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BATHYMETRY OF THE MAKOYE RESERVOIR AND ITS IMPLICATIONS ON WATER SECURITY FOR LIVESTOCK WITHIN THE CATCHMENT

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ABSTRACT

The objectives of the study were to: determine bathymetry of the reservoir; understand seasonal hydrological regimes of the reservoir; determine factors influencing reservoir bathymetry and, examine the implications of the reservoir's bathymetry on livestock water demand and policy decision making. The determined reservoir bathymetries and capacities at low, medium and full levels confirmed drastic changes in water volumes and eventually, a threat to water security for livestock. This unsteady equilibrium in reservoir's bathymetry and water volumes was mainly due to high mean annual siltation rates (>5,000 tyr^{-1}). Using 3D spatial analysts tools in ArcGIS 10.3 and spreadsheet Microsoft Excel to analyze the data based on the study, hypsometric curves showed strong non-linear relationships among water depth and water surface; water depths and water volume, as well as water surface area and water volume. Generally, through inter-seasonal comparisons of reservoir's bathymetries and water volumes between 2015 and 2017, this study illustrates the significance of bathymetric study of small reservoirs as a plinth to provide policy context and guidelines on water resource management for livestock, as a missing component in general studies of bathymetry, which are usually predominated by understanding the physical processes, but with little or no emphasis on their meaning towards addressing societal needs. Hence, a community engaged strategy to addressing upstream sediment-generating activities would help in stabilizing the bathymetry of the reservoir and eventually enhance water security for livestock.

Contribution/Originality: This study is one of very few studies which have investigated implications of bathymetric surveying on sustainable water resource management for livestock. The study documents how bathymetric surveying can be used to understand seasonal hydrological regimes and storage capacity loss of small reservoirs so as to prepare for water security.

1. BACKGROUND

According to Ajith (2016) bathymetry was originally used and referred to the ocean's depth relative to sea level, although it has come to mean submarine topography or the water depths and shapes of underwater terrain. It is a plinth of the science of hydrography, which measures the physical features of a water body, bathymetry has important value in hydrology and planning for water security (International Institute for Geo-Information Science and Earth Observation (IIGSEO), 2016). It involves comparison of reservoirs morphology at two different time periods, first at the time of the construction of the reservoir and second at the time of the survey, which should be at least ten years later to detect significant changes (United States Army Corps of Engineers (USACE), 2013). Bathymetric survey approach provides reservoir needed information such as reservoir depth, capacity and bottom topography with great accuracy to optimize reservoir operations. It can also be used to estimate sedimentation rates.

In his study, Ajith (2016) used Differential Global Positioning System (DGPS), Navitronic Echo-sounder (NS-415), sound velocity probe, survey-computer to conduct bathymetric survey of the Peechi Dam at Full Reservoir Level (FRL) in Kerala area of India. Using such bathymetric tools and Surfer software for analysis, Ajith (2016) concluded that Peechi Dam had lost its reservoir capacity by 14.027% of the original (79.25m depth and 110.436 million m^3 of water). This demonstrated the rate of sedimentation at 0.27 million m^3 (0.25%) per year. The actual calculated capacity was 94.946 million m^3, hence this shows an actual loss of capacity of 15.490 million m^3 in 56 years (Ajith, 2016). Bathymetric survey of the same reservoir in 2004 showed that its capacity was 96.414 million m^3, but as of 2016, the calculated capacity stood at 94.946 million m^3 showing a reduction by 1.468 million m^3 over a period of nine years or 0.1631 million m^3 per year from 2004. Other studies have employed this method, for example, McPherson *et al.* (2009) studied the storage capacity in relation to sedimentation of the Loch Lomond Reservoir in California; Richard *et al.* (2000) used it to assess sedimentation on the Loch Raven and Prettyboy reservoirs in Maryland, USA; Sebnem *et al.* (2009) used similar method to assess bathymetry and sedimentation in the Tahtali Basin in Turkey, others include works with a focus on bathymetry include (Vojinovic *et al.*, 2013) who focused on machine learning approach for estimation of shallow water depths from optical satellite images and sonar measurements and, Yuzugullu and Aksoy (2014) whose earlier works focused on generation of the bathymetry of a eutrophic shallow lake using WorldView-2 imagery.

In their study of the Amazonian reservoirs, Curtarelli *et al.* (2015) used the GPS Extension of ArcGIS, the GPS data feed from the GPS receiver via the Biosonics echo sounder, and the pre-planned transect pattern. Their bathymetric results were outstanding and presented in the same pattern as any other scientific works (Ajith, 2016; IIGSEO, 2016) on bathymetric surveys, but one shortcoming was noted in the way their echo-sounder was recording the depth. The reservoir's depth data was being automatically logged in new files every after 30 minutes by the Biosonics system. This was perhaps the most accurate and available method for their study, but it may not be reliable because sometimes times, sonars record erroneous depths especially in very shallow waters, which cannot be noticed if the records are only showing after half an hour. The current study overcame this methodological limitation because the RC-HSB model S2 measured and instantly record depth per second in real time. Air borne laser scanning technologies are currently being used to determine bathymetric states of water bodies (Smith and Sandwell, 2004; El-Hassan, 2015).

The study by Dalu *et al.* (2013) of the Malilangwe reservoir in Zimbabwe showed seasonal variations in the bathymetric state of the reservoir and that this variation had an influence on nutrients concentration. According to Dalu *et al.* (2013) this was the first bathymetric and limnological study of the reservoir where the morphology and physicochemical quality of the water body were examined. The reservoir exhibited marked seasonal fluctuations in water level, which decreased by over 149 cm between February and October as revealed by bathymetric surveys conducted. The sonar used (CEESTAR dual-frequency digital survey echo-sounder, 30 kHz and 200 kHz) was accurate indeed capable of 0.01% of depth accuracy. However, the GPS accuracy of about 10 cm was not as accurate compared to RC-2HSB (used in the current study) whose accuracy can be in mm and sometimes less than that because it uses DGPS. Although other scholars may argue that the difference would be insignificant, RC-2HSB would give fairly more accurate results as compared to CEESTAR dual-frequency digital survey echo-sounder. 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 (283.92m^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.

Early studies in Zambia (Sichingabula, 1997;1999; Sichingabula, 2000) lack a scientific rigor in bathymetric research because they mainly employed traditional approaches of determining bathymetric state of reservoir, as such, some results were largely based on statistical estimations. Nevertheless, most recent study of four reservoirs by Chomba and Sichingabula (2016) in the East of Lusaka Province showed new methodologies of determining reservoir bathymetry. This study found 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. Much as we appreciate such results, in terms of providing a baseline, there is need for repeated surveys. In order to obtain very reliable bathymetric survey data and other related parameters, at least more than one measurement on the same water body must be conducted at different times in order to check trends over time. Consequently, this study did not only determine the bathymetric state of the Makoye reservoir, but also examined its implications on water security for the people living within the catchment and on their livestock (cattle). A lack of connection of bathymetric analyses to implications on water security was the major gap noted in earlier studies (Dalu *et al.*, 2013; Curtarelli *et al.*, 2015; Ajith, 2016; Chomba and Sichingabula, 2016; IIGSEO, 2016) reviewed in the current study.

2. MATERIALS AND METHODS

Makoye reservoir is found in the Magoye Catchment (434.34 km^2) in Njola area, east of Monze Town in southern Zambia Figure 1a and b. It is specifically located between 16°14'08.4" South to 16°15'06.8" South and 27°40'52.8" East to 27°42'49.8" East and, has a surface area of about 76,437.11 m^2. It was built in 1940 and, it was renovated in 1988.

Table-1. Summary of selected hydro-geomorphometric parameters of Makoye reservoir catchment.

<table>
<tr><th colspan="5">Description</th><th>Values</th></tr>
<tr><td colspan="5">Year of construction</td><td>1940</td></tr>
<tr><td colspan="5">Year of renovation (Dredging and rehabilitation)</td><td>1988</td></tr>
<tr><td colspan="5">Spillway elevation (m)</td><td>1106.700</td></tr>
<tr><td colspan="5">Crest elevation (m)</td><td>1107.788</td></tr>
<tr><td colspan="5">Crest length (m)</td><td>220</td></tr>
<tr><td colspan="5">Downstream elevation (m)</td><td>1102.61</td></tr>
<tr><td colspan="5">Stream order</td><td>2nd</td></tr>
<tr><td colspan="5">Sinuosity of the main depressional channel (Straight <1, Sinuous 1-1.5, meandering >1.5)</td><td>1.4</td></tr>
<tr><td colspan="5">Minimum subbasin elevation (m)</td><td>1070</td></tr>
<tr><td colspan="5">Maximum subbasin elevation (m)</td><td>1145</td></tr>
<tr><td colspan="5">Subbasin Area (km^2)</td><td>66.8</td></tr>
<tr><td colspan="5">Total distance of streams in the subbasin (km)</td><td>3.22</td></tr>
<tr><td colspan="5">Stream density (km/km^2)</td><td>0.05</td></tr>
<tr><td colspan="5">Stream frequency (stream segments/km^2)</td><td>0.04</td></tr>
<tr><td>Drainage shape: Elongated</td><td>Type of drainage pattern: Open dendritic</td><td colspan="2">Flow type: Unsteady</td><td colspan="2">DGPS Accuracy during measurement (m): 0.0013</td></tr>
<tr><td rowspan="3">Reservoir storage Capacity (m^3)</td><td colspan="4">Original *(mean sediment volume (msv)) + (measured water volume at spillway level (wv_{sl}))*</td><td>160,689.67</td></tr>
<tr><td colspan="2" rowspan="2">Measured *((msv+mwv_{sl})-msv))*</td><td colspan="2">By the year 2014</td><td>75,753.56</td></tr>
<tr><td colspan="2">By the year 2016-2017</td><td>74,273.71</td></tr>
<tr><td>Capacity loss (%)</td><td colspan="5">(msv/(msv+mwv_{sl})×100%: 52% by 2014; 54% by 2017</td></tr>
</table>

Source: Field measurements (2014-2017) * $_{sl}$ spillway level.

The sub-catchment in which Makoye reservoir is located has an area of about 67 km^2. The reservoir is located in agro-ecological Zone-IIa with mean annual rainfall of ≤815 mm and maximum temperature range of 33-36°C.

Geologically, it is underlain by the Zambezian belt and, it is covered by lithosol, chromic-pellic, vertisols, and nitosols (Food Agriculture Organization (FAO), 2006). A summary of some of the physical characteristics of the reservoir and catchment is presented in Table 1.

The population of households in the catchment Figure 1 is about 474, of which 77% depend on pastoral and crop farming (CSO, 2015). According to Ministry of Fisheries and Livestock (MLF) (2016) there are over 10,000 heads of cattle that depend on the Makoye reservoir. Makoye reservoir was selected for this study because it is one of the reservoirs that experience serious problem of sedimentation, and it is also used for domestic and livestock water during most parts of the year.

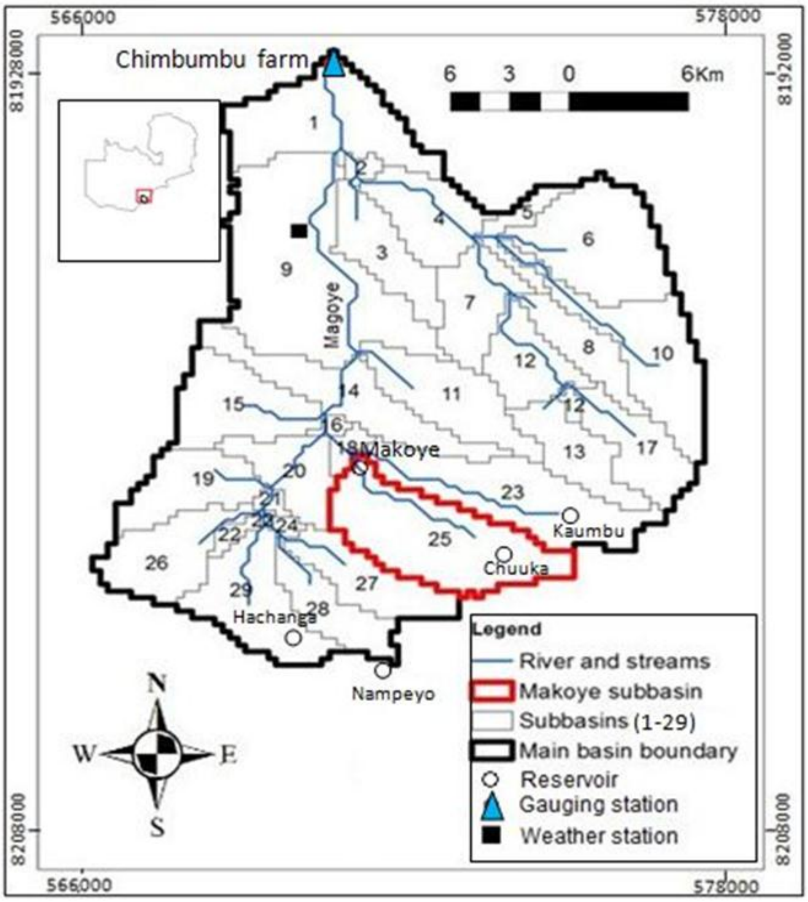


Figure-1. Hydrological location of the study area (Makoye reservoir and catchment).
Source: Field measurements (2014-2017).

2.1. Reservoir Sampling Process

In order to sample Makoye Reservoir, various types of snowball sampling techniques were used. According to Bryman (2008) there are three types of snowball sampling, namely, linear snowball sampling (LSS), exponential non-discriminative snowball sampling (ENDSS) and exponential discriminative snowball sampling (EDSS). Since the population of small reservoirs was initially not known, ENDSS was useful to arrive at the population of small reservoirs (Bryman, 2008; Castillo, 2009). Applied in context, during reconnaissance survey, a reservoir was being identified together with key informant (its owner or stewards) who would provide information about it. Thereafter, key informants at each logged reservoir were requested to refer researchers to other known reservoirs such that the number increased exponentially. During the reconnaissance survey, a listing of reservoirs was made without discriminating those not referred to him because the interest was on seeking sizeable reservoir, useful to communities, and one that dries up during dry season. After generating 96 small reservoirs through ENDSS during the first and second phases of the reconnaissance survey (2013 to 2014), EDSS was used during the third phase of reconnaissance survey to separate 10 small reservoirs that dry up during dry season from the 86 that were perennial for the purpose of measuring sediment depths on the reservoir bed. These 10 reservoirs eventually became the final target population of small reservoirs from which Makoye was selected using homogenous purposive sampling technique (HPST). The HPST allowed for selection of a reservoir with safe environment for camping activities during data collection period.

2.2. Data Collection Process

To collect bathymetric data of Makoye reservoir, Remote Controlled Hydrographic Survey Boat (RCHSB)-Model RC-S2 (mounted with trimble hemisphere OmniSTAR VBS for DGPS recording) was used to conduct bathymetric survey at low, medium and full capacities during the 2015/2016 and 2016/2017 rainy seasons. Inflatable boat mounted with an outboard engine was used to drag the RCHSB's sonar across the reservoir (see survey pathways in Figure 2 so as to collect water depths, water surface perimeter, and bed morphology. All measured parameters were automatically sent by RCHSB to the computer software, which also sent them to the created folder on the laptop as an excel csv.file. Data on volume of water and reservoir capacity were derived from the measured depth computed in ArcGIS 10.3. RCHSB-Model RC-S2 was instrumental in this study because it was quick to deploy and use in shallow waters with the aid of an inflatable boat. To determine how other physical processes (aside sedimentation) affected water levels, weather data were collected onsite and from Department of Water Affairs (DWA).

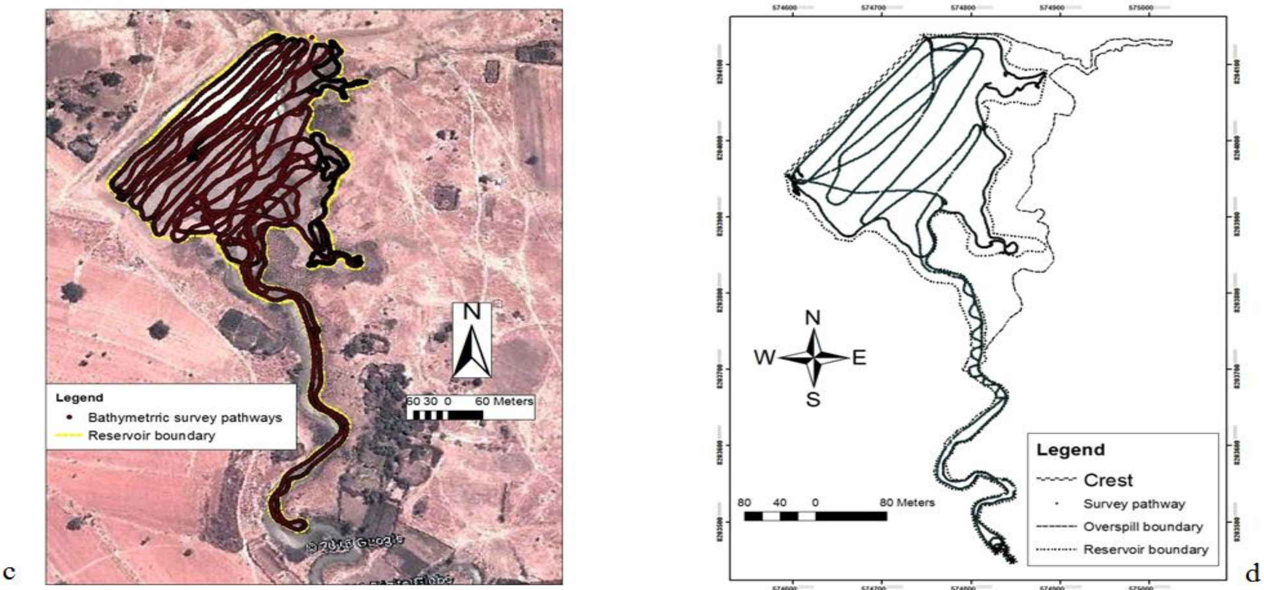


Figure-2. Bathymetric survey pathways at different water capacities: low (20/8/2015) (a); full (3/3/2016) (b); medium (19/6/2016) (c) and; full (17/02/2017) (d).
Source: Field measurements (2015-2017).

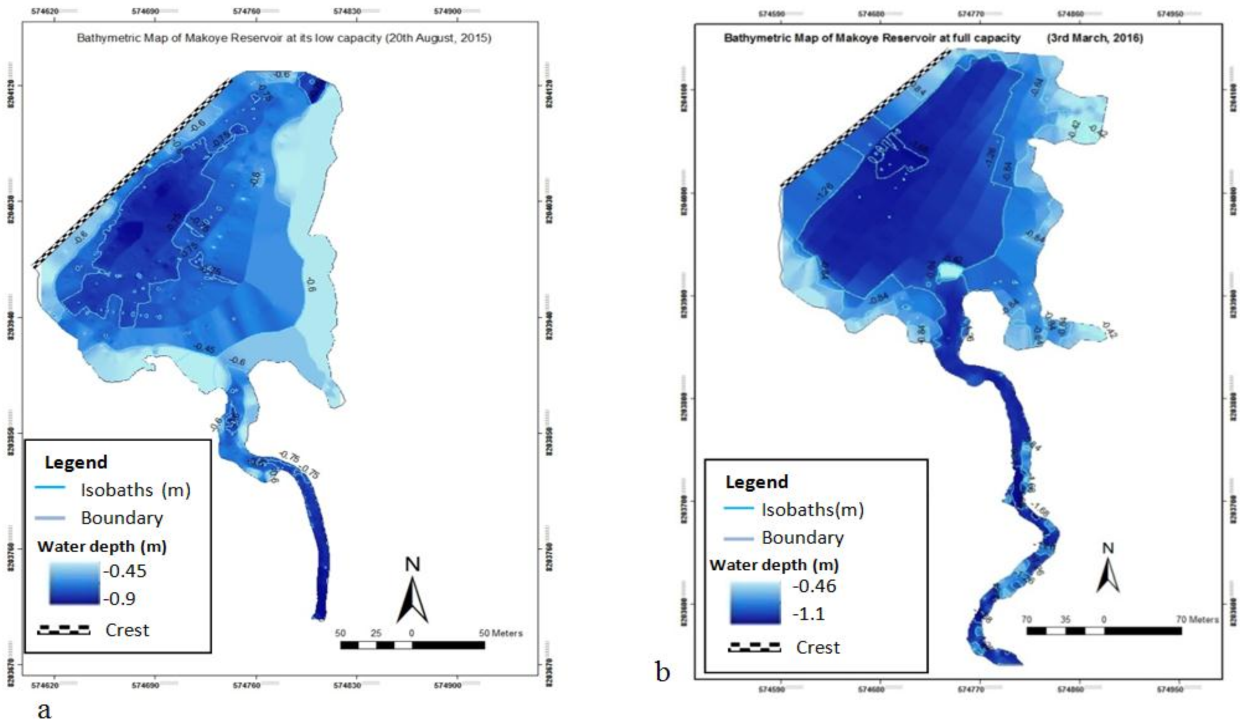
It also drastically reduced the time that would otherwise be needed if traditional methods of bathymetric surveying were employed (Coden, 2014). Bathymetric surveys were conducted at three reservoir water levels namely, low, medium and full levels in order to track bathymetric seasonal trends, allow for comparison and, to derive best capacity estimate.

2.3. Data analysis

Bathymetric data was analysed using 3D spatial analyst tools (3DSATs) in ArcGIS 10.3. The input data included water depths, geographical coordinates measured using Universal Transverse Mercator (UTM) WGS84 format and, perimeters of the reservoir at different times. The reservoir's boundary (perimeter) was converted to points and assigned with a default value of zero. Created reservoir boundary points data were merged with the water depth data using the merge tool in ArcGIS 10.3. The next step involved interpolating a continuous raster surface, using raster interpolation (15 cm, 26 cm and 42 cm contour intervals at low medium and full capacities respectively) under the 3-D Analyst in ArcGIS 10.3. Various interpolation methods namely, Inverse Distant Weighted (IDW), Kriging and, Natural Neighbour were tested and results compared. In the end, the best results display of one of the techniques at 15-42 cm intervals was adopted to ensure good extrapolation. Using the area and volume tool (AVT) under ArcGIS 10.3 3-D Analyst; water volumes and surface areas were computed based on the IDW models. Afterwards, by regression, polynomial hydro-hypsometric curves were generated in order to determine water depth-surface area, water depth-water volume, and water surface-water volume relationships using Microsoft Excel. The computed area and volume associated with each depth were finally tabulated and hydro-hypsometric curves, generated. A structured interview schedule (Bryman, 2008) was administered to 40 household respondents which were sampled using homogenous purposive sampling technique. This was useful in the collection of social concern about the availability of water and water-stressful periods within the catchment and, what key informants thought should be done to address the challenge of sedimentation. Influence of weather on water levels was analyzed using the analysis of variance (ANOVA) and reservoir evaporation formula: (Ev (Reservoir evaporation ($km^3/year)^2$) = ET_o (Reference evapotranspiration (mm/year)) × A (reservoir surface area (km^2) $\times 10^{-6}$).

3. RESULTS

Outputs from analysis of data were presented in maps, graphical and tabular forms. From the maps Figure 3a-e, it is clear that the depth of water varied across the reservoir, and seasonally. Figure 4a-d presents the hydro-hypsometric curves showing positive none-linear relationships of water depth and water volume plotted based on data presented in Table 2.



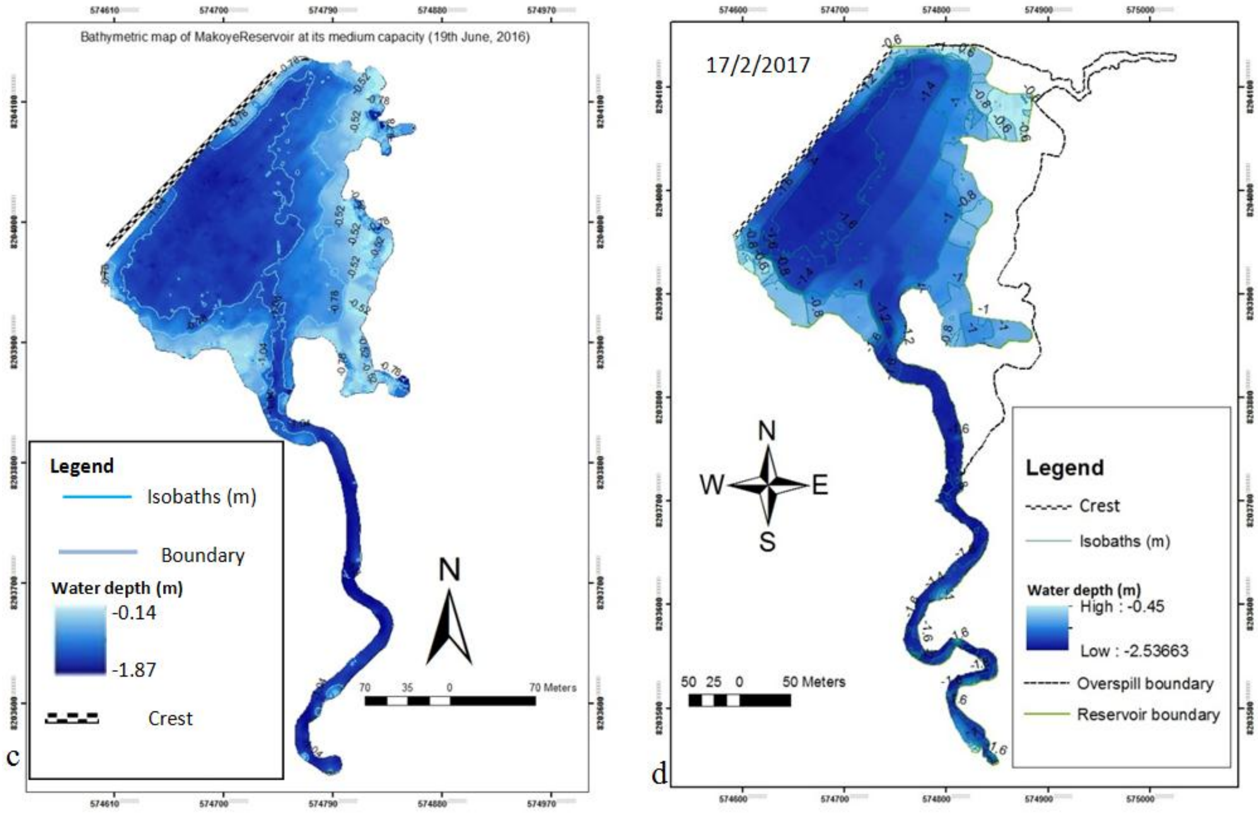


Figure-3. Bathymetry of Makoye reservoir at different seasons and capacities: warm-dry season low capacity (a), warm-wet season full capacity (b); cool-dry season medium (c) and; warm-wet season full capacity (d).
Source: Field measurements (2015/2016 and 2016/2017).

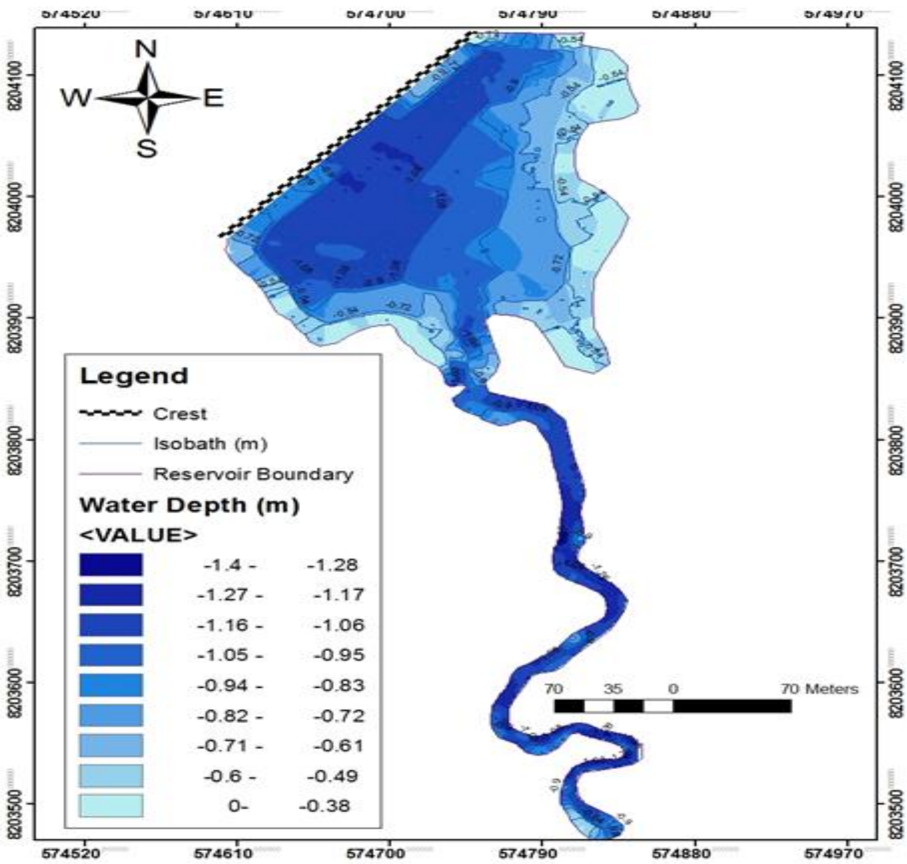


Figure-3e. Bathymetry of Makoye reservoir at its medium capacity in cool-dry season.
Source: Field measurements (14/7/2017).

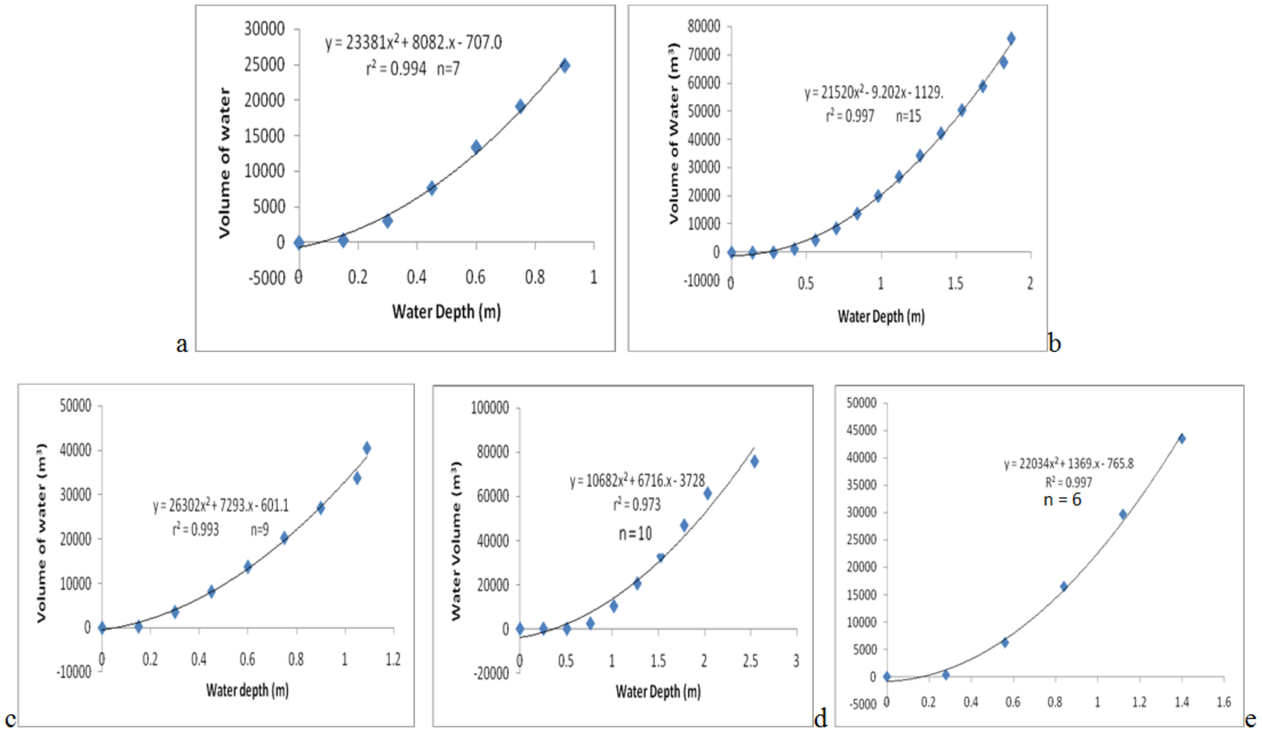


Figure-4. Hydro-hypsometric curves showing non-linear relationships between water depths and volumes for Makoye reservoir at: low capacity (20/8/2015) (a); full capacity (3/3/2016) (b); medium capacity (19/6/2016) (c); full capacity (17/02/2017) (d) and; medium capacity (14/7/2017) (e).

Source: Field measurements (2015/2016 and 2016/2017).

Figure 5 presents a hydrograph showing the seasonal hydrological regime of the Makoye reservoir based on bathymetric surveys conducted in two years period. The graph confirms that Makoye reservoir has very unstable water retention capacity given the rapid rate of volumetric change in water at short time intervals.

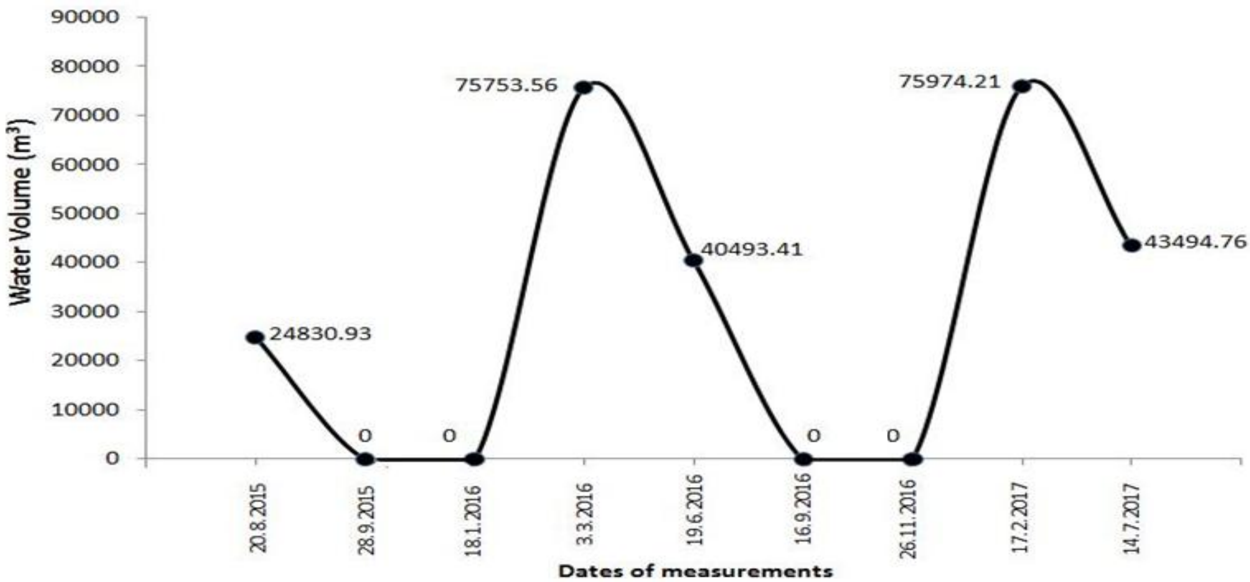


Figure-5. Hydrological regimes of the Makoye reservoir.

Source: Field measurements (2015/2016 and 2016/2017).

Table-2. Water depths, surface areas and volumes of water in the Makoye reservoir at different times of the year.

20 August, 2015 (warm-dry season)			3 March, 2016 (warm-wet season)			19 June, 2016 (cool-dry season)			17 February, 2017 (Warm-wet season)			14 July 2017 (cool-dry season)		
Low capacity			Full capacity			Medium capacity			Full capacity			Medium capacity		
Water depth (m)	Water surface area (m²)	Volume of water (m³)	Water depth (m)	Water surface area (m²)	Volume of water (m³)	Water depth (m)	Water surface area (m²)	Volume of water (m³)	Water depth (m)	Water surface area (m²)	Volume of water (m³)	Water depth (m)	Water surface area (m²)	Volume of water (m³)
0.9	38171.77	24830.93	1.87	60499.41	75753.56	1.09	44950.06	40493.41	2.54	57144.08	75974.21	1.4	49403.1	43494.76
			1.82	60499.4	67283.64									
0.75	38171.76	19105.16	1.68	60361.85	58828.72	1.05	44950.05	33750.90	2.03	57144.06	61459.61			
			1.54	59950.69	50385.22				1.78	56687.55	46953.33	1.12	49403	29661.9
0.6	38171.75	13379.39	1.4	57445.43	42162.43	0.90	44950.04	27008.39	1.52	52900.38	32978.35			
			1.26	54945.52	34284	0.75	44950.03	20265.89	1.27	44450.65	20576.47	0.84	41635.25	16466.34
			1.12	51134.01	26843.62									
0.45	37629.99	7653.56	0.98	46761.1	20004.12	0.60	40539.72	13752.99	1.02	36610.09	10312.77	0.56	29569.95	6220.41
0.3	26820.94	3070.92	0.84	41097.53	13799.72	0.45	33845.09	8157.64	0.76	23571.33	2408.87			
0.15	7828.99	342.96	0.7	32987.05	8562.5	0.30	27208.42	3568.29	0.51	435.89	22.6	0.28	7119.91	324.91
			0.56	26474.59	4418.05									
0	0	0	0.42	17473.48	1244.93	0.15	13090.79	276.87	0.25	20.66	4.54			
			0.28	1460.33	46.17									
						0	0	0	0	0	0	0	0	0

Source: Field measurements (2015/2016 and 2016/2017).

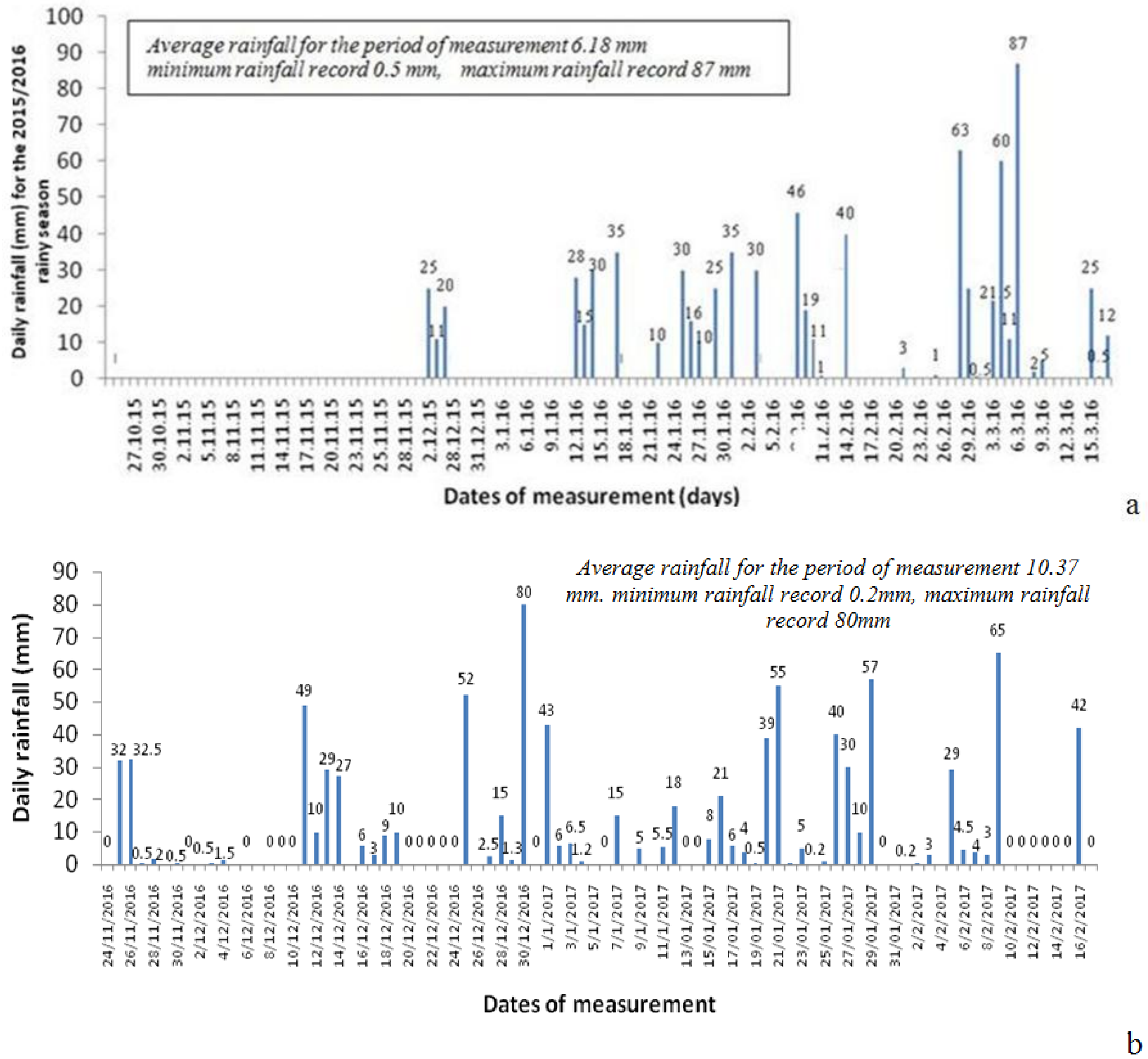


Figure-6. Daily rainfall records at Makoye reservoir (a and b).
Source: Field Measurements (2015/2016/2017 warm-wet seasons).

Figure 6a-b shows that during the 2015/2016 rainy season, the catchment did not receive enough rainfall (about 500 mm), which implies drought conditions. This could be attributed to the El Nino Southern Oscillation experienced during this season. Minimum daily rainfall record of 0.5 mm and, a maximum of 87 mm were recorded. The latter period shows a fair distribution of rainfall across the season as compared to the former period.

3.1. Selected Physical Processes Influencing Bathymetric Dynamics

Other than sedimentation, which was the major factor, there were other factors that partly contributed to the unstable reservoir bathymetry. These included evaporation, temperature, radiation, atmospheric pressure and wind speed Figure 7a-d and 8a-d. The influence of these physical processes on reservoir volume dynamics have been widely documented by FAO (2015).

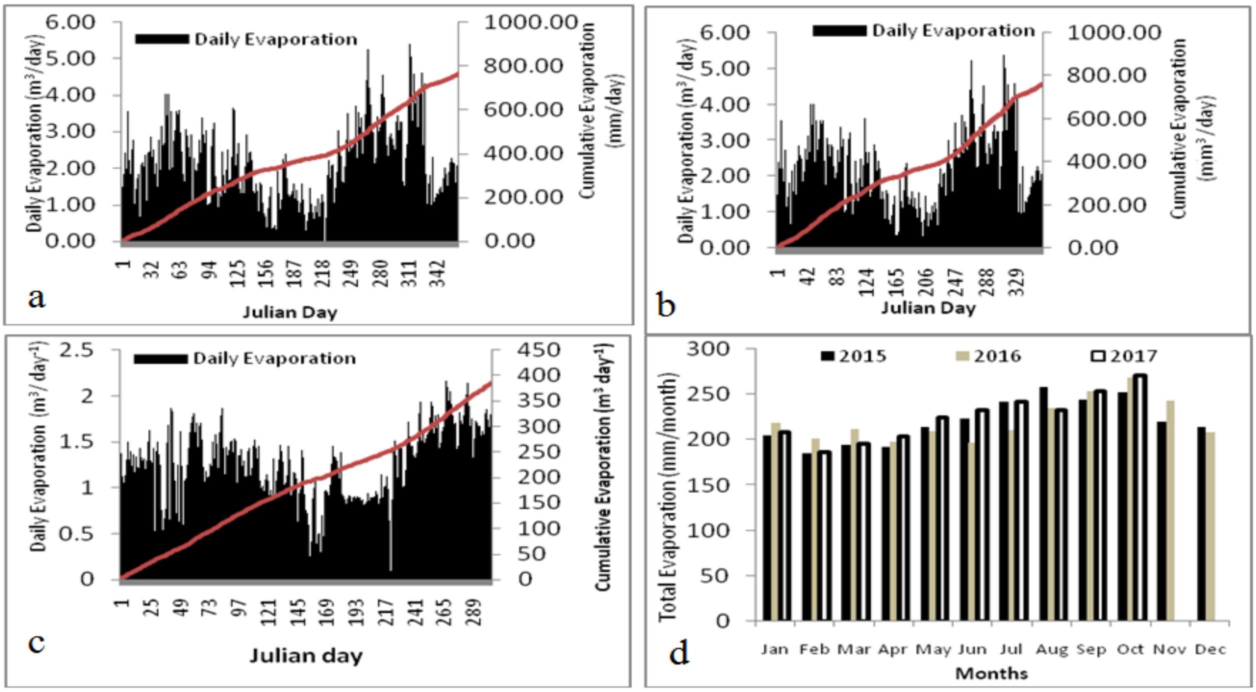


Figure-7. Actual daily evaporation and cumulative evaporation from the Makoye reservoir in the year: 2015 (a); 2016 (b); 2017 (c); and comparison of total monthly evaporation for 2015, 2016 and 2017 (d).
Source: Field measurements (2015-2017).

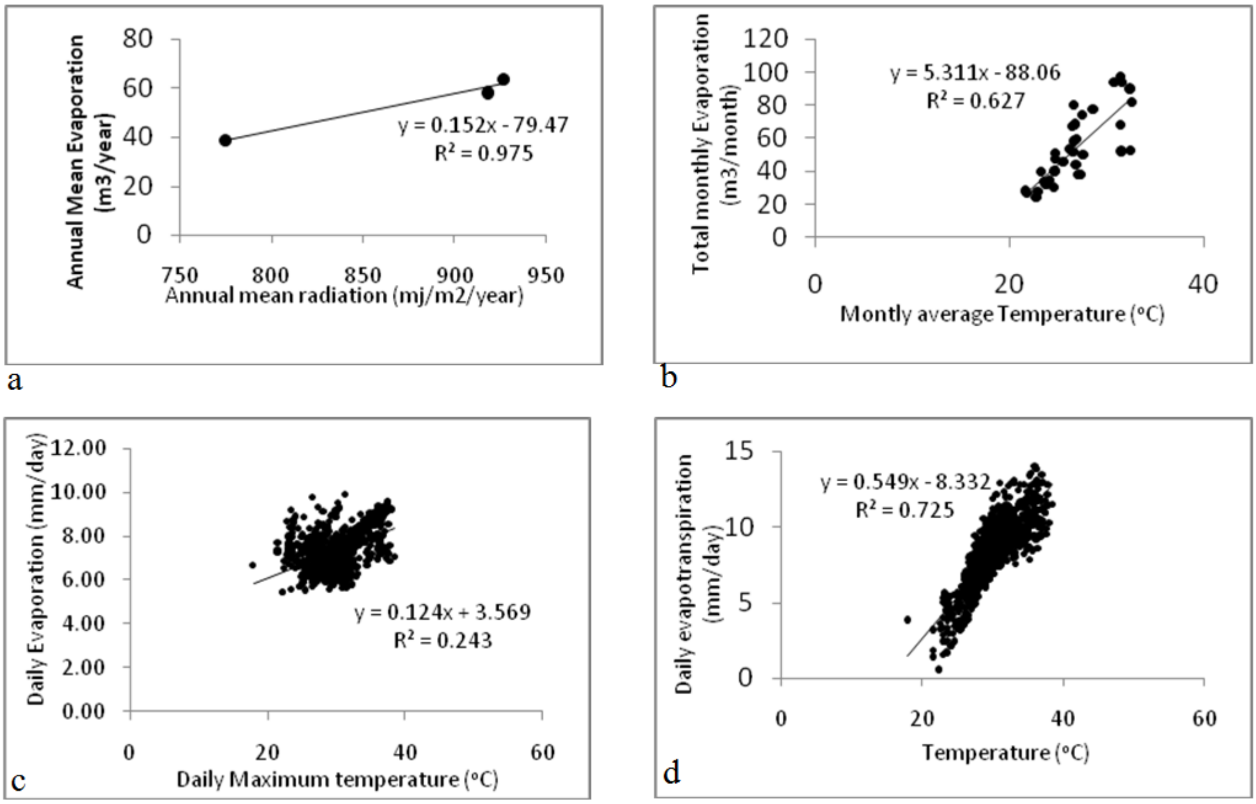


Figure-8. Relationships between: annual mean radiation and annual mean evaporation (a); monthly mean temperature and total monthly evaporation (b); daily maximum temperature and daily evaporation (c); daily maximum temperature and daily evapotranspiration (d).
Source: Field measurements (2015-2017).

The highest evaporation from the Makoye reservoir was recorded during the 2016 hydrological year, which tallied with dry spells recorded during the same year Table 3.

Table-3. Annual average and total evaporation rates from the Makoye reservoir.

Period	Annual average evaporation (m^3/year)	Annual total (m^3/year)	Total annual evaporation (mm/year)
2015	58.15	697.80	2644.39
2016	63.61	763.26	2655.25
2017	38.59	385.87	2252.28
2015-2017	160.34	1846.93	7551.92

Source: Field measurements (2015-2017).

At 0.05 level of significance, a multiple regression analysis showed that, about 30% of the trends in the reservoir bathymetry could be explained by a combination of all the climatic processes (averages of net radiation, wind speed, atmospheric pressure and temperature). This is demonstrated in Table 4.

A strong positive relationship (r^2 = 0.97) between annual mean radiation and annual mean evaporation of water from the reservoir was noted Figure 8a. Figure 8b shows a strong positive relationship (r^2 = 0.63) between monthly average temperature and monthly average evaporation from the reservoir. Table 5 shows the responses obtained from 40 household respondents concerning the availability of water within the catchment. Majority (55%) of respondents felt that water was not readily available because the reservoir dries up quickly.

Table-4. Summary outputs of the multiple regression between selected physical processes (monthly mean atmospheric pressure, monthly mean wind speed, mean daily temperature and incoming solar radiation) and monthly mean evaporation.

Regression statistics	Computed values					
Multiple R	0.55					
R square	0.30					
Adjusted R square	0.19					
Standard error	0.62					
Observations	31					
ANOVA						
Description	Df	SS	MS	F	Significance F	
Regression	4	4.27	1.07	2.76	0.05	
Residual	26	10.07	0.39			
Total	30	14.34				
Description	Coefficients	Standard error	t stat	P-value	Lower 95%	Upper 95%
Intercept	15.70	15.59	1.01	0.32	-16.35	47.75
Monthly mean Atmospheric pressure	-0.01	0.02	-0.79	0.44	-0.05	0.02
Monthly mean wind speed (m/s/month)	-0.22	0.12	-1.75	0.09	-0.48	0.04
mean daily temperature	0.04	0.03	1.33	0.19	-0.02	0.10
Daily mean net radiation	0.12	0.07	1.67	0.11	-0.03	0.27

Resulting multiple regression Equation: Reservoir Evaporation = $15.70-0.01x_1-0.22x_2+0.04x_3+0.12x_4$.

Table-5. Availability of water within the Makoye reservoir catchment.

Water availability in the catchment	Number of household respondents	Percentage (%)
Readily available	5	13
Moderately available	13	32
Not readily available	22	55
Total	40	100

Source: Field Interviews, 2017.

In terms of water stressful period, a majority (73%) of respondents felt that the most water-stressful period in the Makoye catchment ranged from September to January Table 6.

Table-6. Water Stressful Periods within the Makoye Reservoir Catchment

Responses	Number of household respondents	Percentage (%)
July to February	4	10
August to February	7	17
September to January	29	73
Total	40	100

Source: Field Interviews, 2017.

It is evident from Table 7 that, respondents were very concerned about the impact of reservoir sedimentation on their livestock. The most frequent response (18%) was that cows did not receive adequate amount of water per day during dry seasons (July-October) when the reservoir is at low capacity. This also affected dipping of animals which was being prolonged (15%) than ever before due to inadequate water in reservoir. Lack of awareness on management of the reservoir scored the least (4%) among all the concerns raised by the respondents.

Table-7. Common concerns about the state of Makoye reservoir from selected respondents.

No.	Concerns from key informants	Frequency of responses	Percentage of responses (%)
1	The reservoir's depth has drastically reduced.	8	8
2	The cows do not receive adequate amount of water per day during dry seasons.	19	18
3	Water scarcity is forcing people especially women and children to go fetch water from distant places.	14	13
4	People's bad attitude and carelessness has contributed to sedimentation of the reservoir because they plough near the reservoir.	10	10
5	Animals get stack in mud when the reservoir dries and sometimes they die.	4	4
6	Animals are suffering and some get sick and die.	6	6
7	Dipping of our animals is now being prolonged than before because there is no water in dam which is mainly used in the dipping process.	16	15
8	There is a lot of soil (sediment) that enters into the reservoir.	16	15
9	The reservoir cannot supply enough water for animals in the catchment and surrounding areas.	7	7
10	There is no awareness on how to care for the reservoir that is why it is drying quickly.	4	4
Total		104	100

Source: Field interviews (2017).

4. DISCUSSION

There were variations in the inter-temporal bathymetry of the Makoye reservoir (Figures 3a-e), which could be attributed to high sedimentation rate (3,112.97 m^3 yr^{-1}) reducing water holding capacity of the reservoir by 54% (Muchanga, 2017). For example, at its low capacity (20 August, 2015), the reservoir had about 24,830.93 m^3, which completely dried out by 28 September, 2015 Figure 5 showing a highly compromised water holding capacity of the reservoir. Given that the reservoir's average depth (1.1 m) was generally shallow as compare to its large surface area, evaporation partly contributed to these rapid changes in bathymetric state at different times and, at 95% confidence level, muiltiple regression showed that, 30 percent of the changes in water levels could be attributed to a combination of the processes of various weather factors. Long water stressful period was especially during 2015/2016 warm-wet season was punctuated by delayed onset of rainfall Figure 6a due to El Nino Southern Oscillation (ENSO), well known for triggering drought conditions and long dry spells (Robinson and Henderson-Sellers, 1999; World Meteorological Organisation [WMO], 2016). Due to reduced reservoir depth and capacity, water level changed over night from 0 m^3 to almost full capacity making it impossible to measure progression of water volume from zero through medium upto full capacity.

During the 2016/2017 rainy season, Zambia Meteorological Department (ZMD) (2016) which led to heavy rainfall and flash floods such that, the reservoir almost filled to full capacity in a single storm. At the time (3 March, 2016) of first full capacity measurement, water volume in the Makoye reservoir was estimated at 75,753.56 m^3, but within a short space of about 90 days (3 March to 17 June, 2016), it plummeted to 40,493.41 m^3 as the reservoir approached its medium capacity. This implies that just within about three months 35,260.15 m^3 (47% of the volume at full capacity) was lost from the reservoir. During the 2016/2017 rainy season, the reservoir overflowed by 15 December, 2016 just about 20 days from onset of serious rainfall on 26 November, 2016. However, over time,water level receded slightly below the spill way until late December, 2017. Rapid filling of water into the reservoir within such short temporal intervals showed that, the reservoir had lost its water holding capacity. When the reservoir delays to fill up, it would increase water stressful period and, conversely, when it fill up quickly, it leads to downstream flooding of crop fields, gardens, households and, huge water loss during heavy storms occur (Dalu *et al.*, 2013). This shows that sedimentation of reservoirs is a double pronged problem that water scientists need to frequently investigate because it affects the bathymetry of reservoir and eventually, social livelihood for water-dependent economic activities such as patoral farming.

At its low capacity in the 2015/2016 warm-dry season, Makoye reservoir's water surface area was 38,171.77 m^2, but at its full capacity, it rose to 60,499.41 m^2 which represents 37% increase. At medium capacity, the surface area was 44,950.06 m^2, which represents a 26% decrease from the water surface area at full capacity. During the 2016/2017 rainy season, water surface area at full capacity of the reservoir showed a slight decrease by about 6% compared to 2015/2016 measurement at full capacity Table 1. These statistics imply that timing in seasons may cause flunctuation in surface areas covered by water and eventually, water availability. The study noted that, the best timing to precisely determine the influence of surface area on water volume is when the reservoir is at its full capacity, however, it is quite challenging especially in reservoirs like Makoye that are highly silted because the actual boundaries of the reservoir seem to be obscured by water inundation such that, part of the water that is pupported to be part of the reservoir is in the actual sense supposed to be excess or simply an over spills, which posed a challenge to compute the surface area.

Water volume was almost perfectly dependent on depth as demonstrated by very strong postive r^2 values of 0.99 at all measuremnt times in 2015/2016 rainy season and, 0.97-0.99 for the 2016/2017 bathymetric measurements. In all instances, it was noted that the volume of water was increasing towards the deepest point and vice versa. Therefore, if the reservoir was to be depenned by dredging, it would store plenty of water that would be useful for various agricultural and domestic uses. This implicitly entails how important it is to prevent reservoir sedimentation so as to preserve the water depth for sustainable supply of water for various uses.

The computed iinter-seasonal average volume of water in the Makoye reservoir was 48,879 m^3. The sudden changes in water volumes within short periods as illustrated in the reservoir's hydrological regimes implies that over 10,000 cattle and about 474 households (MLF, 2016) that depend on the reservoir would not have a adequate supply of water from mid March to August during which reservoir utilisation is most critical. In fact, 73% of informants testified that the most water-stressful period (especially for cattle Table 4 in the catchment ranged from September to January. This water stressful period refers to the time when all the reservoirs in proximity are dry and, Makoye which is usually the last to dry has completely or almost completely dry. According to MFL (2016), on average, a grown up cow requires 40 litres of water per day, but it could be higher in dry-warm climatic zones like Monze East, which is partly located in the Agro-ecological Zone-I (ZMD, 2016).

Water requirements are also dependent on purposes which a cow serves (dairy, beef, farm works, etc) and age (MLF, 2016). In the context of the study area, such water requirements for a cow per day, translates into over 400, 000 (400 m^3) litres of water per day to satisfactorily supply the water needs of over 10,000 heads of cattle. Based on such statistics, the annual water requirements for the entire population of cows in the catchment turns out to be 146, 000, 000 litres (146000 m^3). This implies that, 75,754 m^3 to 75,974 m^3 (75,754,000 to 75,974,000 litres) of water obtained at full capacity of the reservoir was extremely insufficient to supply the water demands of all heads of cattle. There was a deficit of almost 50% compared to the quantity of water required by all the cattle. This availed a serious threat to water security especially that, during onset of water stressful period, hundreds of heads of cattle from other distant areas like Chuuka (5-7 km away) come to drink from the Makoye reservoir. This explains why the majority of respondents (55%) thought that water was not readily available in the catchment. Given the highly variable bathymetric and volumetric states of the water, water scarcity in the catchment of the Makoye reservoir could be said to be chronic as it was found to be incapable of fully meeting water demands for livestock. Such a situation is also likely to trigger other problems such as water-based conflict, travelling long distances (by both animals and people (especially women and children)) to fetch water, animal diseases and deaths, possible collapse of the local socio-economic livelihood and, forced migration, as once was the case in Bangladesh and India (Swain, 1996).

4.1. Synthesis of the Study Findings

Although sedimentation could be the main causal factor influencing unsteady bathymetry of reservoirs, understanding other physical processes such as temperature, radiation, in terms of how they independently and mutually influence bathymetry is critical. In fact, other factors such as ground water level delays and type of soils though not considered in this study, can lead to a more profound and perspicuous understanding of the science of bathymetry and how it may influence socio-economic livelihood so as devise better management strategies.

Based on aforementioned findings, the study suggests that bathymetric studies need not only to be more related to fundamental science of hydrology (as was the case in most reviewed studies (Richard *et al.*, 2000; Smith and Sandwell, 2004; McPherson *et al.*, 2009; El-Hassan, 2015; Ajith, 2016; Chomba and Sichingabula, 2016) but must also be linked to social hydrology, which ventures into understanding pressing societal problems such as water security. Effective management and planning for water in the reservoir needs not only to be more related to fundamental and technical scientific issues which are just understood by water scientists, but also to the solving of pressing societal problems related to unstable bathymetries and, eventually, poor water supply such as those in the Makoye reservoir catchment. Srinivasan *et al.* (2016) argue that, to make progress in hydrological science, we need to revisit the notion of a value-neutral scientist making time-series projections of water availability for a particular study basin. "Instead, we need to explore what managers need to know to help them make strategic decisions that have long-ranging implications".

In order to help water managers especially in Zambian context, participatory bathymetric studies would play an integral part, otherwise, the water-based societal problems such as those articulated by some respondents in Table 7 would persist in affecting socio-economic livelihoods whilst we presumptuously claim that we are doing everything possible scientifically, but in the actual sense, these sciences cannot be understood by many policy makers in their decision making. Therefore, to improve understanding of bathymetric science and solution it offers to societal problems, shrewd integration of social knowledge and physical science of hydrology would be imperative because it would pave way for a sustainable *planning with*, instead of *planning for* the affected society whose upstream activities are main propellants of sediment, the main cause of unsteady equilibrium in reservoir's bathymetries. Social hydrology is currently one of the main concepts being debated in the community of water science and, some studies (Heidi *et al.*, 2016; Srinivasan *et al.*, 2016; Theresa *et al.*, 2016) are evolving, but in Zambian context, it is quite very scanty if not, non-existent.

Worth mentioning is the thought that, seasonal changes in bathymetric and hydrological regimes as noted from the Makoye reservoir implicitly entail that different proactive management and planning strategies for reservoir water should be applied especially during water stressful periods. It may not be appropriate to use monotonous strategies for different seasons because of variations in levels of water stresses, availability and accessibility.

5. CONCLUSION

Premised on the seasonal comparison of reservoir's bathymetries and water volumes at different times, the study concluded that Makoye reservoir's bathymetry and water holding capacity are unsteady and inadequate to meet the water demands for livestock. The reservoir's unstable hydrological regimes indicated a current and future threat to water security for livestock. The study further showed that bathymetric studies should not only focus on fundamental understanding of physical processes, but also on providing decision guidelines for livestock water planning and management. Redredging of the reservoir or possibly constructing another one down stream would offer a solution to this problem, but as earlier hinted out in the context of social hydrology, community-engaged bathymetric surveying would be imperative to raise a critical conscious among local people to avoid acitivities that propel the generation of sediment and its transportation to the reservoir.

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