediments are desperately needed for replenishing nutrient depleted agricultural land and for landscaping in degraded lands. By mining the accumulated sediment, dam water storage capacities can be restored, more water can be stored and intended agricultural areas can be irrigated. In addition, extra incomes may be earned from the sell of the sediment. In Zambia, programmes aimed at the rehabilitation or constructions of small dams have been ongoing for a long period of time (Nordic Consulting Group, 2010). Experiences available so far have only looked at the financial, economic and social impacts including the contribution to poverty alleviation or as part of rural and community development projects and programmes. On the other hand, the sustainability and environmental aspect of the dams and the sediment that accumulates in the dams have been lacking and this study has provided information in that area. It is hoped that other multilateral or donor agencies currently supporting the rehabilitation or construction of small dams as a component of natural resources or water resources management and development projects or as part of rural and community projects and programs will consider using these findings.

6.4 Local Peoples' perception and Value of Sediment and Sedimentation

This study explored the household valuation of sediment and sediment accumulation in dams meant for irrigation and water supply as a management alternative to the negative impact of sediment and sedimentation. Keeping other factors constant, compared to women, men were more likely to be WTP at the rate of 18.8 percent. This could be that men have higher education and incomes hence they were more willing to pay. The household size was found to have a negative effect on the WTP to support the programme of sediment removal from dams. This marginal effect indicates that increasing the number of dependent household members relative to the number of currently economically active members, that is, a one-unit marginal increase reduces the probability of being willing to pay. This could be explained by the fact that increase in household size reduces income that can be spent on other needs and wants that might not bring immediate value to the household. Small households are more likely to spend on future needs because they might have enough and extra income to save from immediate necessities than would large households. The residence time period of respondents had no effect on willingness to pay. The possible reason for this could be that both new and old residents were aware of alternative sources of water such as ground water which they can still use if water in the dams was not available.

A CVA revealed that the majority of the people attach some social and environmental awareness and were willing to pay for the control of sediment and sedimentation to their dams. The results of the CV suggest an average willingness to pay of about ZMW 268.35 annually per household for the preservation of the useful lives of the dams. The mean WTP was more than the price of selling a tonne of sediment an indication that accumulated sediment mining and reselling is a practical venture that can be supported by local people. Further analysis suggests that this value depends on respondents' characteristics such as gender, age and household size.

Respondents were willing to buy or pay for the mined sediment on average at a higher price than the price of a tonne of black soil. Thus, the average WTP has the potential to offset the lost opportunity costs of sedimentation that occurs in the dams annually. If people would be willing to buy or support sediment mining at a price equal to or more than the current price of black soil, then the chances of mining the sediment and later reselling would be possible to implement. It is also a better alternative that gives a positive NPV for all the dams. This is something that should be encouraged in all the dams as a measure for sustainable reservoir and sediment management. If adopted, this could provide in some sense interesting and credible information about people's sentiments towards changes in their environments and natural resources. Contingent Valuation Surveys performed in a CBA can improve the decision making in the environmental and economic policy formulation domain.

Comparison of the results of CBA and CVS gives a measure in societal value resulting from the proposed removal or reduction in sedimentation in the small dams. This information may help strengthen and expedite the decision as to whether some form of intervention (remediation) is necessary. Societal value is very important because the success of any beneficial use programme requires community involvement (Great Lakes Commission, 2013). Communities play a vital role in identifying projects that might be able to use dredged sediment. Communities can pool their resources to promote dredged material recycling by forming committees.

However, the respondents might have given a WTP amount that differs from their true WTP amount in an attempt to please or gain status from the eyes of the interviewer. Other than this, some would not even pay if required to. This has the potential to make such a program of sediment reuse fail to be a success.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

Major findings are concluded and the need for future research is proposed in this chapter.

7.1 Conclusion

Overall, It is concluded that the studied small dams in Lusaka and Southern Provinces were experiencing severe sedimentation which lowered the benefits from intended dam uses. Mining of the accumulated sediment in the dams could raise the NPV of the dams as well as extend the useful lives of the dams. The results of the Contingent Valuation Survey results indicate that local people, dam owners and operators prefer dreading of sediment. Because of the high potential benefits that could be derived from sediment, local communities, dam owners or operators should be encouraged to exploit this abundant natural resource in their areas.

7.2 Recommendations

Based on the study findings, it is recommended as follows:

(1) Bathymetric surveys for small dams should be done and documented by dam developers on annual basis to get more accurate rates of sedimentation as well as the opportunity cost sediment puts on dam users and operators. Such information can give a better understanding for decision making on the value of sediment to intended uses of the dams.

(2) Dam developers and environmentalists must sensitize local communities, dam owners and operators on the benefits of reuse of sediment that accumulates in the dams.

(3) Further research is required on the determination of nutrients of agricultural value in the accumulated sediment and the suitability of sediment for various commercial purposes.

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Appendix i: Interview guide for the local household heads that use water from the dams for irrigation

Dear respondent,

Please answer the following questions to the best of your knowledge. This interview is for academic purposes only.

1. Gender……………………………………………………………………………………………..
2. Age………………………………………………………………………………………………….

3. Marital status…………………………………………………………………………………
4. Household size…………………………………………………………………………………
5. Education attainment……………………………………………………………………………..
6. Household income…………………………………………………………………………….…
7. Cultivated land size……………………………………………..………………………….…..
8. Length of water availability in a year……………………………………………………………
9. Monthly water tariff or dam fee contribution?...
10. How long have you lived in this area?..
11. Do you own the land you cultivate? ……………………………….…………………
12. What is the size of your area under agricultural irrigation irrigation?……………………..………………………………………………………..
13. What crops do you grow using the water from the dam?...
14. How much do you make after selling your crops in a year?...………………………………………………………...
15. How many times do you produce the mentioned agricultural produce in the dry season/ year?…………………………………………………………………………………
16. How do you explain the trend in your agriculture output in the past years you've been cultivating in relation to sediment presence in the water or dam?..............................
17. Do you pay any fees for using water from the dam?...
18. If yes, how much?...
19. Do sediments affect your use of water for irrigation?...
20. What is your perception of sediments in this dam?...
21. What other costs or benefits do you incur due to the presence of sediment/sedimentation in the dam water?..
22. Do you think government or local people like you who use water from this dam must be responsible for preventing sediment entering the dam?..
23. Suppose that the dam you are using in your area was to disappear tomorrow due to sediment accumulation and that persons like yourself had a chance to save this particular structure, what would you reasonably estimate to be the maximum you would be willing to pay each month/year in order to guarantee the use of this area for you and your household?..

24. Would you approve of soil erosion protection measures or program of sediment removal if it reduced your income by some kwacha value?..

Appendix ii: Interview guide for the local household heads that use water from the dams under municipal water supply

Dear respondent,

Please answer the following questions to the best of your knowledge. This interview is for academic purposes only.

1. Gender……………………………………………………………………………………………..
2. Age………………………………………………………………………………………………….
3. Marital status………………………………………………………………………………………

4. Household size……………………………………………………………………………………
5. Education attainment……………………………………………………………………………..
6. Household income…………………………………………………………………………………
7. Ownership of dwelling house………………………………………………………………………
8. Length of residence in the area……………………………………………………………
9. Dwelling size or number of rooms in the house…………………………………………………….
10. Length of water availability in a year……………………………………………………
11. Monthly water tariff or dam fee contribution?..
12. How do you explain the trend in the water you are receiving in relation to sediment presence in the water or dam?..
13. Do you pay any fees for the water you are supplied?..
14. If yes, how much?..
15. Do sediments affect your use of water in the home?...
16. What is your perception of sediments in the dam where your water comes from?...
17. What do you recommend to make water supply more sustainable throughout the dry season/year in relation to sediment in the dam?..
18. What other costs or benefits do you incur due to the presence of sediment/sedimentation in the dam water?...
19. Do you think government or local people like you who use water from this dam must be responsible for preventing sediment entering the dam?..
20. Suppose that the dam you are using in your area was to disappear tomorrow due to sediment accumulation and that persons like yourself had a chance to save this particular structure, what would you reasonably estimate to be the maximum you would be willing to pay each month/year in order to guarantee the use of this area for you and your household?...
………………………………………………………………………………………………
21. Would you approve of soil erosion protection measures or program if it reduced your income by some kwacha value?...

Appendix iii : Interview guide for technocrats involved in water supply from small dams.

Dear respondent,

Please answer the following questions to the best of your knowledge. This interview is for academic purposes only.

1. When was the dam constructed ?..

2. How much did it cost to construct the dam?...
3. What is the projected life time for the dam?...
4. Are you aware of any problems of sediments to the dam?..
5. If experiencing sediment problems, who is responsible for the maintenance of the dams?……………………………………………………………………………………
6. If you are to remove sediments from the water, how much does it cost and how frequent is it done?...
7. What is the number of water connections in this area?...
8. What are your tariffs for the water service you are providing?..
9. How many hours in a day is water available to your customers?.......................................
10. Have you achieved the specific purpose for which the dam was constructed?.....................
11. What are your operational costs?..
12. How many staff are employed to purify water?..
13. Are there any sediment control measures around the dams?...
14. If sediment control measures are put, how effective are they and how much does it cost to install them?..
15. How serious is the problem of sediments and sedimentation in the dams?..........................
16. Are there any other benefits you are realizing from removing sediments from the water?...
17. Are you experiencing any other costs of sediment removal and prevention of sedimentation from these dams?...

Appendix iv: Interview guide for technocrats in the Ministry of Agriculture or dam committee members involved in the management of small dams for irrigation schemes.

Dear respondent,

Please answer the following questions to the best of your knowledge. This interview is for academic purposes only.

1. When was this dam constructed?...
2. How much did it cost to construct this dam?..
3. What was the purpose for the construction of the dam?……………………………….
4. At construction, what was the estimated dam life time?...
5. Have you realized the benefits for the construction of the dam?....................................
6. If not, why?...
7. Are there any other benefits you have realized from the dam other than the ones the dams was constructed for?..
8. Are you aware of the presence of sediments and sedimentation to the dams?.............
9. If experiencing the above problems, who is responsible for the maintenance of the dams?..
10. If experiencing the already mentioned problems, how frequent is sediment removal done and how much does it cost?..
11. Are there any sediment control measures around the dam?..
12. If present, are they effective and how much does it cost to put up these sediment control measures?…………………………………………………………………..………………
13. What are your costs for ridding off of sediments from the water?..................................
14. How many individual farms is the water supplied to?...
15. What is the average farm size?………………………………………………………..……
16. What crops are irrigated using water from the dams?..
17. How much produce are the farmers expected to produce?..
18. Without sedimentation, situation, how much did farmers produce?...…….............
19. With the sedimentation, situation, how much agriculture produce do farmers realize?.......