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Sedimentation and Its Effects on Selected Small Dams East of Lusaka, Zambia

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Abstract: In Zambia, the need to conserve water resources has resulted in the construction of small dams. However, small dams are adversely impacted by sedimentation. The aim of this study was to assess the water storage capacity loss for the selected small dams east of Lusaka Zambia. These included Lwiimba, Silverest, Morester and Katondwe dam. Data was collected by bathymetric survey for each small dam using hydrographic boat with echo sounding. The initial storage capacity data were collected from the dam owners and through interviews with key informants on the effects of sedimentation on dam uses and on the existence of sediment control measures. Results of the study revealed that the measured reservoir storage capacities in year 2015 for Lwiimba, Silverest, Morester and Katondwe dams were 101,051.43 m^3, 379,480.00 m^3, 14,724.88 m^3 and 10,714.88 m^3, respectively. The estimated rates of sedimentation for Silverest was 14,595.40 m^3yr^{-1}; Lwiimba (2,200.99 m^3yr^{-1}); Katondwe (283.92 m^3yr^{-1}), and Morester (251.01 m^3yr^{-1}). These rates of sedimentation has led to reservoir capacity storage losses of 99,044.57 m^3; 379,480.5 m^3; 13,805.68 m^3 and 9,937.12 m^3 for Lwiimba, Silverest, Morester and Katondwe, respectively, with the general consequences of reservoir drying especially in the dry season. Natural vegetation is the main sediment control measure used in the catchments. It is concluded that the studied small dams East of Lusaka are seriously affected by sedimentation. This calls for periodic dredging of deposited sediment in order to increase reservoir storage capacity for sustainable use of the water resource in small dams' impoundments.

Key words: sedimentation, bathymetric survey, small dam, reservoir capacity, erosion

1. Introduction

Small dams are important for the communities as the impounded water is used for various purposes including flood control, domestic supply, crops, animal watering and recreation. The progressive loss of water-storage capacity resulting from sedimentation in dam reservoirs, coupled with increasing societal water demand, negatively affect environmental, social and economic benefits of small dams. Globally, there is evidence of steady rise in siltation in reservoirs, endangering reservoir projects which cause doubts about the viability of existing and future reservoirs. The impoundment of water for irrigation, domestic and flood control is a necessary step towards socio-economic development. However, reduction in the storage capacity of a reservoir by sedimentation beyond a limit hampers the purpose for which the dam was constructed. Thus, assessment of sedimentation becomes very important for the management and operation of such reservoirs [1].

In Zambia, land degradation in different parts of the country is a major problem and is accelerating soil erosion such that mobilized soil particles end up in water bodies. It is argued that many of the dams constructed in Zambia in the 1950s and 1960s are today silted up and need to be dredged [2]. This implies that if sedimentation is not checked, the usefulness of small dams in future will be much lower than at present. Sedimentation process is one of the most important problems that affect directly the performance of reservoirs due to the reduction of the storage capacity. Sedimentation is a single natural process that all

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reservoirs worldwide share in common, to differing degrees due to the natural process of erosion in catchment areas. However, it has to be pointed out that though erosion is a natural process, it is speeded up by anthropogenic activities. The main anthropogenic activities increasing sediment supply to water bodies in Lusaka Province include; changes in land use in catchment areas; increased areas of sedentary agriculture and deforestation leading to greater areas of bare soils susceptible to erosion. Sichingabula (1997) highlighted the seriousness of soil erosion and sedimentation in small dams in Southern Province and in some parts of Lusaka Province [3]. He reported that this was due to increased human and cattle population and the existence of large cultivated areas in catchment areas. The problem is that in Lusaka Province, there is limited research done on current storage capacities of small dams and the effects of sedimentation on the usefulness of these dams. Therefore, this study investigated sedimentation and its effects on four (4) selected small dams located East of Lusaka.

2. The Study Area

This study was carried out on four small dams known by their owners or place name, namely; Lwiimba, Silverest, Morester and Katondwe, located east of Lusaka (Fig. 1). Lusaka lies between latitudinal 14°40″ South to 16° 00’’ South and longitudes 27°45″ East to 30°26″ East. The approximate size of Lusaka Province is 21,896 km^2 [4]. Surface water drainage system constitutes less than one percent of the total land mass of Lusaka Province and is represented largely by the three major rivers in the country, the Kafue and Zambezi running through the Kafue district and the Luangwa through Luangwa district. The Province also has about forty small dams [5]. The major drainage basins for Lusaka Province include the Zambezi, Luangwa, Chongwe, Kafue and Chalimbana catchments (Fig. 1). The geomorphology of Lusaka Province has a major influence on the sitting of small dams and hence the sparse distribution of dams in the Province. For instance, the eastern part of the Province is largely hills and not quite suitable for construction of small dams due to increased potential for erosion and sedimentation.

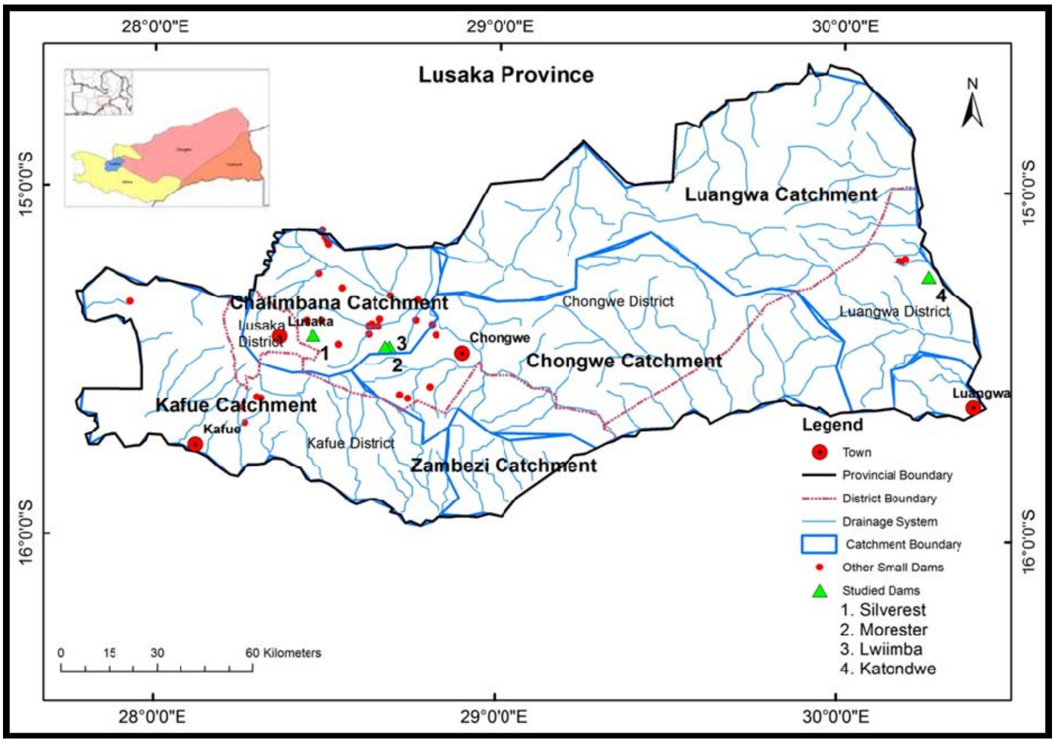


Fig. 1 The Drainage System of Lusaka Province and Spatial Distribution of Existing Small Dams.

3. Methodology

3.1 Data Collection

Bathymetric surveys were conducted from 24th February, to 12th March, 2015 when the small dams were at full supply level and water was spilling over the crest spillway. A hydrographic boat was used to conduct the bathymetric surveys for each dam. During the bathymetric survey, the hydrographic boat was used to measure water depth, water surface elevation and the Universal Transerves Mercator (UTM) coordinates for each measurement along the travel pathlines were automatically recorded. The survey boat path lines were overlaid for each reservoir on Google maps to show the exact locations of the depth points on reservoir surfaces. The positions of the boat path lines for each of the four dams are shown in Fig. 2. Similarly, the depth data were also mapped for each reservoir at different vertical intervals to produce bathymetric maps shown in Figs. 3.1 and 3.2. The maps show relative sizes of the dams when compared to each other.

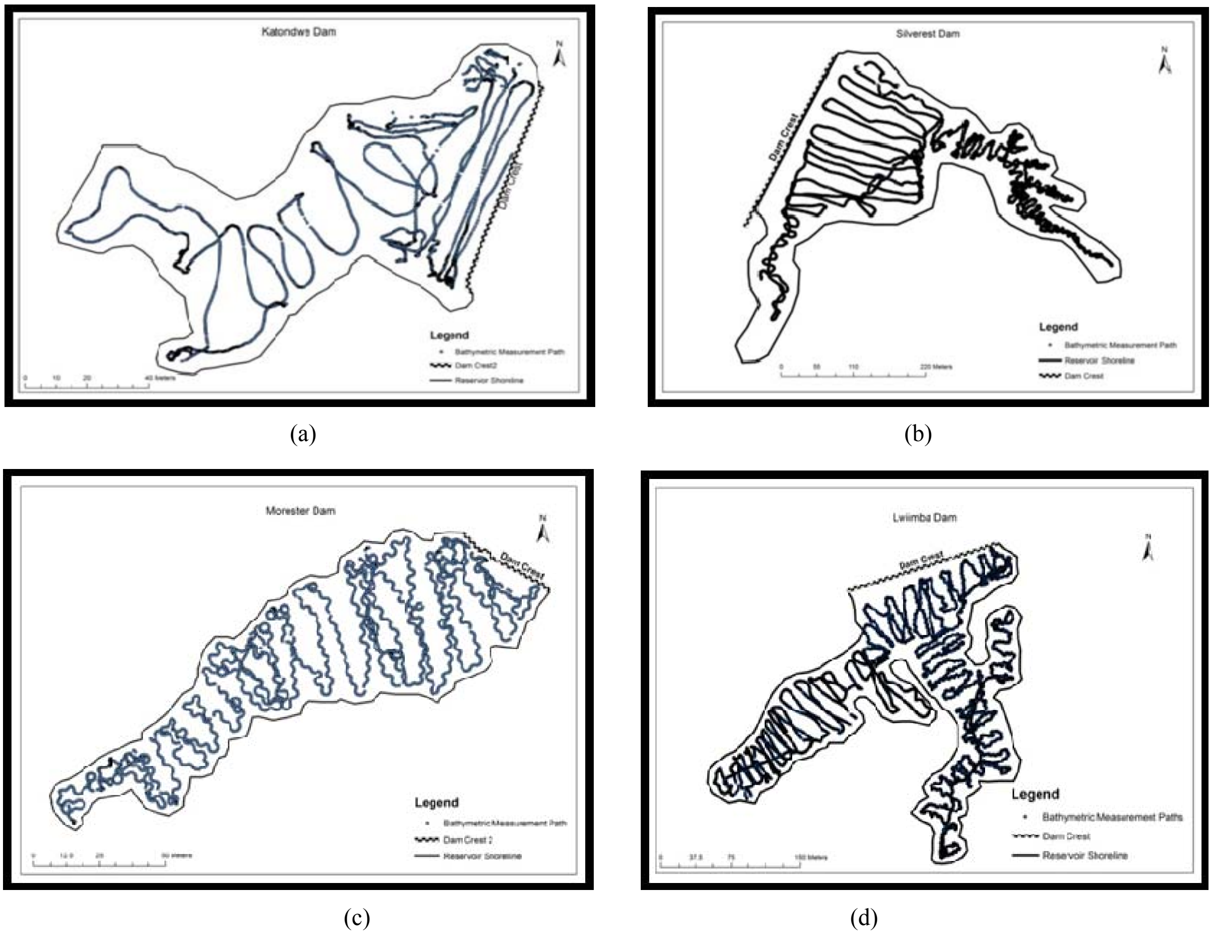


Fig. 2 Bathymetric Survey Pathlines for: (a) Lwiimba Dam (07/03/15), (b) Silverest Dam (04/03/15), (c) Morester Dam (08/03/2015) and (d) Katondwe Dam on 29/02/2015, East of Lusaka Province.

The perimeter and elevation of the water surface for reservoirs were measured with the hydrographic boat taking several points along the shoreline. The use of Differential Geographical Position System (DGPS) on the hydrographic boat was important for location accuracy because of the OMNISTAR location VBS services utilized. The DGPS is an enhancement to Global Position System that provides improved location accuracy [1]. The location accuracy for the data collected for this study was less than 20 cm of

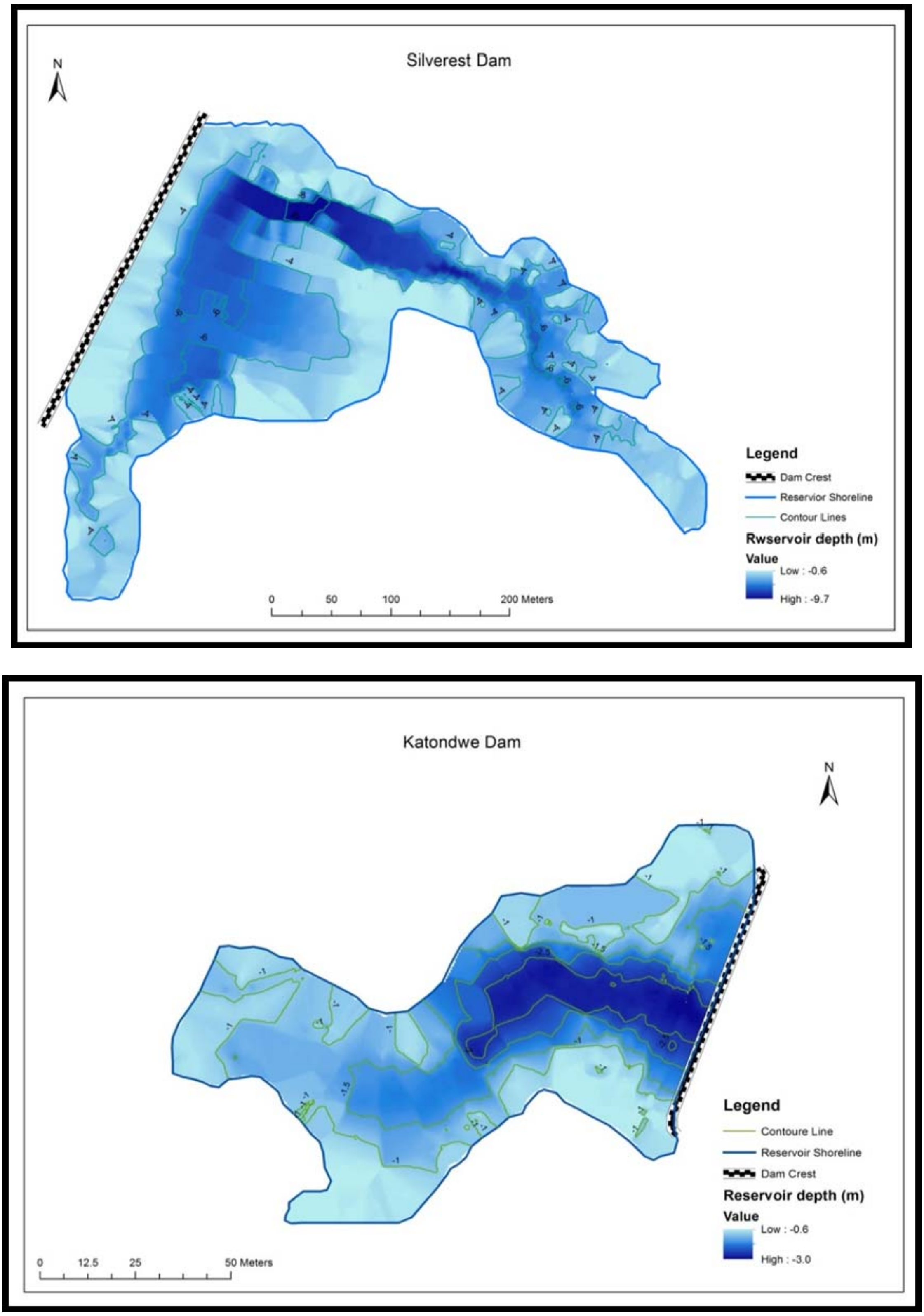


Fig. 3.1 Bathymetric Maps for (a) Katondwe Dam in Luangwa catchment and (b) Silverest dam Located in Chalimbana Catchments, Measured 24 and 27 February, 2015, Respectively.

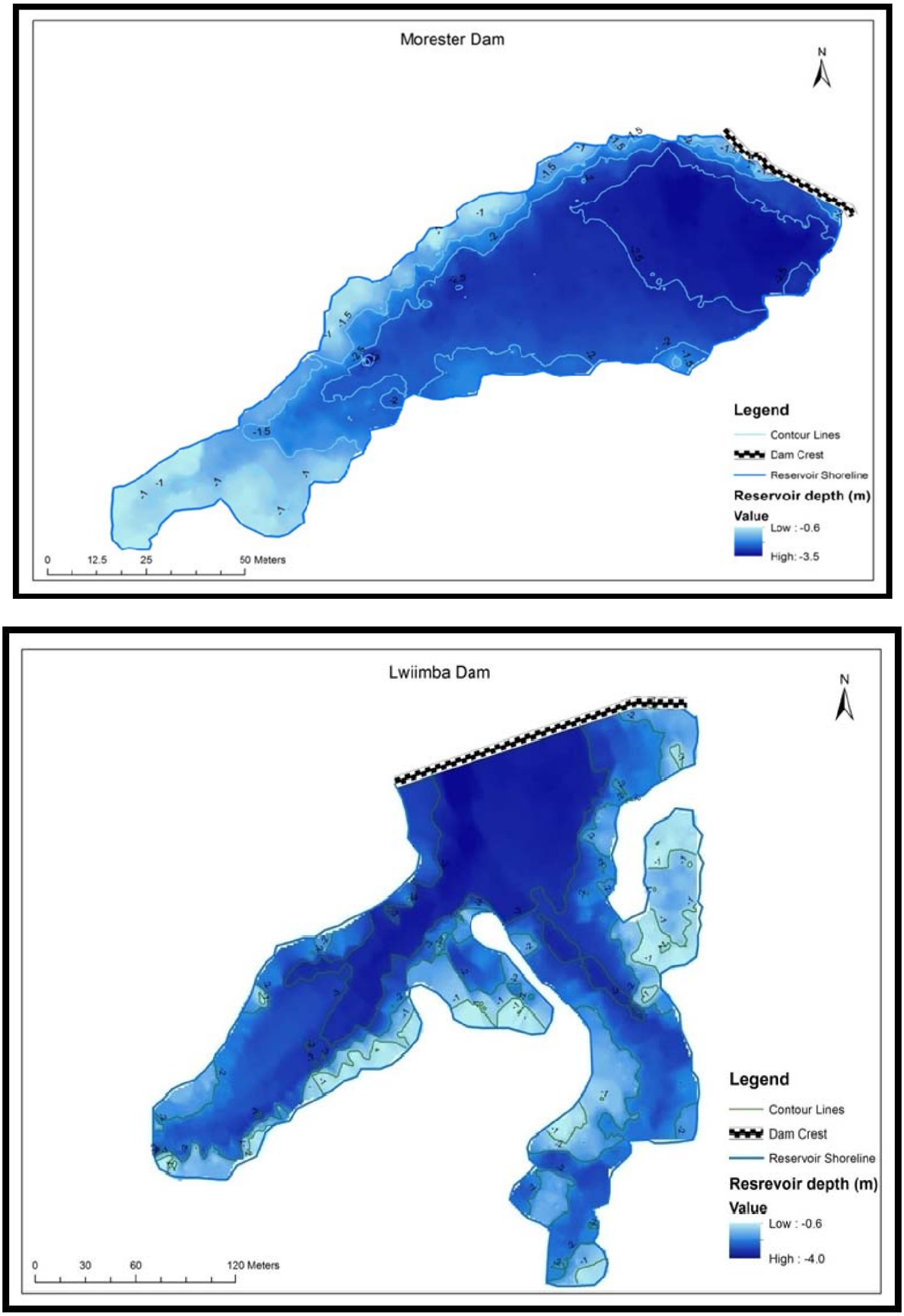
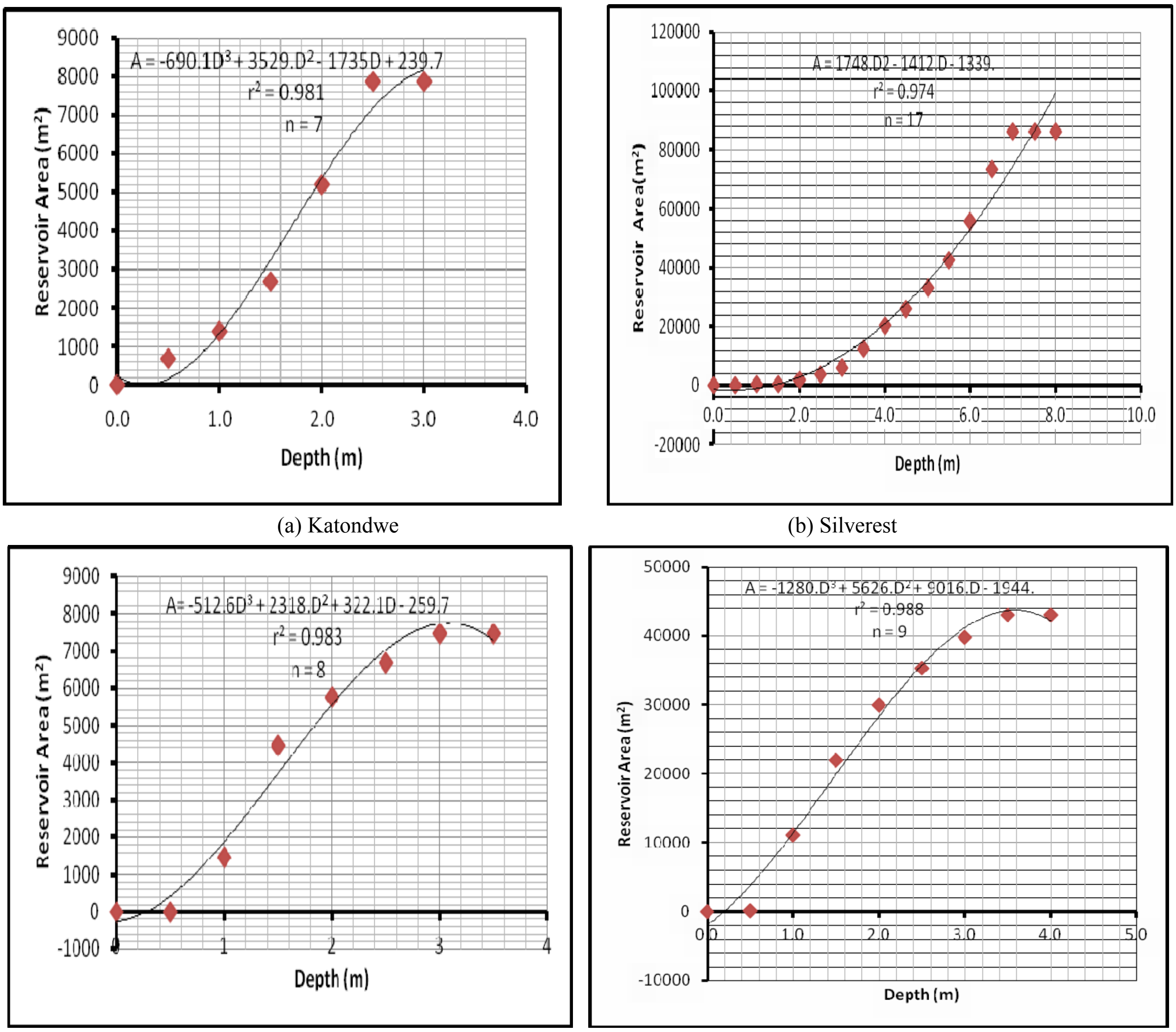


Fig. 3.2 Bathymetric Maps for (a) Lwiimba Dam and (b) Morester Dam, Measured 7 and 8 March, 2015, Respectively.



(a) Katondwe (b) Silverest

(c) Lwiimba (d) Morester

Fig. 4 Depth-Area Curves for (a) Katondwe, (b) Silverest, (c) Morester and (d) Lwiimba Dam, East of Lusaka.

which if DGPS was not used, the location accuracy from Garmin GPS would have been between 4 and 20 meters. The actual location accuracy for each dam was 0.09 m, 0.08 m, 0.10 m and 0.13 m for Lwiimba, Silverest, Morester and Katondwe dams, respectively. The observed variability in the location accuracy was due to a number of factors such as existence of big trees and hills, at dam sites. These factors influence the number of satellites used for DGPS values recorded. The larger the number of satellites captured, the more accurate the location of a place and vice versa.

Since the studied dams are privately owned, data on the effects of sedimentation on dam uses was collected from key informants who included owners of the small dams. Interviews with key informants were conducted using the interview guides on the purposes for which the dams were constructed and challenges faced with regard to sedimentation. In order to collect data on the nature and type of soil erosion/sediment control measures, interviews with Key Informants were carried conducted. Three key informants included the owners of the small dams (one for each dam), the Departments of Water Affairs and the Department of Agriculture. The Department of Water Affairs (DWA) and Agriculture were included on the key informants because they are among the key authorities with the mandate of development and maintenance of small dams in Zambia. Interviews with key informants were conducted using the interview guides. Water samples were also collected from each dam using dipping method for laboratory analysis at Environmental Laboratory at the University of Zambia, using standard methods for water quality analysis.

During the bathymetric survey, the hydrographic boat measured the water depth, water surface elevation and the Universal Transerves Mercator (UTM) coordinates for each measurement along the travel path (Fig. 2). To account for the spatial variability of sediment deposition within the reservoirs, more than 2000 point measurements covering the water surface were collected for each reservoir. Bathymetric survey points for Lwiimba, Silverest, Morester and Katondwe dams were 8,026; 9,802; 2,423 and 7,952, respectively. The perimeter and elevation of the water surface for each reservoir were measured with the hydrographic boat taking several points along the shoreline. DGPS on the hydrographic boat was important for accuracy and it was using the OMNISTER VBS service. The DGPS is an enhancement to Global Position System that provides improved location accuracy.

3.2 Data Analysis

The reservoir water storage capacity and surface area were calculated for each reservoir using bathymetric data from the hydrographic boat for each reservoir with the application of ArcGIS 10.1, 3D, Area and Volume Spatial Analyst tools. The point data in x, y, z were downloaded from the boat software from back data file of which an extract is shown in Table 1.

The Z (depth) values were given a minus (-) sign. This is so because water surface was taken as the reference level and if minus sign was not given, the surface volume 3D analyst tool would have calculate Z values as elevations instead of depth. The imputing of recorded measurements from the hydrographic back data to ArcGIS 10.1 was accomplished by using the Tools — Add XY Data option. The x, y coordinates of

Table 1 An Extract of Back Data from Hydrographic Boat During Bathymetric Survey.

Y	X	Depth	Date
8289868	680612.9	2.6	05/03/2015
8289868	680612.5	2.62	05/03/2015
8289869	680612.0	2.61	05/03/2015
8289870	680611.6	2.64	05/03/2015
8289870	680611.2	2.64	05/03/2015
8289871	680611.7	2.65	05/03/2015
8289871	680611.3	2.65	05/03/2015
8289872	680609.8	2.69	05/03/2015
8289872	680609.4	2.71	05/03/2015
8289873	680609.0	2.66	05/03/2015

the reservoir shoreline were also imported, the reservoir boundaries x, y points were given a default values of zero associated with each point. The projection information was specified at this time, World Geodetic System 1984 (WGS84).

Files were displayed as event files in ArcGIS, and were then exported as shapefiles. The point shapefile(s) were visually evaluated for any points with spurious latitude and longitude coordinates. The attribute tables were also examined for any points reporting a value of 0 in the depth file and if found, these points were deleted of errors. The Z (depth) values were given a minus (-) sign. This is so because water surface was taken as the reference level and if minus sign was not given, the surface volume 3D analyst tool would have calculate Z values as elevations instead of depth.

The reservoir boundary points data were then merged with x, y, z data set using the merge tool in ArcGIS. Thereafter, ArcGIS Spatial Analyst was used to produce an interpolated surface using Inverse Distance Weighted (IDW). It is from this raster surface that the volume and surface area of the reservoir were calculated using the Area and Volume tool under ArcGIS 3-D Analyst. Since the reservoir boundary had zero values representing the reservoir surface, the plane height was set at zero and all the reservoir depths were taken to be negative using metres as units of measurement. These methods have recently been applied in Zambia by Sichingabula et al. (2014) [5] and Chisola (2015).

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

$$SV=RSC_i - RSC_{i+n} \quad (1)$$

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

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

4. Results

Results for each of the four studied small dams, namely, Katondwe, Silverest, Lwiimba, and Morester dams, are presented below under different subheadings.

4.1 Bathymetric Survey

The dams were constructed at different times with Morester dam being the oldest having been constructed in 1960 followed by Lwiimba (1970), Katondwe (1980) and Silverest the youngest was constructed in 1989. Bathymetric measurements obtained for each dam showed that Silverest dam was the deepest at 9.5 m of water depth while Katondwe was the shallowest at 3.0 m (Table 2). For water surface area again Silverest was the biggest with a water surface area of 86,082.47 m^2 followed by Lwiimba (43,013.89 m^2), Morester (7,479.63 m^2) and Katondwe, the smallest, with 7,881.63 m^2. Combining the design historical data with estimated reservoir capacities based on measurements conducted in March and February 2015, it was found that these dams suffered considerable loss of water holding capacities. Silverest dam the biggest which was designed for a total of 747,812 m^3 was found to hold 368,311.46 m^3, Morester dam 28,530 m^3 at construction reduced to 14,724.32 m^3 in 2015, Lwiimba 200,096 m^3 at construction was found to be 101,051.43 m^3 in 2015, and lastly, Katondwe reservoir capacity reduced from 20,652 m^3 at construction to 10,714.88 m^3 in 2015 (Table 2).

4.2 Bathymetric Survey: Hydro and Sediment Hypsometric Relationships

The results in Table 2 have been plotted to produce hydro and sediment hypsometric curves for the studied dams reported separately.

Katondwe dams: Fig. 4a shows a very strong relationship between depth and reservoir area, and so is the relationship between depth and reservoir volume (Fig. 5a) for Katondwe dams. The observed total storage capacity of Katondwe dam in 2015 was found to be 10,714.88 m^3 whereas, 35 years ago, at construction time (design), the storage capacity was 20,652 m^3. The sediment deposition between 1980 and 2015 in Katondwe reservoir has resulted in a loss of approximately 9,937.12 m^3 of reservoir storage capacity.

Silverest Dam: The generated hypsometric curves for Silverest dam between water depth and water surface area (Fig. 4b) and between depth and reservoir volume (Fig. 5.2b) show very strong relationships that exist between depth and reservoir capacity, and between depth and reservoir volume, respectively. The reservoir measured storage capacity was found to be 368,331.5 m^3 while the design total storage capacity of Silverest dam in 1989 was 747, 812 m^3. This shows that Silverest dam lost 379,480.5 m^3 storage capacity attributed largely to sediment deposition and partly due to plant colonisation.

Table 2 Bathymetric Survey and Analysis Results for the Four Studied Dams East of Lusaka, Zambia, February-March, 2015.

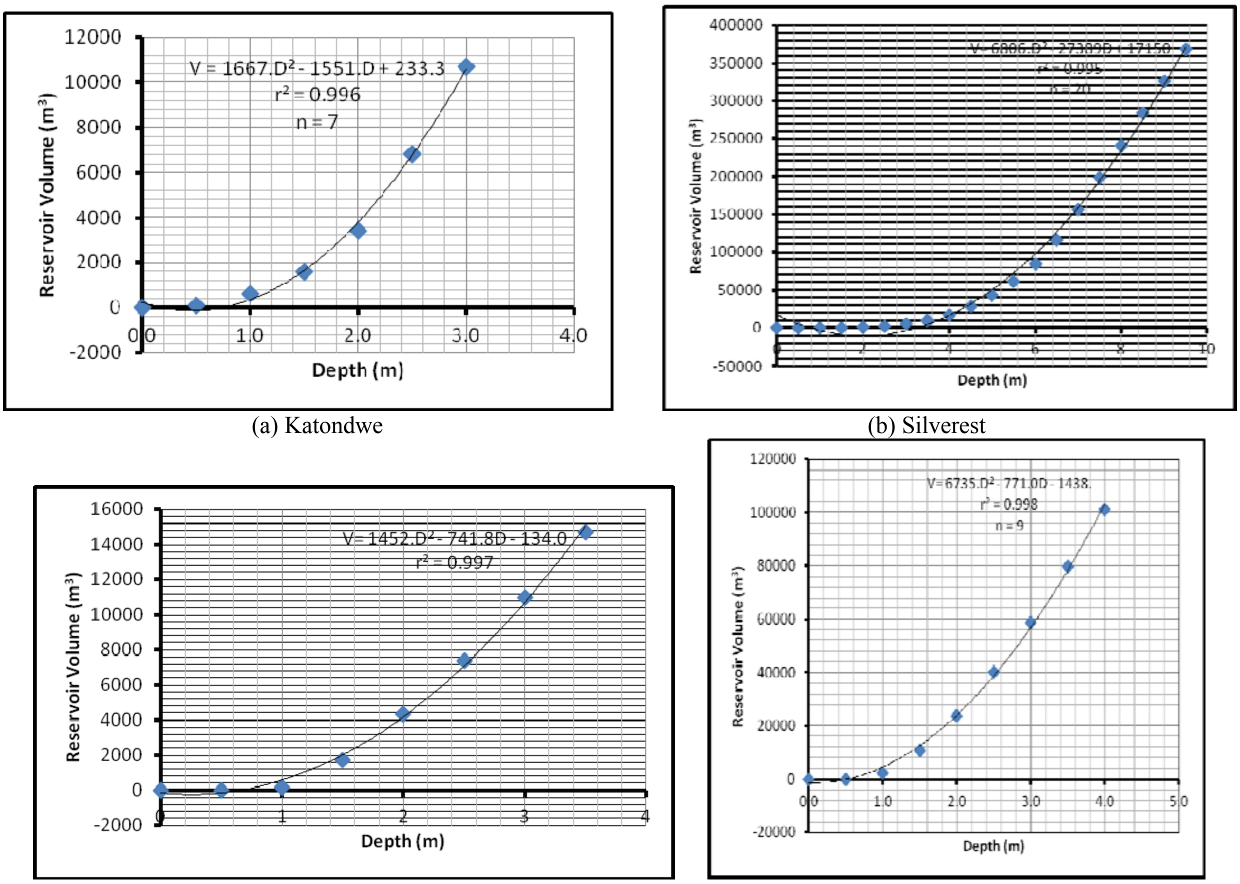
Katondwe Dam			Silverest Dam			Morester Dam			Lwiimba Dam		
Water Depth (m)	Water Surface Area (m^2)	Water Volume (m^3)	Water Depth (m)	Water Surface Area (m^2)	Water Volume (m^3)	Water Depth (m)	Water Surface Area (m^2)	Water Volume (m^3)	Water Depth (m)	Water Surface Area (m^2)	Water Volume (m^3)
3.0	7881.63	10714.88	9.5	86082.47	368331.46	3.5	7479.63	14724.32	4.0	43013.89	101051.43
2.5	70421.41	6806.57	9.0	86080.41	325983.17	3.0	7369.38	11006.95	3.5	42136.19	79669.83
2.0	5189.66	3423.84	8.5	86078.38	283634.88	2.5	6680.85	7418.07	3.0	39732.06	58819.22
1.5	2681.85	1598.29	8.0	86075.23	241286.59	2.0	5747.73	4320.90	2.5	35353.47	40077
1.0	1402.33	628.11	7.5	86070.51	198937.21	1.5	4469.87	1728.91	2.0	29966.61	23785.53
0.5	681.57	113.14	7.0	86074.36	156590.12	1.0	1464.48	186.87	1.5	21991.35	10813.48
0.0	0.00	0.00	6.5	73332.51	116214.78	0.5	2.24	0.26	1.0	11144.54	2474.66
			6.0	55720.18	84846.13	0.0	0.00	0.00	0.5	91.00	3.76
			5.5	42466.40	61210.64				0.0	0.00	0.00
			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						
			2.0	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						

Morester dam: The depth and volume of Morester dam shown in Table 1. The hypsometric curves for this dam between water depth and water surface area (Fig. 4c) and between depth and reservoir volume (Fig. 5c) show a very close relationship that exist between depth and reservoir capacity, and depth and reservoir volume.

Lwiimba dam: Fig. 4d shows a very close relationship between depth and reservoir area, and so is the relationship between depth and reservoir volume (Fig. 5d). The reservoir current storage capacity was found to be 101,051.43 m^3 which was much lower than 200,096 m^3 at construction in 45 years. This indicates that sediment deposition between 1970 and 2015 in Lwiimba reservoir has resulted in a loss of approximately 99,044.57 m^3 of storage capacity.

4.3 Estimated Volume of Deposited Sediment in Reservoirs

Katondwe reservoir experienced the sediment deposition of approximately 9,937.12 m^3 between 1980 and 2015. This gives an annual sediment rate of 283.92 $m^3\ yr^{-1}$. At this rate the estimated lifespan of Katondwe dam was 38 years. Meanwhile, Silverest dam in 45 years had an estimated sediment deposition of 379,480.5 m^3. This gives an annual sedimentation rate of 14, 595.4$m^3\ yr^{-1}$. At this rate Silverest life span was estimated to be 26 years. While for Morester reservoir, approximately 13,805.68 m^3 of sediment volume was deposited in 55 years. This gave an annual sedimentation rate of 251.01 $m^3\ yr^{-1}$. At this rate, the lifespan of Morester dam was estimated to be 58 years.



(a) Katondwe (b) Silverest

(c) Lwiimba (d) Morester

Fig. 5 Depth-Volume Curves for (a) Katondwe, (b) Silverest, (c) Morester and (d) Lwiimba Reservoirs, East of Lusaka.

Lastly, the sediment deposition between 1970 and 2015 in Lwiimba reservoir resulted in a sediment volume of 99,044.57 m^3. This gave an annual sedimentation rate of 2,200.99 m^3 yr^{-1}. If this rate is divided into the current reservoir storage capacity, the estimated lifespan for Lwiimba dam was estimated to be 46 years. Table 3 summarises reservoir capacities, estimated sediment volumes, rates of sedimentation and other statistics for the four studied dams east of the city of Lusaka, Zambia.

4.4 Effects of Sedimentation on Uses of Small Dams

During the study respondents reported that sedimentation affected mainly usage of small dams due to reduced water storage. For instance, the loss in storage capacity at Lwiimba dam is negatively irrigation and livestock watering. It quickly fills up with water at the onset of rain season the storage capacity has been lost due to sedimentation. As a result, there are high chances that Lwiimba dam dries up in dry season. It is no longer able to conserve water for both livestock and irrigation throughout the year. This was also the case for Silverest dam where the loss of storage capacity is affecting the irrigation. It was revealed that though the dam does not dry out completely in the dry season, the stored water during that time is not enough for pumping to the centre pivots for irrigation. Consequently, towards the dry season, irrigation is suspended so as not to deplete the water completely and reserve some water for livestock watering. Meanwhile, the loss of water storage at Morester farm has contributed to the abandonment of the dam for irrigation. The dam is no longer holding enough for irrigation such that it is now just used for livestock watering [6].

Whilst Katondwe dam which is exclusively used for domestic water supply through the use of pressure pumps for Katondwe Mission, which encompasses Katondwe Secondary School and Katondwe Hospital. Loss of storage capacity is posing a challenge to Katondwe Mission in the provision of water supply to Katondwe School and the Hospital. It was reported that due to low water storage, especially in dry season, Katondwe management faces challenges of adequately supplying water to these two facilities. As such, boreholes have been sunk to supplement the water supply from the dam.

In addition to the effects of sedimentation on small dams, data on water quality from the water samples were collected and analysed at the Environmental Laboratory at the University of Zambia. Knowledge of the quality is important because some people drink dam water directly without treatment. Seven parameters were tested for the studied dams (Table 4). The Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) which are the main resultants of eroded sediment are a measure of total salts, and other inorganic substances that are dissolved and suspended in water, respectively, including Sulphates, Chlorides and Nitrates. These parameters have important implications on the quality of water as they cause pollution when concentrations exceed the natural levels, thereby having detrimental effect on water quality and its associated uses. The concentration of the measured parameters for Katondwe and Morester dams were all within the WHO permissible limits for drinking water while Silverest dam had concentrations of Sulphates beyond the permissible limit. The pH levels for Silverest and Lwiimba reservoirs were all found to be below permissible levels.

Table 3 Summary of Storage Capacity and Sedimentation Statistics for Studied Small Dams in Lusaka Province.

No.	Dam Name	Year Constructed	Catchment Area (km^2)	Reservoir storage capacity at construction (m^3)	Measured reservoir storage capacity (m^3)	Measured Water mean depth (m)	Estimated Sediment Volume (m^3)	Estimated Mean Sediment Depth (m)	Years since construction	Estimated Annual Rate of sedimentation (m^3yr^{-1})
1	Katondwe	1980	2.2	20,652	10,714.9	1.22	9,937.1	1.26	35	283.9
2	Silverest	1989	28.2	747,812	379,480.0	4.41	379,480.5	4.41	26	14,595.4
3	Morester	1960	6.3	28,530	14,724.3	1.93	13,805.7	1.84	55	251.0
4	Lwiimba	1970	11.8	200,096	101,051.4	2.30	99,044.6	2.30	45	2,200.9

Table 4 The Physico-Chemical Results of Analysed Water Samples for the Studied Small Dams, February to March, 2015

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

4.5 Sediment Control Measures

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

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

One Key Informant from Department of Agriculture stated that there were no specific sediment control measures for small dams except the natural vegetation. However, he went on to say that there was a limited soil conservation measure being practised. This measure is minimum tillage conservation farming which was encouraged to reduce the disturbance of soil and sheet erosion that may be susceptible to water erosion.

5. Discussion

This discussion of study findings focuses on measured taken to be the current reservoir storage capacity, storage loss, sediment volume, rate of sedimentation, and effects of sedimentation on uses of small dams and sediment control measures for the studied small dams in relation to similar studies elsewhere in the world.

5.1 Reservoir Storage Capacity

The results of studied four small dams east of Lusaka revealed that the reservoirs have lost substantial amounts of storage capacity since time of their construction. The reservoir storage capacity losses for the Lwiimba, Silverest, Morester and Katondwe dams ranged from 49 percent to 50 percent which are within the same order of magnitude as those observed by Onwuegbunam et al. (2009) [7] in Nigeria for a small reservoir constructed in 1987 at the Afaka Forest Reserve in Kaduna State. This Nigerian study showed that about 35 percent of the reservoir storage capacity was filled with sediment within a period of 26 years, caused a serious problem because it was undermining water uses of the dam. It was further ascertained that there were several similar small-dams within Kaduna State, some of which were almost completely silted up [7]. Similarly, Rooseboom and Lotriet (1992) [8] reported on the Welbeck Reservoir constructed in 1973 in South Africa had lost most of its storage capacity (66 percent) within the first 13 years of its existence due to sedimentation. Reservoir capacity storage loss is one of many sedimentation problems that are affecting the four small dams investigated by this study. As was found elsewhere, this study also attributed loss of reservoir storage capacity on small dams east of Lusaka to sedimentation. This implies that with time and as dams age sediment will continue to accumulate, and sediment related problems will likely increase and affect water resources availability in the four catchment. However, combinations of other environmental factors that include changes in climate, water seepage and plant colonisation do affect storage capacity of dams. In order to restore high reservoir storage capacity for these dams, a number of practical means of removing the sediment from reservoirs such as dredging, and excavation can be done to ensure that these dams operate on sustainable basis to better save local communities and livestock.

The derived hypsometric curves, depth-area and depth-volume relationships which showed very strong correlations for all the studied dams, can be used for monitoring of reservoir capacities from stage data, if gauge plates were installed for each dam. This suggests that there is need to install gauge plates for small dams to allow easy monitoring of water levels and for sustainable management of the water resources impounded by small dams.

5.2 Sediment Volumes and Rate of Sedimentation

The four studied small dams have substantial amounts of deposited sediment. Silverest dam had a greater amount of deposited sediment of 379,480.50 m^3, followed by Lwiimba 99,044.57m^3, then Morester 13,805.68 m^3 followed by Katondwe 9,937.12 m^3. Additionally, the rates of sedimentation for Silverest dam of 14,595.40 m^3yr^{-1} was higher followed by Lwiimba 2,200.99 m^3yr^{-1} then Katondwe 283.92 m^3yr^{-1} and lastly Morester dam, 251.01 m^3yr^{-1}. The results of the rates of sedimentation obtained in this study were within the order of magnitude as those observed by Aynekulu et al. (2007) [9] in the study conducted in Tigray, northern Ethiopia where the annual rate of sedimentation of Filiglig and Grashito reservoirs were found to be 6,928 m^3 yr^{-1} and 11,987 m^3 yr^{-1}, respectively. The differences in the deposited sediment and sedimentation rates among these dams can be attributed to the differences in catchment characteristics as well as the number of years the dam has been in operation. Additionally, a number of other environmental factors do affect the sediments yield at the catchment area such as precipitation (with regard to quantity, intensity and frequency), type of soil, vegetation coverage, soil management practices (cultivation practices, forest exploitation, building activities and conservation measures) and the nature of the drainage network (density, slope, shape, size and channels configuration) [10]. Thus, appropriate measures should be put in place especially for the catchment management in order to arrest the rates of sediment deposition for the studied dams.

5.3 Effects of Sedimentation on Uses of Small Dams

Retained rainfall water in reservoirs can ensure sufficient water availability for households, livestock and agriculture during both wet and dry seasons. Reduced reservoir storage capacities for Lwiimba, Silverest, and Morester and Katondwe dams related to sedimentation is affecting the full utilisation of their intended uses. The increasing demand on water, coupled with their decreasing storage capacity, means that the reservoirs are being used below their intended yields. This implies that the owners of the dams have to stop using the dams especially in dry season in order to maintain water supplies for other critical uses, such as livestock watering as it is the case with Silverest and Morester dams. Thus, these dams are failing to contribute significantly in ensuring whole year round reliable water supply for domestic use in case of Katondwe dam and for livestock watering and irrigation farming in case of Lwiimba, Morester and Silverest dams. This is similar to a study by Kamutukule (2008) [11] in Malawi on the impacts of sedimentation on water availability on Chamakala small dam, where sedimentation was found to be a serious problem by undermining the usefulness of Chamakala dam especially during dry season as the dam could not contain enough water for irrigation and livestock watering. Ainworth (2005) [12] argues that loss of reservoir storage capacity due to sedimentation exacerbates the problem of providing enough storage for the rising population with its rising aspirations and standards. Apart from reduced storage capacity, sedimentation also does affect reservoir water quality. Hargrove (2008) [13] argue that sedimentation is said to not only to reduce water-storage capacity of reservoirs, but deposited sediments containing nutrients, and trace metals significantly pollute and affect reservoir water quality. For this study, the pH for Lwiimba and Silverest were slightly below the acceptable permissible limits for drinking water based on WHO standards. Meanwhile, Sulphate concentration for Silverest was above the acceptable levels. This means that the catchment area contributing water to Silverest dam may have soil and rock formation that contains sulphate minerals. The effects of high concentration of sulphates give water a bitter taste and when the water is used for livestock watering as it is the case with Silverest, it may cause diarrhoea as animals are also sensitive to high levels of sulphates especially in young animals [14].

5.4 Sediment Control Measures

Lack of adequate soil erosion/sediment control measures in the catchment as revealed in this study is one of the factors contributing to reservoir observed sedimentation for the studied dams. The other possible factor that positively is contributing to sedimentation for Lwiimba, Silverest, Morester and Katondwe dams could be the size of the watersheds. Since these dams have smaller watershed size, the suspended sediment being carried by the runoff do reach the reservoir in a relatively shorter distance without settling somewhere in the watershed. Sediments reaching the reservoir from surface runoff depend on soil erosion in the catchment. Thus, lack of proper implementation of soil control measures in the catchment might be a major factor in accelerating soil erosion and consequently high sedimentation rates for the studied dams. In a study conducted in Ghana to assess the impact of landuse management on the Burekese catchment, the results showed a loss in reservoir storage capacity of 45 % due to siltation over a period of six years. The causes for the quick silting up of the reservoir were attributed to lack of adequate soil conservation measures, deforestation and lack of proper education of the communities in soil erosion catchment management practises [15]. Sichingabula (1999) argues that if the catchments are not protected from activities such as tree clearing for charcoal production, settlement and agriculture, sediment yield in the catchments is likely to increase. Hence, for the studied dams, more attention should be given to concerns in preventing or at least slowing down, the process of soil erosion by applying an integrated soil and water conservation techniques at catchment scale as it was done in the 1970s under the region and catchment conservation planning which was included in the First and Second National Development Plans (Robinson, 1978). Such measures would help in dealing with the problem of soil erosion from a spatial dimension. Conservation programmes should be done through changes in land use, notably reforestation and altering agricultural practices to emphasise soil conservation.

6. Conclusion

Sedimentation is one of the most important problems that directly affect the performance of reservoirs due to the reduction of the storage leading to reduced useful lifespan of small dams. This study found that that measured reservoir storage capacities in year 2015 for Lwiimba, Silverest, Morester and Katondwe dams were 101,051.43 m^3, 379,480.00 m^3, 14,724.88 m^3 and 10,714.88 m^3, respectively. The estimated rates of sedimentation for Silverest was 14,595.40 m^3yr^{-1}, at this rate the reservoir lifespan was found to be 26 years; Lwiimba (2,200.99 m^3yr^{-1}), the lifespan was 46 years; Katondwe (283.92 m^3yr^{-1}), had a lifespan of 38 years and Morester (251.01 m^3yr^{-1}), had lifespan of 58 years. These rates of sediment deposition has led to reservoir capacity storage losses of 99,044.57 m^3; 379,480.5 m^3; 13,805.68 m^3 and 9,937.12 m^3 for Lwiimba, Silverest, Morester and Katondwe, respectively, with the general consequences of reservoir drying especially in the dry season. Lack of adequate soil erosion/sediment control measures at the catchment scale has been attributed to be one of the factors contributing to high reservoir sedimentation East of Lusaka.

Overall, this study has also demonstrated the value of bathymetric mapping and the value of sediment monitoring to water resources management for Zambia. It is concluded, that as small dams in Lusaka age, sediment continues to accumulate and sediment-related problems increase in severity with negative effects on their reservoir usefulness due to shortening of lifespans. This calls for periodic dredging of deposited sediment in order to maintain high level storage capacities and to increase dam lifespans, with good erosion control measures. More sedimentation studies need to be conducted in Zambia.

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