DETERMINATION OF SEDIMENT, WATER QUANTITY AND QUALITY FOR SWAT MODELLING OF SEDIMENTATION IN THE MAKOYE RESERVOIR, SOUTHERN PROVINCE, ZAMBIA

By

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DECLARATION

I, Manoah Muchanga (513805037), declare that this thesis represents my own work. It has not previously been submitted for a postgraduate degree or any award at the University of Zambia or any other institution. All cited works and materials from other sources have duly been acknowledged and references thereby given.

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APPROVAL

This thesis prepared by Manoah Muchanga (513805037) is approved as fulfilling the requirements for the award of Doctor of Philosophy (PhD) Degree in Geography of the University of Zambia.

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ABSTRACT

Reservoir sedimentation is one of the temporally and spatially distributed challenges facing managers of small reservoirs today. Fluvial system formed the geomorphological plinth of the study. The study was motivated by the problem of sedimentation in the Makoye Reservoir (about 60500 m^2), which had been affecting 474 pastoralist households rearing over 10,000 cattle. The objectives of the study were to: (i) determine the bathymetry of the Makoye Reservoir at different temporal scales; (ii) measure the long-term quantity of sediment deposited in Makoye Reservoir; (iii) determine the short-term real time sediment settling rate in the Makoye Reservoir; (iv) examine concentration levels of selected physical and chemical parameters of water for livestock in Makoye Reservoir; (v) evaluate the efficiency of Soil Water Assessment Tool in simulating sedimentation in the Makoye Reservoir; and (vi) to develop a conceptual model for understanding sedimentation process in small reservoirs in Zambia.

The study used Critical Analytical Experimental Research Design implicitly inspired by Critical Empirical Analytic Paradigm. Five bathymetric surveys were conducted using a Remote Controlled Hydrographic Survey Boat with the aid of an inflatable boat. Sediment pits (195) were dug across the dry reservoir bed with aid of picks, ranging poles, measuring tape, Differential Global Position System and iron pegs. Real time sediment depth was measured using SediMeter SM3A, whose 36 Optical Backscatter Detectors captured sediment depth with resolution of 0.001 mm. The data inputs for Sediment simulation included the 90m Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) , weather data, soils and landuse maps. Three soil samples (50cm) were collected using augers, and suspended and settled sediment samples were collected using grass carpets and coring. Bathymetric data was analysed using 3D Spatial Analysts Tools (3DSATs) in ArcGIS 10.3 and spreadsheet Microsoft Excel. This enabled determination of volumes, surfaces areas and development of hypsometric curves showing relationship among water depths, volume and surface areas. Real time sediment data was analysed using descriptive statistics and time series. Simulated sediment data was analysed using SUFI-2 in SWATCUP 2012. Soils, sediment and water physico-chemical analysis were done in the Soils Sciences and Environmental Engineering laboratories at the University of Zambia, respectively.

Seasonal comparison of reservoir's bathymetries and water volumes showed drastic changes in average depths and volumes of water (24,830.93 m^3 to 75,974.21 m^3). This supply was below the water demand for cattle due to diverse physical processes (weather conditions, drainage hydro-geomorphology and mainly, sedimentation). On average, the real time daily sediment settling rate was 0.0003 m/day. Between 1988 and 2017, the average rate of long term sedimentation was 5,834.12 tonnes/year. SWAT efficiently simulated sediment with both r^2 and NSE at 0.77 and 95PPU at 57 percent. Sediment was sourced from Agricultural land (35%) grazing land (26%), deciduous forest (22%) and range-brush land (17%). Water quality was influenced by sediment upstream and 80 percent of its chemicals parameters were within Maximum Permissible Limits for cattle. The study designed a conceptual model on understanding and simulating sedimentation by integrating sediment depths from Sedimeter SM3A and regression model, which can be adapted to different spatial and temporal contexts. Conclusively, the reservoir was highly silted with about 54 percent of its capacity reduced. Community and government agencies awareness on how to reduce sedimentation in the catchment is highly recommended.

Key Words: Bathymetry, Geomorphology, Sedimentation, Sedimeter SM3A, SWAT Modelling

DEDICATION

To my late brother Andrew Muchanga for supporting me during my early academic journey

My parents Mr. Andrew Chola Muchanga and Mary L. Muchanga for teaching me hard work and discipline during my early childhood

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OPERATIONAL DEFINITIONS

Animals In this study they refer to cattle that drink water from the reservoir.

Bathymetry It means the depth of water and surface area, wetted perimeter, water surface area, crest and spill way elevations, water volume and reservoir capacity.

Catchment Same as subbasin or basin, which is a space that collects water that feeds into a reservoir

Dam Refers to a barrier that impounds flowing water so as to create a reservoir of water for irrigation, animal watering and domestic use.

Ecosystem Biophysical surroundings of the small reservoir.

Fluvial system Refers to the systemic processes associated with rivers, streams and other water bodies like small reservoirs including weathering, transportation and deposition of sediment as well as landforms created by them.

Reconnaissance It is a rapid pre-examination or preliminary survey of project area and pre-testing of the methodology to gain insight before the actual survey.

Sediment Clastic earth material that is deposited to the reservoir bed or fragmental material that originates from the chemical or physical disintegration of rocks.

Sediment burden The total quantity (tonnes) of sediment that has inundated a small reservoir.

Sediment fluxes Movement of sediment.

Sediment simulation Modelling of sedimentation using climatic, landuse and soils and optimisation parameters to liken it as closer as possible to the measured sedimentation.

Small reservoir A body of water created either anthropogenically or naturally to impound water whose depth ranges between 1 and 14 metres, with Crest $\leq$ 5m and is predominantly in static equilibrium in terms of water velocity during most parts of the years except during the peak rainy season.

ACRONYMS AND ABBREVIATIONS

3DSATs	3 Dimensions Spatial Analyst Tools
95PPU	95percent Prediction Uncertainty
AED	Analytical Experimental Design
AGRR	Agricultural Land-Row Crops
ANOVA	Analysis of Variance
ANSWERS	Areal Nonpoint Source Watershed Response Simulation
ArcGIS	Aeronautical Reconnaissance Coverage Geographical Information System
AVT	Area and Volume Tool
BLMS	Bedload Monitoring System
BMPs	Best Management Practices
CBD	Central Business District
CDOW	Colorado Division of Wildlife
CDS	Cool Dry Season
cmol	Centimole
CRS	Chain Referral Sampling
CSO	Central Statistical Office
CV	Coefficient of Variation
DEM	Digital Elevation Model
DGFM	Discrete Grey Forecasting Model
DGPS	Differential Global Positioning System
DMMU	Disaster Management and Mitigation Unit
DRC	Democratic Republic of Congo
DWA	Department of Water Affairs
ECM	Elevation Change Method
ECZ	Environmental Council of Zambia
EDSS	Exponential Discriminative Snowball Sampling

ACRONYMS AND ABBREVIATIONS

EDSS	Exponential Discriminative Snowball Sampling
ENDSS	Exponential Non-Discriminative Snowball Sampling
ENDSS	Exponential Non-Discriminative Snowball Sampling
ENSO	El Nino Southern Oscillation
ERSSR	Expert-Based Reservoir Siltation Severity Rank
ESHIA	Environmental, Social, and Health Impact Assessment
EUROSEM	The European Soil Erosion Model
FAO	Food Agriculture Organisation
FRL	Full Reservoir Level
FRSD	Forest Deciduous
FRST	Forest Mixed
GDZ	Geological Department of Zambia
GEC	Gravity Environmental Consulting
GLUE	Generalised Likelihood Uncertainty Estimation
GPS	Global Positioning System
ICOLD	International Commission on Large Reservoirs
IAHS	International Association of Hydrological Sciences
IDW	Inverse Distant Weighted
JAMS	Jena Adaptable Modelling System
IWRM	Integrated Water Resources Management
LHS	Latin Hypercube Sampling.
LSS	Linear Snowball Sampling
LWASCO	Lusaka Water and Sewerage Company
MAL	Ministry of Agriculture and Livestock
MASL	Mean Altitude above Sea Level
MCMC	Markov Chain Monte Carlos
MDZ	Meteorological Department of Zambia

ACRONYMS AND ABBREVIATIONS

Mean_obs	Average of observed variable
Mean_sim	Average of simulated variable
MNS	Modified Nash Sutcliffe
MPCA	Minnesota Pollution Control Agency
MPLs	Maximum Permissible Limits
MTENR	Ministry of Tourism, Environment and Natural Resources
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NDVI	Normalized Difference Vegetation Index
NID	National Inventory of Reservoirs
NRSC	National Remote Sensing Centre
NSE	Nash Efficiency
NTU	Nepherometric Turbidity Unit
NWASCO	National Water and Sewerage Company
OBD	Optical Backscatter Detectors
OF	Objective Functions
ParaSol	Parameter Solution
PBIAS	Percent Bias
PMCC	Pearson Product Moment Correlation Coefficient
PSO	Particle Swarm Optimisation
PVC	Polyvinyl Chloride
RCHSB	Remote Controlled Hydrographic Survey Boat
rf	Rainfall
RNGB	Range-Brush
RNGE	Range-Grasses
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Use

ACRONYMS AND ABBREVIATIONS

SDBD	Sediment/Soil Dry Bulk Density
SDG	Sustainable Development Goals
SDZ	Survey Department of Zambia
SediMeter	Sediment Meter
SFTMP	Surface Temperature
SRST	Simple Random Sampling Technique
SS	Simulated sedimentation
StdDev_obs	Standard deviation of measured variable
STRM-DEM	Shuttle Radar Topography Mission Digital Elevation Model
SUFI-2	Sequential Uncertainty Fitting version 2
SWASCO	Southern Water and Sewerage Company
SWAT	Soil and Water Loss Assessment Tool
SWATCUP	Soil Water Assessment Tool Calibration and Uncertainty Prediction.
TDS	Total Dissolved Solids
TE	Trap Efficiency
TIN	Triangulated Irregular Network
TSL	Total Sediment Load
TSS	Total Suspended Sediment
UNDP	United Nations Development Programme
UNESCO	United Nations Education, Scientific and Cultural Organisation.
USA	United States of America
USACE	United States Army Corps of Engineers
USDA-ARS	United States Development Agriculture-Agriculture Research Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator

ACRONYMS AND ABBREVIATIONS

UNZA	University of Zambia
VBS	Virtual Base Station
VM	Verhulst Model
WARMA	Water Resource Management Authority
WATEM/SEDEM	Water and Tillage Erosion Model/ Sediment Delivery Model
WD	Water Depth
WDS	Warm Dry Season
WEPP	Water Erosion Prediction Project
WMO	World Meteorological Organisation
WWS	Warm-Wet Season
ZMD	Zambia Meteorological Department
ZARI	Zambia Agriculture Research Institute

CHAPTER ONE: INTRODUCTION

1.1 Background

Reservoir sedimentation is one of the temporally and spatially distributed challenges facing managers of small reservoirs (with ≤5m height of embankment) today (Nissen-Petersen, 2006). Its persistence in literature (Rubey, 1933; Krumbrein, 1942; Langbein and Schumm, 1958; Thornbury, 1965; Meade, 1982; Walling, 1988; Sichingabula, 1997; Collins and Walling, 2004; Lu *et al.*, 2013; Sichingabula *et al.*, 2014; Chomba and Sichingabula, 2015; Mavima *et al.*, 2015; Briak *et al.,* 2016; Khaba and Griffiths, 2017) intrinsically begs for further studies particularly in Zambia where sediment studies are quite scanty.

Runoff and river channel erosion provide a continuous supply of sediment that is finally deposited into reservoirs (Randle *et al.*, 2008). Reservoirs tend to be very efficient sediment sinks due to that, water in reservoirs is almost always in static equilibrium where none of the observable movements of water change significantly (Chorley and Kennedy, 1971). Rapid sedimentation often lead to untimely loss of reservoirs' useful life, storage capacity as well as reduced water quantity and quality (Lu *et al.*, 2013).

Collins and Walling (2004) noted that information on sedimentation is an important data requirement for a number of reasons. Firstly, it would be essential for reconstructing historical catchment erosion patterns and assist in the interpretation of sediment burden in small reservoirs so as to ensure sustainable supply of water for livestock and people at large. Secondly, substantive sediment data base supports reliable forecasts of the potential problem of sedimentation and development of a model for understanding sedimentation process (Collins and Walling, 2004). Moreover, the capacity to manage current and predicted sedimentation problems depends, in part, upon an improved understanding of sediment burden on water resources (Collins and Walling, 2004).

About two-third of the 17 Sustainable Development Goals (SDGs) (such as 1, 2, 3, 13, 14 and 15) are water dependent (United Nations Development Programme (UNDP), 2018), hence, understanding processes such as sedimentation that affect water quantity and quality is critical to the successful and domesticated implementation of SDGs in various parts of the world and Zambia in particular by 2030. This would also ensure sustainable supply of water for livestock and thereby strengthening rural economies that are dependent of pastoral and crop farming. It should be noted in advance that, in this study, the term livestock or animals is contextually referring to cattle.

Although sedimentation in reservoir may be a natural process, in places such as Zambia, it is enhanced by anthropogenic activities such as deforestation, mismanagement of riparian area, poor farming activities especially near the reservoirs (Gharehkhani, 2011). According to Sichingabula (1997), sedimentation is recognized as a problem in Zambia accelerated by long history of sedentary agriculture and the large herds of cattle kept by local people especially in southern Zambia. Neglect of land especially near the reservoirs usually punctuates reservoirs' sedimentation or siltation due to high levels of erosion (Sichingabula, 1997).

Sichingabula (1997) observes that in some parts of Southern Province, pre-1970 reservoirs have lost up to three quarters of their storage capacity due to siltation leading erratic water supply for livestock. To this effect, Sichingabula (1997) generally recommended detailed quantitative studies on the problem of sedimentation in small reservoirs. This mainly motivated undertaking of the current study in order to contribute to enhanced understanding of the nature of the problem and best management strategies for sustainable water security for livestock, especially cattle.

Thorndycraft (2008) suggests that, research in Fluvial Geomorphology in general and Fluvial System in particular needs not only to be more related to technical scientific issues which are just understood by a few technical scientists, but also to the solving of pressing societal problems such as those that emanate from sedimentation in small reservoirs. The term fluvial refers to streams and rivers-associated process, as well as depositional features created by them (Leopold *et al.,* 1995). Fluvial system is made up of fluvial landforms and fluvial process that shape them and the dominant feature being the hill slopes, drainage network, rivers and streams, catchment ecosystem, sediment erosion, transport and deposition, fluvial forms and processes, landscape change, reservoirs, ponds and wetlands, among others (Leopold *et al*., 1995). In fluvial systems, all the aforementioned components are hydrologically systemic in one way or the other (Leopold *et al*., 1995). The main thrust of this study was to enhance understanding of sedimentation process in reservoirs so as to develop a conceptual model that could be useful in other catchment contexts whose anthropo-physical characteristics are similar to those of the studied area.

The thesis of this study is that although sedimentation in small reservoirs is detrimental, it also offers opportunities such as community cooperation to address a common problem facing them, development of strategies for sustainable management of the reservoir, supply of sediment nutrients for crop fertilisation, among others, which communities could use in various ways and about which people need to be sensitised. This was based on the understanding that, mapping the bathymetry of the reservoir, determining its sedimentation rates, composition of its water and sediment, could give an idea of activities taking place on the upstream of the catchment and its geomorphological features could be understood. This understanding would generate the baseline necessary for assessment of required interventions to avoid adverse impact of sediment on the reservoir whilst maximising its beneficial utilisation by communities that depend on it for survival.

1.2 Problem statement

Sichingabula (1997) states that sedimentation in reservoirs is generally a major problem in Southern Zambia and particularly, Makoye Reservoir, which was built in 1940 and renovated in 1988. The study problem was reservoir sedimentation whose state in terms of sediment fluxes, accumulation rates, distribution, physical-chemical properties and their effects on reservoir capacity, lifespan, water quality as well as quantity are widely unknown in the Zambian context. Sedimentation is a dawdling process that builds up slowly in a reservoir unnoticed for many years, and in most cases, its end results are detected late. For example, some concerns were being raised by the users of water from the Makoye Reservoir that the reservoir was no longer able to sustain over 474 households and 10,935 livestock because of silting. Makoye

Reservoir was drying up quickly and thereby supplying less quantity and quality of water by 2016 than when it was first constructed in 1940 (Ministry of Livestock and Fisheries (MLF), 2016). Some households may possibly lose their reservoir water-dependent livestock due to reduction in water quantity and quality due to sedimentation (MLF, 2016). This situation provided the basis for the investigation in order to provide knowledge base to forecast potential problem of sedimentation and to develop a conceptual model for understanding sedimentation processes in the future.

Moreover, the capacity to effectively manage current and predicted sedimentation problems in the Makoye Reservoir depends, in part, upon an improved understanding of sediment burden on water resources without which, sediment would punctuate many challenges and also obscure possible opportunities that could be associated with the problem itself. Therefore, this study sought to determine the degree of sedimentation in terms of sediment fluxes, accumulation rates and their related influence on water quantity and quality as well as possible implications on livestock.

1. 3 Aim

The aim of this study was to enhance understanding of sedimentation process, its related effects on water quantity and quality for livestock, so as to devise a conceptual model for simulation of sedimentation in ungauged reservoir catchments.

1. 4 Specific objectives

The objectives of the study were:

(i) to determine the bathymetry of the Makoye Reservoir at different seasonal scales;

(ii) to determine the long-term quantity of sediment deposited in Makoye Reservoir between 1988 and 2014;

(iii) to determine the short-term real time sediment settling rate in the Makoye Reservoir;

(iv) to examine concentration levels of selected physical and chemical parameters of water for livestock in Makoye Reservoir;

(v) to evaluate the efficiency of Soil Water Assessment Tool in simulating sedimentation in the Makoye Reservoir; and

(vi) to develop a conceptual model for understanding sedimentation process in small reservoirs in Zambia.

1.5 Research questions

In line with the above specific research objectives, the specific research questions were as follows:

(i) how was the bathymetric state of the Makoye Reservoir?

(ii) what quantity of sediment was already deposited in the Makoye Reservoir between 1988 and 2014?

(iii) how was the real time sediment accumulation rate in the Makoye Reservoir?

(iv) what were the concentration levels of selected physical and chemical parameters of water for livestock in the Makoye Reservoir?

(v) how was the efficiency of Soil Water Assessment Tool in simulating sedimentation in the Makoye Reservoir?

(vi) how amenable were the results to the construction of a conceptual 3D model for understanding the process of sedimentation in small ungauged reservoirs in Zambia?

1.6 Research hypotheses

(i) Other than sedimentation, combined processes of mean monthly atmospheric pressure, wind speed, temperature and radiation partly influenced the rapid loss of water from the Makoye reservoir at 95% level of confidence.

(ii) On average, selected physico-chemical parameters of water for livestock in the Makoye Reservoir were highly concentrated during warm-wet season than during the cool-dry season at 0.01 level of significance.

(iii) There was a very strong positive correlation between the long term observed and simulated sedimentation in the Makoye Reservoir at 0.01 level of significance.

1.7 Study Assumptions

i. Real time settling of suspended sediment was taking place only in the main reservoir, not its throwback.

ii. The Makoye Reservoir was assumed to have a trapezoidal shape and that sediment of same size and weight settled at the same time.

iii. Other than sedimentation, atmospheric processes also had influence on the loss of water from the Makoye Reservoir.

iv. The study assumed that, if the simulated discharge and sediment were correct on the main outlet gauging station, they were also correct in the upstream subbasins that had no gauging stations.

1.8 Conceptual Framework

Based on Miles and Huberman (1994) definition, a conceptual framework is a visual or written product that explains, either graphically or in narrative form, the main factors, concepts, ideas, assumptions, variables and the presumed relationships among them, through which a particular research would be understood. Maxwell (2005) further elaborates that, a conceptual framework provides an intrinsic theoretical meaning of the study making it possible to quickly decipher what is going on in such a study. A conceptual framework was developed for this study (Figure 1). It depicts the idea that sedimentation process in the context of sediment fluxes into the reservoir is inextricably linked to sediment distributed and accumulated on the reservoir bed (Ferrari and Collins, 2006). Sediment can be transported as pebbles, sand and mud, or as solution in water. Deposition in reservoirs takes place in different depositional zones namely, topset bed (where coarse suspended bedload are deposits), foreset bed (where sediments with grain size smaller than the latter are deposited) and bottom set bed (where fine sediments are deposited) (Ferrari and Collins, 2006).

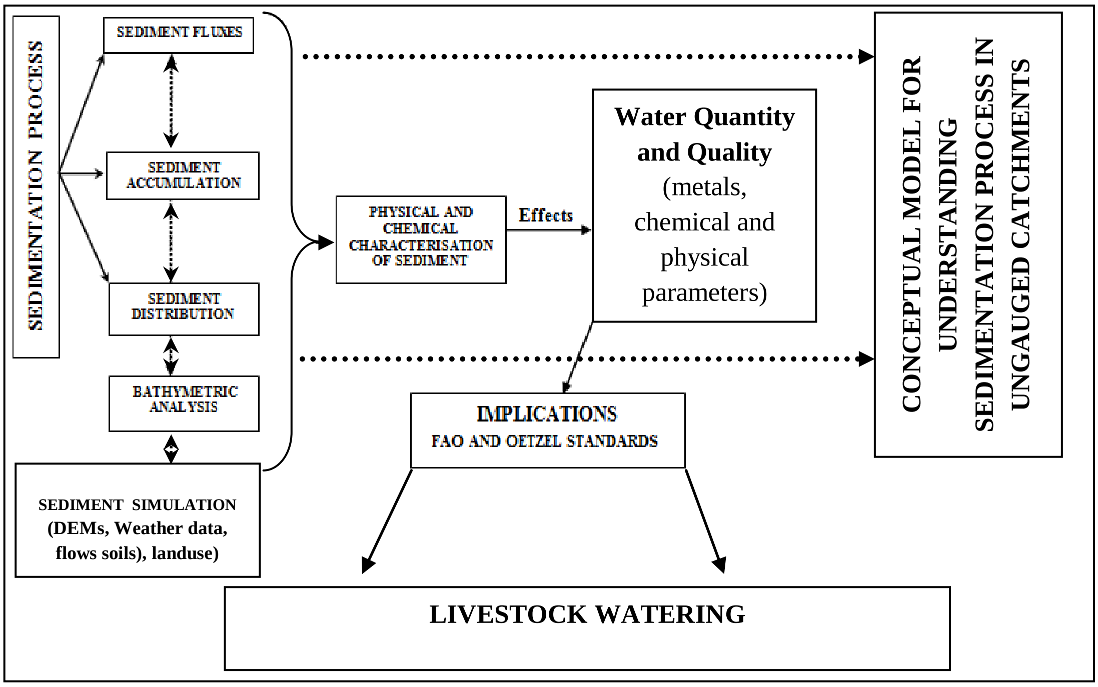


Figure 1: Conceptual framework of the study on the determination of sediment, water quantity and quality for SWAT Modelling of Sedimentation in Small reservoirs

Sediment larger than clay and silt are deposited first, but there remains a sedimentation process of aqueous clastic sediment which are too minute to be deposited in a shortest possible time. These eventually affect reservoir bathymetry, its life span, storage capacity and quantity and quality of water. Detailed analysis of reservoir water in terms of its physical and chemical parameters compared to the physico-chemical characteristics of incoming sediment help track out sources of sediment and its implications on livestock.

According to FAO (2013), the water quality standards for animal consumption should be as follows: Total Dissolved Solids (TDS) (1000 mg/l), Total Suspended Solids (TSS) (1000 mg/l) and Turbidity (1000 Nephelometric Turbidity Units (NTU)), Sulphates (1000 mg/l), Nitrates (100 mg/l), Chloride (1000 mg/l), Phosphorus (1 mg/l), Ammonia (0.5 mg/l)), and Total phosphates (0.1 mg/l). The pH (9) and Alkalinity (500), Iron (0.3 mg/l), Magnesium (80 mg/l), Calcium (200 mg/l), Sodium (100mg/l), Fluoride (2 mg/l), Copper (0.5 mg/l), Lead (0.1mg/l) and Cadmium (0.05 mg/l). These were used to determine whether the measured parameters in water were within Maximum Permissible Limits (MPLs) for animal consumption.

1.9 Significance of the study

This study is significant to the broad field of geomorphology as it contributes to the use of new technique (Real-time measurement using Sedimeter SM3A) on how to measure sediment in altimetric terms and from which gravimetric and volumetric sediment data can be determined using regression models so as to calibrate sediment simulation in Arc SWAT. The conceptual model developed in this study is useful in understanding sedimentation simulation and calibration process in small ungauged catchments in Zambia so as to improve sediment monitoring and ensure sustainable water resource management. In southern Zambia, small reservoirs are the main sources of watering for livestock (Sichingabula, 1997). It is no mere exaggeration to say that southern Zambia and Monze in particular, experience diverse water challenges which require continuous investigation as recommended by Sichingabula (1997). This study responded to such a recommendation and provides insights that may help local communities with improved reservoir and catchment management knowledge so as to help them minimize generation, transportation and deposition of sediment where they are least or not desirable. Thorndycraft (2008) suggests that fluvial geomorphology needs not only to be more related to technical scientific issues which are just understood by a few academicians, but also to the solving of pressing societal problems such as those (water scarcity and animal diseases that come with shortage of water) that emanate from sedimentation in small reservoirs. The study also provides broad baseline data that may guide decision making around water resource management in small reservoir catchments.

1.10 Organisation of the thesis

There are nine chapters in this thesis. Chapter One presents the background, geomorphological basis of the study, problem statement as well as the general and specific objectives. It also presents research questions, conceptual framework and significance of the study. Chapter Two reviews existing literature related to the current study and thereafter, a summary of reviewed literature is provided. Chapter Three geographically describes the study area.

Chapter Four shows the methodological approaches, methods and techniques. It starts with a brief explanation of the philosophical orientation that influenced research thoughts and methodological decisions. Afterwards, it shows the research design, target population and how it was generated, sample size and sampling techniques. Methods of primary and secondary data collection are presented just before ethical considerations, data analysis as well as methods of data validation and study limitations, respectively. Chapter Five presents and discusses results on bathymetry. Chapters Six presents and discusses results on long-term and real time sediment quantities. Chapter Seven presents and discusses results on the composition of sediment and soils as well as water in the reservoir. The last part of the seventh chapter discusses the links between the composition of soils, sediment and the composition of water. Chapter Eight presents and discusses all results on modelling of sedimentation as well as the devised block model for understanding sedimentation process and simulation in small reservoir basins in Zambia. Last, but not the least, Chapter Nine presents the study finding summary, reflections on some contributions of the study to the general field of hydro-geomorphology of a drainage basin a well as conclusions and recommendations. References and Appendices are respectively presented just after the latter Chapter.

1.11 Chapter summary

Chapter One synoptically shows that reservoir sedimentation is a ubiquitous challenges across the world and Zambia in particular. Upstream sheet and river channel erosion constantly supply sediment that is eventually deposited into reservoirs. Since reservoirs are almost in static equilibrium during most parts of the year, they tend to be efficient sediment sinks, which lead to rapid loss of water and decline in storage capacity. The chapter has further shown that, although sedimentation in reservoir may be a natural process, in Zambia, it is punctuated by upstream human activities such as market gardening, deforestation and mismanagement of riparian area. In some parts of Southern Province where this study was conducted, pre-1970 reservoirs lost up to half to three quarters of their storage capacity due to siltation leading to erratic water supply for livestock. This formed the main plinth of the study problem and around which the study objectives and questions were in the context of the Makoye Reservoir, which was built in 1940 and renovated in 1988.

CHAPTER TWO: REVIEW OF LITERATURE

This chapter presents a review of literature on what others scholars have done in line with current study at different spatial and temporal scales. This chapter closes with a summary of emerging ideas and limitations from reviewed literature.

2.1 Reservoir bathymetry

One of the first bathymetric mapping was made by James Clark Ross in 1840 (Dierssen and Theberge, 2014). Jeffers (1960) defined bathymetry as hydrographic surveying, which seeks to determine the configuration and composition of the bottom of water bodies; the depth of the water and channel position. Tharp (1999) further defined bathymetry as a determination of water bottom depth and bed morphology through eco-sounding. Chakraborty and Fernandes (2012) defined it as measurement and charting of the water bottom. According to Ajith (2016), the term bathymetry refers to study of water depths, volume and shapes of water bodies. The bathymetric approach is based on a simple comparison of reservoirs morphology at different temporal scales, which according to United States Army Corp of Engineers (USACE) (2000) and Ajith (2016) should be at least ten years order to detect significant changes in sediment accumulation or bed change. Bathymetric survey is mainly used to estimate the capacity of reservoir and consequently, the amount of sedimentation over time (Curtarelli *et al.*, 2015). Curtarelli *et al.* (2015) add that the bathymetric and morphometric characteristics of reservoirs affect many processes, which occur on the water surface and in the water column. In this way, detailed bathymetric mapping is important for determining hydrodynamics and water quality modelling in aquatic environments (Curtarelli *et al.*, 2015). Moreover, bathymetric map is an important data source, which allows for the extraction of valuable information used for the operational monitoring of reservoirs (Ajith, 2016).

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 Reservoir at Full Reservoir Level (FRL) in Kerala area of India. Using such bathymetric tools and surfer software for analysis, Ajith (2016) concluded that Peechi Reservoir had lost its reservoir capacity by 14.03 percent of the original capacity. Bathymetric survey of the same reservoir in 2004 showed that its capacity was 96.414 million m^3, but by 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 (Ajith, 2016). The study by Ajith (2016) focused on detection of sedimentation and water changes over a period of 10 years, but this favoured a time scale determination of sedimentation than hydrodynamics of the reservoir at different seasonal scales. Sedimentation is indeed a major factor in reservoir's volumetric change, but it is not the only one that affects the volume, there are other physical factors such as temperature, evaporation, humidity, among others that may seasonally affect the bathymetry (Tanny *et al.* 2011; Abtew and Melesse (2013); Friedrich *et al.*, 2018). These should have been factored in by doing bathymetry at different seasons in relation to how weather dynamics could have affected changes in the bathymetric hydrograph.

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 scholarly work 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 (Curtarelli *et al.*, 2015). This was perhaps the most accurate and available method for their study, but it may not be reliable because sometimes, 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 will overcome this methodological limitation by using Remote Controlled Hydrographic Survey Boat (RCHSB) measures and instantly record depth per second and in real time, thus, overcoming some errors that may come with wide intervals of measurement.

In the Southern African context, Mavima *et al.* (2015) assessed land use impact on reservoir sedimentation during the 2009-2010 rainfall season. Using hydrographic surveys and grab sampling methods at Chesa Causeway Reservoir in the Upper Ruya Sub-catchment of Zimbabwe, Mavima *et al.* (2015) showed that Chesa Causeway Reservoir had a very low storage ratio, which implies that, at design stage, a substantial amount of available runoff had not been utilized. Nevertheless, the conventional methods of determining bathymetry such as manual hydrographic surveying and grab sampling methods do not provide very accurate data because they are inherently marred with several inaccuracies. A study of Malilangwe Reservoir in Zimbabwe by Dalu *et al.* (2013) showed seasonal variations in the bathymetric state of the reservoir and that, this variation had an influence on nutrients concentration. The reservoir exhibited marked seasonal fluctuations in water level, which decreased 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 percent of depth accuracy. The depth sounding positions were fixed using a NOVATel RTK GPS with DGPS capability, which yields real-time horizontal and vertical accuracy of ≤ 0.1 m. This accuracy was achieved due to real-time correction information being transmitted via satellite and from various terrestrial base stations, arguably better than the methods used by Curtarelli *et al.* (2015). The water volume was determined at about 11 million m^3 with water depth ranging between 0 and 14 metres. As earlier noted from other tools of determining bathymetry, the accuracy of about 10 cm or less was indeed very good, but that of RC-2HSB is in mm and sometimes less than that. Although it may be argued that the difference would be insignificant, RCHSB would give fairly more accurate results as compared to CEESTAR dual-frequency digital survey echo-sounder.

Like Mavima *et al.* (2015), Kamtukule and Kaseke (2012) also used a hydrographic survey to assess bathymetry on Chamakala-II Reservoir in Malawi. Originally, the capacity of Chamakala-II Reservoir was 34,760 m^3 with an average depth of four metres, but results from the hydrographic survey demonstrated that the reservoir capacity in 2008 was 21,294±1,000 m^3 with an average water depth of 1.3±0.5 m and a surface area of 15,942±1,000 m^2. This translated into a capacity of 61 per cent of the designed storage volume and a respective average water depth of 32.5 per cent of the original depth. A loss of 39 per cent (13,466 m^3) of the designed capacity due to sedimentation over a 6-year period after reservoir de-silting and rehabilitation in 2002 was quite significant. The limitation in Kamtukule and Kaseke's (2012) study was similar to that of Mavima *et al.* (2011), thus, they were too conventional method-based.

Brunner (2011) also conducted bathymetric survey of the Dano Reservoir in Southwest of Burkinafaso. The Echolot Sonar equipment used was found very helpful, especially for the sampling of larger reservoirs and the integrated GPS-unit. A limitation of the described sonar device was that, depth-measurements could only be taken at 10cm depth intervals and shallow depths ≤0.5m could not be considered. Therefore, the water depth was cross checked with a simple stadia rod, which according to Brunner (2011) was still a very good and low cost tool. However, when using the stadia rod alone, an accompanying hand-held GPS is needed for geo-referencing. Inability of the adopted method to capture water depth shallower than 0.5 m was definitely a source of errors in estimation of reservoir bathymetry and related parameters. In the current study, the RCHSB used is able to read depth from 0.3m as long as the satellite signals are good enough.

In the Zambian context, limited existing studies (Sichingabula 2000, 1999, 1997) of reservoir bathymetry mainly employed traditional manual methods of determining bathymetric state of reservoir, as such, their results were largely based on estimation. Nevertheless, most recent study of four reservoirs by Chomba and Sichingabula (2016) in the Eastern part of Lusaka Province demonstrated methodologies of determining reservoir bathymetry, which were also adopted in this study. The study by Chomba and Sichingabula (2016) provides insight of the state of reservoir storage capacities for Lwiimba, Silverest, Morester and Katondwe reservoirs which were 101,051.43 m^3, 379,480.00 m^3, 14,724.88 m^3 and 10,714.88 m^3, respectively. However, as much as we appreciate such results, they had an inherent limitation given that the study did not carry out triangulated measurements at different temporal scales. 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 in order to check the consistency of the measurements (Ajith, 2016). Chomba and Sichingabula (2016) would have conducted minimum sample of two or more bathymetric measurements per reservoir in order to track the accuracy and consistency of hydro-geodynamics of these four reservoirs. A similar observation was made by Khaba and Griffiths (2017) in their study of Muela reservoir in Ethiopia, Vyleta *et al.* (2017) in western Slovakia and Busker *et al.* (2018) in different parts of the world. All these studies suggest that bathymetric study require multi-temporal surveying, not a one-off approach.

2.2 Theoretical background of sedimentation

In his theory of sedimentation, Clarke (2009) argues that sediment particles in water reservoirs are usually in static equilibrium because the water is almost stationary during most parts of the year. Happ (1948) and Colby (1963) further state that, there are three forces acting on sediment before it sinks to the bed of a reservoir.

The first one is the force of gravity, which is the gravitational attraction that causes even the most diminutive sediment to settle down to the bed of a reservoir after a particular period of time (Stokes, 1901; Clarke, 2009). The impact of the force of gravity is greater in reservoirs than in streams, rivers and other lotic systems whose waters are always in dynamic equilibrium (Chorley and Kennedy, 1971) during most parts of the year. According to Pidwirny (2006), dynamic equilibrium refers to an average condition of processes or to systems that are temporally never repeated; a combination of both static equilibrium and high force of gravity in reservoirs is partly the reasons why they easily get silted up.

The second force which acts on sediment is buoyancy (Rubey, 1933; Clarke, 2009). Buoyancy is an upward opposing force exerted by water on the weight of incoming sediment (Leopold *et al*., 1995). All water bodies exert a force of buoyancy on sediment that is deposited in them and this makes the sediment to first float before slowly sinking. For example, when bed load is first deposited in a reservoir, its weight will appear less due to the buoyancy of the water in reservoir. Buoyancy will act on the sediment in a suspension, trying to push the sediment to the surface of water even when it sinks (Clarke, 2009). The higher the volume of water, the higher the buoyancy force would be and the longer it would take for sediment especially suspended ones to settle on to the bed of the reservoir and vice versa (Pidwirny, 2006). This entails that, bathymetric survey must frequently be conducted, so as to frequently monitor water depth and volume in view of regulating sediment settling rate in the reservoir. However, for reservoirs like Makoye whose bathymetry at diverse and short temporal scales were highly stochastic and variable, such that buoyancy spasmodically reduces whilst the force of gravity increases thereby leading to rapid deposition of sediment on to the bed especially during dry season. The third force is known as force due to viscous drag. Any sediment being transported through a water body such as a reservoir experiences a force opposing its motion due to viscosity (Clarke, 2009). This viscous drag acts in the line of, but opposition sense to, the direction of motion (Clarke, 2009).

In his earlier study, Rubey (1933) noted that, it is not only these three forces that influence the period of settling of sediment, but also the shapes and sizes. The forces acting on sediment at the earth's surface due to gravity and nature of fluid before it settles to the bottom of the reservoir have been previously described by Allen (1900); Stokes (1901); Richards (1908); Gilbert (1914); Wentworth (1922); Rubey (1933); Happ (1948); Chorley and Kennedy (1971); Leopold *et al*. (1995); Clarkes (2009) and McGaughy (2013), among others such that the processes are well understood.

Synoptically, it is logical that if sediment is suspended in a reservoir, it will immediately experience a force downwards due to gravity and a force upwards due to buoyancy. Assuming the density of the particle is greater than that of the surrounding solution, gravity will pull the particle towards the reservoir's bed. As soon as the sediment starts to move, the drag will come into operation, horizontally opposing the motion (Rubey, 1933; Krumbrein, 1942). As the sediment accelerates, so the drag increases, until this drag force just equilibrates the difference between gravitational and buoyancy forces. At this stage, the sediment will continue to fall through the water depth towards the bed of the reservoir moving with a constant terminal velocity (Clarke, 2009).

All of the above processes, are silent and creepy in nature and unproblematic though they may seem they control sedimentation and if the denuding processes on the upstream are not checked, the three silent processes cannot only catalyse rapid sedimentation, reduce the reservoir's useful life, storage capacity, water and quality, but may also spell diverse implications on socioeconomic livelihood especially among pastoral communities whose animals depend on reservoir water. At the same time, it should also be realised that, in its natural process or under controlled conditions, sedimentation is not a problem; in fact, its absence may create 'hungry water' especially on the downstream or terrains with sharp declivity and can possibly lead to violent bank erosion (Brune, 1953; Kondolf, 1997).

2.3 Sedimentation challenges in selected areas

Assessment of sedimentation in Ethiopian small reservoirs by Tamene *et al.* (2011) showed that the area-specific sediment yield of the reservoirs ranged between 345 and 4,935 tonnes $km^{-2}yr^{-1}$ with a mean of 1,900 tonnes $km^{-2}yr^{-1}$. The study concluded that most of the reservoirs would be sediment clogged in less than 50 per cent of their useful life (Tamene *et al.,* 2011). A related study in Ethiopia by Haregeweiny *et al.* (2005) showed that 50 percent of the studied irrigation small reservoirs had a siltation problem that would shorten their economic life by half of the design period and another 20 per cent of the reservoirs would lose their effectiveness between 50 and 100 per cent of the design period. Haregeweiny *et al.* (2005) concluded that only 30 per cent of the reservoirs were expected to last for the entire design period.

Between 1972 and 2009, eighteen reservoirs had been constructed in Libya (Mostafa, 2009). All reservoirs were built in the northern part of the country where precipitation could result in flooding of agriculture fields and infrastructures including main cities and other small communities. Due to the arid nature of the country (95 per cent of the land is desert) and the characteristics of the floods, soil erosion is a major problem facing the operation of the already constructed reservoirs. Annual rainfall is extremely low, with about 93 per cent of the land surface receiving less than 100 millimetres per year. Arid conditions have extremely contributed to soil erosion and consequently sedimentation in almost all reservoirs (Mostafa, 2009). During time of operation (37 years by 2008) of Wadi El Megenin reservoir, about 8,295,718 m^3 of sediment was deposited in the reservoir. About 70 percent of the reservoir volume had been devoted to the dead storage for the life time of the reservoir (Mostafa, 2009). In their case study in Algeria, Remini and Hallouche (2007) noticed that reservoirs were silting more quickly than 10 years ago and with differing intensity. The useful life of some reservoirs could have been reduced to 60 years when originally, they should have lasted for three centuries. In Algeria, 18 old reservoirs had been seriously threatened due to the acceleration of silting and will reach the end of their useful life if remediation measures were not carried out (Remini and Hallouche, 2007). Remini and Hallouche (2007) generally noted that even if the intensity of silting intra-spatially varied, the annual rate of sedimentation for the 57 reservoirs in operation was evaluated to 45 million m^3. The loss of the capacities at different reservoirs ranged from 0.5 per cent to 0.65 per cent per annum of total volume over 10-year period.

Chihombori *et al.* (2012) used assorted mathematical algorithms to evaluate the rate of sedimentation of Marah Reservoir in Zimbabwe with a view to determine the capacity of the reservoir based on current sedimentation rate as well as the lifespan of the reservoir under the current management practices. They observed that during the first seven seasons of Marah Reservoir's life, it silted at a rate of 1.77 per cent per season, reducing its capacity from 6.67×10^5 m^3 to 6.55×10^5 m^3 (Chihombori *et al.,* 2012). At this rate, the life span of the reservoir was considered to be 57 years. A sharp rise in sedimentation was experienced by the reservoir from 1977/78 season to 1979/80 season. Sedimentation rate rose from 1.77 to 15 per cent. The reservoir's lifespan dropped from 56.5 years to seven years during the same period. Like Mavima *et al.*'s (2011) conclusion, Chihombori *et al.* (2012) attributed this increase in the rate of sedimentation to activities such as stream bank cultivation in the three wards of Gutu, which also form part of the reservoir's catchment. This conclusion also follows well with one of Sichingabula's (1997) research observations although from different spatial contexts and it shows that spatial similarities are possible in terms of sources and impact of sedimentation. Nonetheless, sediment in a catchment come from diverse sources and hence, could not only be attributed to a point source such as bank cultivation, which is just one of the sources of sediments. Probably, they could have used applications such as Soil and Water Assessment Tool (SWAT) (Abbaspour, 2015) to track sediment sources from entire catchment area.

Senar, Roseires and Girba are major Sudanese reservoirs in eastern Nile (Abdallah and Stamm, 2012). Using Grey System Approaches (GSA) namely, Discrete Grey Forecasting Model (DGFM), Verhulst Model (VM) and soil sampling measurements, they found that Senar Reservoir had lost its reservoir capacity by 85 per cent by 2010 due to sedimentation. This loss represented 790.5 million m^3 in

2010 as compared to the design capacity of 930 million m^3 in 1925. By 2010, Roseires Reservoir had lost 35 per cent of its original design capacity of 3,100 million m^3 whereas; Girba Reservoir lost 53 per cent of its original design capacity of 1,300 million m^3. Further analysis of data showed a high sedimentation rate which reduced the total reservoirs' capacity dramatically by about 50 percent from above 5.2×10^9 m^3 in 1966 to less than 2.7×10^9 m^3 in 2010. The study by Abdallah and Stamm (2012) showed the potentiality of using grey system in reservoirs storage capacity prediction particularly, where system information are scarce and uncertain. Although the grey forecasting model had been successfully adopted in various fields and demonstrated promising results, the literatures show its performance could be further improved (Xie and Liu, 2009; Abdalla and Stamm, 2012).

Bunyasi *et al.* (2013) conducted a survey of Masinga Reservoir, one of the most important reservoirs in Kenya. In their study, Bunyasi *et al.* (2013) showed that the reservoir had lost its water storage capacity due to increased sedimentation associated with watershed activities, river characteristics, and reservoir design. By employing both primary and secondary data, Normalized Difference Vegetation Index (NDVI), descriptive and inferential statistics, Bunyasi *et al.* (2013) observed that Masinga Reservoir had lost about 215.26 million m^3 (13.59 percent) of its design storage capacity to sedimentation by 2011. This informed the need to develop an effective catchment management strategy to improve the reservoir's sedimentation regime. This study was unique in that it revealed other factors such as reservoir design that lead to sedimentation unlike soil erosion and cultivation, which had been a common source of sedimentation in other studies. However, a methodical explanation of NDVI in relation to sedimentation would have provided replicability platform from which other proceeding studies would learn from. Moreover, NDVI may not be very appropriate in catchment where land cover data is not readily available (Bunyasi *et al.*, 2013).

Sichingabula (1997) used a regression model to assess sedimentation in small reservoirs of southern Zambia, his study shows that sedimentation in small reservoirs ranged from; 2 to 183 m^3 yr^{-1} with a mean of 24.6 m^3 yr^{-1}. The study further shows that sedimentation in reservoirs of Southern Province was serious because many small reservoirs had lost considerable storage capacity due to sedimentation (Sichingabula, 1997). However, there are extremely few studies in Zambia that have had a focus on measurements of fluxes and quantities of sediment into reservoirs and perhaps, this was the most imposing limitation from the Zambian context because there are very scanty studies around sedimentation (Sichingabula, 2018). Hence the need for further studies such as the current one.

2.4 Determination of real time sediment settling rates in reservoirs

Most of existing literature and studies (Sichingabula 1997; 1999; 2000; Mavima *et al.* 2011; Chihombori *et al.* 2012; Bunyasi *et al.* 2013; Ajith 2016; Chomba and Sichingabula 2016) on sedimentation are based on derivative computation of other variables unlike real in-situ measurement. This implies that if the initial data from which sedimentation rates were computed had errors, the computed values would also be inaccurate. The study by Chomba and Sichingabula (2016) in Lusaka East, Zambia only estimated rates of sedimentation using empirical mathematical models proposed by Chihombori *et al.* (2012) on annual basis. The estimated rates of sedimentation for Silverest was 14,595.40 m^3yr^{-1} and at this rate, the reservoir lifespan was found to be 26 years. For Lwiimba, sedimentation rate was estimated at 2,200.99 $m^3yr^{-1}$with chances of living up to the next 46 years; Katondwe's rate of sedimentation was at 283.92 m^3/yr with a remaining lifespan of 38 years. Morester's rate of sedimentation was determined at 251.01 m^3/yr with a lifespan of 58 years. These rates of sediment deposition 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. However, these results were highly dependent on estimations which imply that, if the measured data had huge errors, such errors would radiate to the derived sedimentation rates. In Zambia and Africa as a whole, there are no studies done on real time sedimentation measurements, if they do exist, they are extremely scanty and untraceable. The current study therefore, bridged this huge gap in the general field of hydro-geomorphology whose methodologies can be adapted to other spatial contexts. Nonetheless, there are still some scanty existing case studies outside Africa on real time determination of sedimentation. The first one was done by USACE (2009) to measure sediment deposition over mussel beds during maintenance dredging on the Ohio River, West Virginia, in the United States of America (USA). However, it was not directly used in a reservoir environment and the results were not scientifically publicized, as they were only meant for internal use, hence, the current study still stands as a potential contributor to new knowledge and methodology on how real time sedimentation can be determined in heightmetric terms and eventually, in volumetric and gravimetric terms.

The second case study of real time measurement of sedimentation was recorded in Kazakhstan in the northern part of the Caspian Sea, which had a large input of sediment from the Volga and Ural rivers, reducing its depth to only around 5 meters in a large area. In this case study, sedimeter was deployed only to assess real time rates of sedimentation for the Environmental, Social and Health Impact Assessment (ESHIA) programme and not for scientific publication (Gravity Environmental Consulting (GEC), 2013). The gaps in this case study are similar to those of USA in the sense that neither was the sedimeter used in the reservoir environment nor were its recordings published for scientific use.

The third case study was recorded in 2014 in the Washington State, north-eastern part of the USA. In 2007, the Port of Olympia found elevated levels of dioxins in an area scheduled for maintenance dredging. During this project, sedimeters were installed in the area to monitor turbidity levels and to determine sedimentation in real time, however, the results of this case study were not and have not been published for scientific use (GEC, 2014). The only published work was done by McKenzie *et al.* (2016), who did an experimental study where they concluded that sedimeter is capable of detecting bed elevation change with mm accuracy level. However, the focus of this study was purely to determine the accuracy of instrument using psuedo reservoir environment.

Sumi *et al.* (2012) also did a real time measurement of suspended sediment concentration in reservoirs in Taiwan, but their study did not consider sediment depth or depth of suspended sediment that settled on the bed. Similarly, a study by Hsu *et al.* (2011) in China documented real-time predicted peak suspended sediment without necessarily considering the depth of what would physically settle on the bed. Haun *et al.* (2015) also did a real time-based study to compare suspended sediment transport in river environments, but the study never delved into measuring the depth of moving sediment that was being deposited on the bed of settled sediment. The closest study was carried out by Curran *et al.* (2015) where they developed a Bedload Monitoring System (BLMS) to monitor suspended sediment transport and changes in bed morphology of a flume, but not really in a reservoir setting. The main thrust of this study was however, more oriented towards transport and qualitative change in bed morphology unlike quantitative or actual depth accumulated on the bed. This entails that, the current study bridged the gap by doing a study on the real time sediment depth measurement, part of whose results have already been published (Muchanga, 2017). Based on the literature that has been reviewed under this theme, it has been made clear that this is the first time in Africa and Zambia in particular, sediment settling rates, depths, volume and loads have been determined in real time at hourly interval using SediMeter SM3A (Erlingsson, 2018).

2.5 Modelling sedimentation in small reservoir catchments

Currently, there is an overwhelming collection of models for sediment simulation across the globe. This section reviews some of them, but with emphasis on SWAT. The Areal Nonpoint Source Watershed Response Simulation (ANSWERS) Model is one of the tools useful in modelling sedimentation (Bussi, 2014). It includes a hydrological conceptual model and a physically based erosion model. It assumes that sediment movement can be triggered by rainfall or surface runoff whilst its transportation could only be attributed to runoff. The ANSWERS model splits the catchment into independent regular grids within which runoff and erosion are treated as independent functions of the hydrological and sediment parameters. The rill effect is described by the manning roughness coefficient as such, it is not explicitly treated (Bhuyan *et al.*, 2002).

The ANSWERS was later on used by Ahmadi *et al.* (2006) to simulate sediment concentration in the Badjgah Watershed in Iran. Results based on statistical analysis showed that the simulated sediment concentrations by original sediment transport equation of the ANSWERS model were more consistent with observed data than the Yalin Equation. Both of these equations tended to underestimate the sediment concentration. However, neither the original equation of the model, nor the Yalin

Equation gave good approximations of sediment concentration. In line with earlier observations by Bhuyan *et al.* (2002), this implies that more modifications are still required to improve simulation of sediment concentration. These modifications can be regarded as incorporating the fine particles of the soil surface in the transport equations, considering the effect of raindrop impact on the overland flow, flow depth, and channel erosion. The primary results showed that the original equation of the model tended to overestimate the sediment concentration whenever the runoff coefficient exceeded 0.3 under moderate rainfall intensity condition (Bhuyan *et al.,* 2002).

Furthermore, results by Bhuyan *et al.* (2002) revealed that initial soil moisture is a key factor in simulation of sediment concentration. Wet and dry soil conditions caused overestimation and underestimation of sediment concentration for the original model, respectively (Ahmadi *et al.*, 2006). The limitation of ANSWERS lies in its requirement of complex and large data collection and pre-processing (Bhuyan *et al.,* 2002). In earlier studies by De Roo (1993) in the Netherlands and United Kingdom, it was noted that ANSWERS involves large percentage errors especially when used in areas other than those for which it was originally developed and tested and may therefore, not be suitable in Zambian context where modelling of sedimentation is generally not yet fully developed. Moreover, the sediment routing method is very limited as it only considers curve number or surface runoff, which indisputably brings in several errors.

Another model that relates to sediment modelling is the Water Erosion Prediction Project (WEPP), which was developed to compute soil erosion and sediment transport in agricultural field, rural zones, forest areas, grasslands and urban areas (Nearing *et al.*, 1990). In 2006, Ahmadi *et al.* (2006) used the ANSWERS to simulate sediment yields and runoff of the Orazan Watershed, but two years later (2008) they used WEPP on the same watershed to model sediment yields and runoff on the same reservoirs. Comparison between predictions and measurements indicates that WEPP under-estimates sediment volumes by 23 percent and over-estimates runoff volumes by 27 percent (Ahmadi *et al.*, 2006).

In combination with Geographic Information System (GIS) database Kirnak (2002) used WEPP to predict flow and sediment discharges for Rock Creek Watershed - an agricultural watershed in Ohio, USA. They compared observed and predicted mean monthly values between 1988 and 1990. They noted that WEPP is area size-sensitive. In case of not keeping watershed size limit, statistical results showed that model simulation for sediment and runoff were poor with an r^2 of 0.59 and 0.51 respectively. In the second case, the WEPP watershed model was applied to Rock Creek watershed by dividing whole watershed into 41 sub-watersheds and by using a watershed routing programme. In case of obeying size limitation, statistical results between observed and predicted data for flow and sediment discharges were r^2 of 0.92 and 0.83, respectively. This result proved that watershed size issue is one of the important subjects while applying WEPP model to watersheds (Kirnak, 2002).

Generally, results from various studies (Nearing *et al*, 1990; Zeleke, 2001; Zhang, 2004) ; showed that WEPP is reliable model in predicting erosion than sediment modelling and it requires complex physically measured data for calibration. Results showed that sediment yield and runoff outputs were relatively well predicted, but lack of input data to run WEPP model was a challenge in Iranian conditions and this would even prove to be more challenging in Zambia where there is dearth of sediment data for model calibration and validation. Only few studies (Lier *et al*., 2005; Renschler, 2003; Kirnak, 2002; Savabi *et al.*, 1995) have investigated WEPP's applicability to environmental conditions that differ from those where the model was developed.

The European Soil Erosion Model (EUROSEM) is another physically based small catchment scale model for the prediction of erosion (Bussi, 2014). It is a dynamic model capable of simulating soil erosion, sediment transport and deposition, computes total runoff, soil loss, hydrograph and the sedigraph (Bussi, 2014). EUROSEM model was used in the Catsop Catchment in the Netherlands where the study revealed that it is a reliable tool for short storm events with unique peak (Folly *et al*., 1999). However, in an environment like Zambia where input data sets such as hillslope rill erosion, long term sediment data and others, sparsely exist, EUROSEM would prove challenging to use (Bussi, 2014).

Water and Tillage Erosion Model/ Sediment Delivery Model (WATEM/SEDEM) is one of the most recently developed models (Brunner, 2011). It is spatially distributed soil erosion and sediment delivery model and a combined version of two empirically-based soil erosion models, namely WaTEM (Water and Tillage Erosion Model) Van Oost *et al.* (2000) and SEDEM (Sediment Delivery model) (Van Rompaey *et al.*, 2001). They can be applied at small catchment, watershed and regional scale under a wide range of environmental conditions. The main aim of the model is to predict sediment delivery to river channels and to simulate transport and deposition within a drainage basin (Van Rompaey *et al.*, 2001). The model focuses on spatial variability and is useful in estimating the spatial patterns of soil loss and sediment flow across land units (Brunner, 2012). Like other models earlier mentioned, WATEM/SEDEM is a Universal Soil Loss Equation (USLE)-based model. The advantage of WATEM/SEDEM is the relative simple structure and the relative small amount of input data needed. However, as most models, the results are only as good as input data, so before starting modelling one should think of the availability and quality of data. Users could use the model without a lot of calibration against data as long as reasonable data for the USLE factors used in the model are available. The transport of sediment is also partly calculated from USLE factors and some calibrated transport coefficients, so if there is no option for calibration (e.g. against long-term sedimentation in a reservoir, there is need to keep more or less the standard resolution of the Digital Elevation Model (DEM) at 20 x 20 m or less (Fiener, 2016). Van Oost *et al.* (2000) however, adds that a long-term measured sedimentation record is very important to effectively use WATEM/SEDEM in sediment modelling. Simpler though it may appear, it has certain data requirements (DEMS with spatial resolution less or equal to 20 m) which may not be readily available in Zambian context.

Kralisch *et al* (2007) had used Jena Adaptable Modelling System (JAMS) to model various hydrological systems including part of the Luanginga catchment in western Zambia. This Model is user friendly, but the challenge is, it is still at experimental phase and lacks substantive literature about it. The developer also acknowledged that the model has only been used once in Germany to model sediment fluxes whose results are not widely published. The model is suitable on modelling discharges and climatic data rather than sediment.

2.5.1 Theoretical overview of SWAT modelling and review of selected case studies

One of the widely used and documented tools of modelling sediment delivery is the Soil Water Assessment Tool (SWAT) which was developed by Jeff Arnold of the United States Department of Agriculture-Agriculture Research Service (USDA-ARS) to predict the impact of land management practices on water, sediment and agriculture chemical yields in watersheds that have varying soils and landuse (Neitsech *et al.,* 2005). It is a physically-based and semi-distributed model (Winchell *et al.,* 2013).

It operates on a continuous daily and hourly time step (Neitsech *et al.,* 2005). SWAT is also designed to simulate management impacts on water and sediment movement for un-gauged basins (Habte *et al.,* 2013). SWAT is an extension tool in Geographical Information System (GIS) software. Premised on the inputs which include spatial data: (DEM, soils, landuse) and climatic data: (daily precipitation, daily temperature, daily humidity, daily wind speed (2m above the ground), solar), SWAT simulates an hydrological cycle using default water balance equation as shown in equation 1 and illustrated in Figure 2.

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

where:

Ea	amount of evapotranspiration on day i (mm H_2O)
Q_{gw}	amount of groundwater infiltration on day i (mm H_2O)
Q_{surf}	amount of surface runoff on day i (mm H_2O)
R_{day}	amount of precipitation on day i (mm H_2O)
SW_0	initial soil water content on day i (mm H_2O)
SW_t	final soil water content (mm H_2O)
t	time (days)
W_{seep}	amount of water entering the vadose zone from the soil profile on day i (mm H_2O)

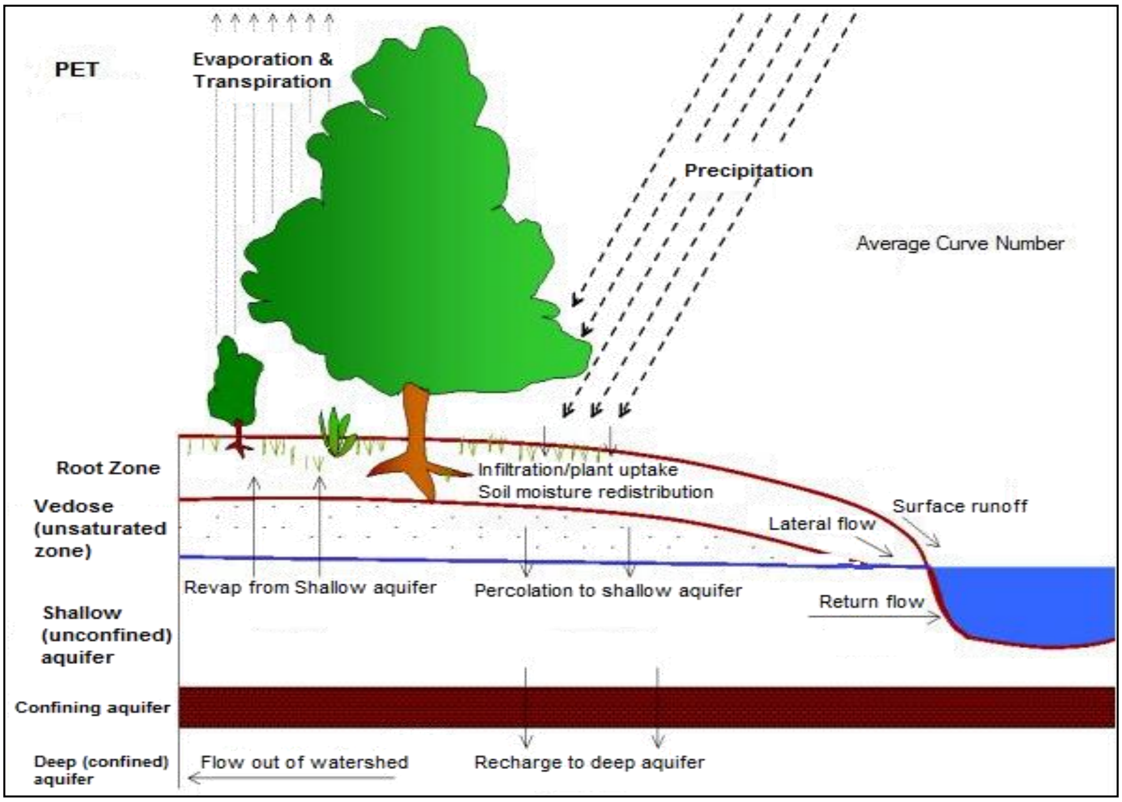


Figure 2: Illustration of simulated hydrological cycle in SWAT.
Warm-up ArcSWAT simulation (2018).

SWAT helps in the subdivision of the watershed into subbasins, which are further re-subdivided into smaller units known as Hydrologic Response Units (HRUs) premised on soils and landuse/cover inputs (Habte *et al.*, 2013). These subdivisions provides an imminent propensity for the model to predict runoff at HRU level and to further route it so as to add up to aggregate watershed runoff. Through this process, accuracy is achieved and a better simulated hydrological cycle can be obtained (Neitsch *et al*., 2011). The simulated hydrology is what eventually influence sediment and nutrient outputs. For further details, SWAT is very well documented by Arnold *et al.* (2012) in the SWAT Input-Output documentation.

The major challenge with this model lies in its being a very data-demanding model whose temporal resolution should be wide enough and on daily climatic and hydrological data. The physical processes such as surface runoff, subsurface flows, rainfall, depicted in Figure 2 above have a profound influence on sediment transport and even the bathymetric dynamics of a hydrological system (Leopold *et al*. 1995; Walling *et al.* 2001; Viessman and Lewis, 2012). SWAT uses a default sediment routing method known as simplified Bagnold Equation (Arnold *et al.*, 2012).

2.5.1.1 Sediment routing

The default sediment routing method by Bagnold and Beech (1977) depends on peak flow rate and mean flow per day. A delineated watershed constitutes subbasins each of which constitutes routing reaches, which also systemically handover to succeeding reaches on the downstream (Equation 2).

$$conc_{sed,ch,mx} = Csp * v_{ch,pk}^{sp\exp} \tag{2}$$

Where:

$conc_{sed\ ch\ mx}$	is the maximum concentration of sediment that can be transported by water (*tonne*/*m* or *kg* / *L*)
C*sp* and *sp*exp	coefficient and exponent of the equation (varies between 1.0 and 1.5 SWAT2012, but can be user defined)
$V_{ch\ pk}$	peak channel velocity (m^3/s). (refer to Equation 3).

The peak channel velocity influence the peak amount of sediment that can move from one subbasin to the other (Equation 3) (Arnold *et al.*, 2012).

$$v_{ch,pk} = \frac{q_{ch,pk}}{A_{ch}} \tag{3}$$

Where:

$q_{ch,pk}$	peak flow rate (m^3/s)
A_{ch}	cross-sectional area of flow in the channel (m^2)
$q_{ch,pk}$	refer to Equation 4

$$q_{ch,pk} = prf * q_{ch} \tag{4}$$

Where:

prf	peak rate adjustment factor
q_{ch}	average rate of flow (m^3/s).

When sediment is generated, it is transported to the sinks, but before it reaches the sink(s), part of it is obviously abstracted due to potholes, surface lag, among other factors. The final total amount of sediment that is finally deposited in the sink is calculated based on Equation 5.

$$sed_{dep} = (conc_{sed,ch,i} - conc_{sed,ch,mx}) * V_{ch} \quad (5)$$

Where:

sed_{dep}	amount of sediment re-entrained in the reach segment (tons)
V_{ch}	the volume of water in the reach segment (m^3)

Equation 5 is applicable where initial sediment concentration from the source is greater than the maximum sediment concentration in the reach, but if the opposite situation is the case, net sediment in the reach is calculated using Equation 6.

$$sed_{deg} = (conc_{sed,ch,mx} - conc_{sed,ch,i}) V_{ch} * K_{CH} * C_{CH} \quad (6)$$

Where,

sed_{dep}	sediment re-entrained in the reach segment (tons)
K_{CH}	channel erodibility factor
C_{CH}	channel cover factor.

Further details can abundantly be found from Neitsech *et al.* (2005). Aggregation of deposition and degradation is preceded by computation of grand net sediment in the reach using Equation 7.

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg} \quad (7)$$

Where,

sed_{ch}	amount of suspended sediment in the reach (tons)
$sed_{ch,i}$	amount of suspended sediment in the reach at the beginning (tons)
sed_{dep}	amount of sediment deposited in the reach segment (tons)
sed_{deg}	amount of sediment re-entrained in the reach segment (tons)

Premised on the above processes, sediment load flowing from the reach is derived using the Equation 8.

$$sed_{out} = sed_{ch} \cdot \frac{V_{out}}{V_{ch}} \quad (8)$$

Where:

sed_{out}	amount of sediment transported out of the reach (tons),
V_{out}	volume of outflow during the time step (m^3)
V_{ch}	volume of water in the reach (m^3)

SWAT runs all these processes in the background in order to eventually simulate the sediment either at reservoir or subbasin scale. This study simulated at reservoir scale.

Further details of the processes can be accessed from Neitsech *et al.* (2005) and Arnold *et al.* (2012).

In their study of runoff and sediment modelling using SWAT in Gumera Catchment, Ethiopia, Habte *et al.* (2013) noted 4,598,286 tonnes/yr of observed sedimentation as compared to that of simulated of 4,889,753 tonnes/yr. Ijam and Al-Mahamid (2012) also used SWAT to simulate Mujib Reservoir Catchment area in Jordan. The results of their study assessed the quantity of water and sediment inflow to the reservoir. They also identified the regions of high soil erosion, sediment yield and delivery ratio in order to manage these regions by applying techniques which reduce these values in sequence to decrease the sediment yield reaching the reservoir. It was predicted that the average annual sedimentation in the Mujib Reservoir would be about 300 × 103 m^3/yr^{-1}. This was considered a real threat of reducing the operational life of the reservoir due to decreasing active storage. To protect the reservoir, Ijam and Al-Mahamid (2012) recommended management and conservation practices to be applied for the sub-basins with high quantities of erosion and sediment yield. The study revealed that the model is able to predict water flow and sediment yield, which might be beneficial for future planning and management.

Betrie *et al*. (2011) also applied SWAT to model spatially distributed soil erosion/sedimentation processes at daily time step and to assess the impact of three Best Management Practices (BMPs) scenarios on sediment reductions in the Upper Blue Nile River Basin in Egypt. The model showed that erosion and sediment delivery could be determined at Hydrological Response Units (HRUs) level. Working on sediment transport in ungauged catchment is always very challenging as most hydrological/erosion models need a calibration (in most cases also validation) against physically measured data (Abbaspour, 2004; 2015; 2018), but SWAT, once properly used, is able to estimate what is happening at each subbasin within the catchment, even if that subbasin does not have a gauging station. For example, Emam *et al.* (2016) used SWAT to study ungauged Aluoi Sub-basin in Aluoi District, which is located in central Vietnam and they determined sediment loads based on regionalisation. There are also several other studies (Begou, 2016 in West Africa; Halefom *et al.*, 2017 in India; Ang and Oeurng, 2018 in Cambodia;

Djebou, 2018 in the USA, among others) that have used regionalisation approach and that is what gives SWAT an advantage over other simulation models. SWAT Model is widely used and documented (Ndomba and Griensven, 2011; Abbaspour *et al*., 2007; Abbaspour 2015; Begou, 2016, Amam, 2016, Halefom *et al.* 2017; Ang and Oeurng, 2018, Djebou, 2018, among other studies, such that its nature and use is well known.

However, in the Zambian context, modelling using SWAT and other model tools is still at a very novice level especially with regard to sedimentation. Moreover, how SWAT can be used to model sediment fluxes in ungauged hydrological subbasins within a wider gauged catchment is not widely documented, the closest use of this tool was by Muzumara (2012) who just used it for simulating discharge in Kabompo, North-western Province of Zambia.

2.5.1.2 Theoretical overview of SUFI-2 in SWATCUP for hydro-geomorphic model calibration

SWATCUP is an acronym that stands for Soil Water Assessment Tool Calibration and Uncertainty Prediction. It was developed by Karim Abbaspour as an independent window programme for SWAT model calibration (Abbaspour *et al.*, 2007). SWATCUP has five analytical techniques namely Sequential Uncertainty Fitting version 2 (SUFI-2), Generalised Likelihood Uncertainty Estimation (GLUE), Particle Swarm Optimisation (PSO), Parameter Solution (ParaSol) and Markov Chain Monte Carlos (MCMC) (Abbaspour, 2015). The linkage between SWAT and the mentioned calibration programmes is as illustrated in Figure 3. Since the current study was aimed at calibrating the sediment SWAT model using SUFI-2, the emphasis in this section is on the latter. SUFI-2 is a stochastic method of model calibration (Abbaspour *et al.*, 2007). Abbaspour (2015) states that, deterministic approach of try and error till one reaches acceptable or meaningful results is an outdated and unreliable approach for calibrating stochastic hydrological systems. On the other hand stochastic calibration as it is in SUFI-2 challenges scientists to acknowledge inherent uncertainties and error surrounding the model. This is so in order to account for our imperfect understanding of processes not initially accounted for in the initial running of the model (Tejaswini and Sathian, 2018). Uncertainty analysis is unavoidable pre-requisite without which modelling loses its meaning and many a time, misleading.

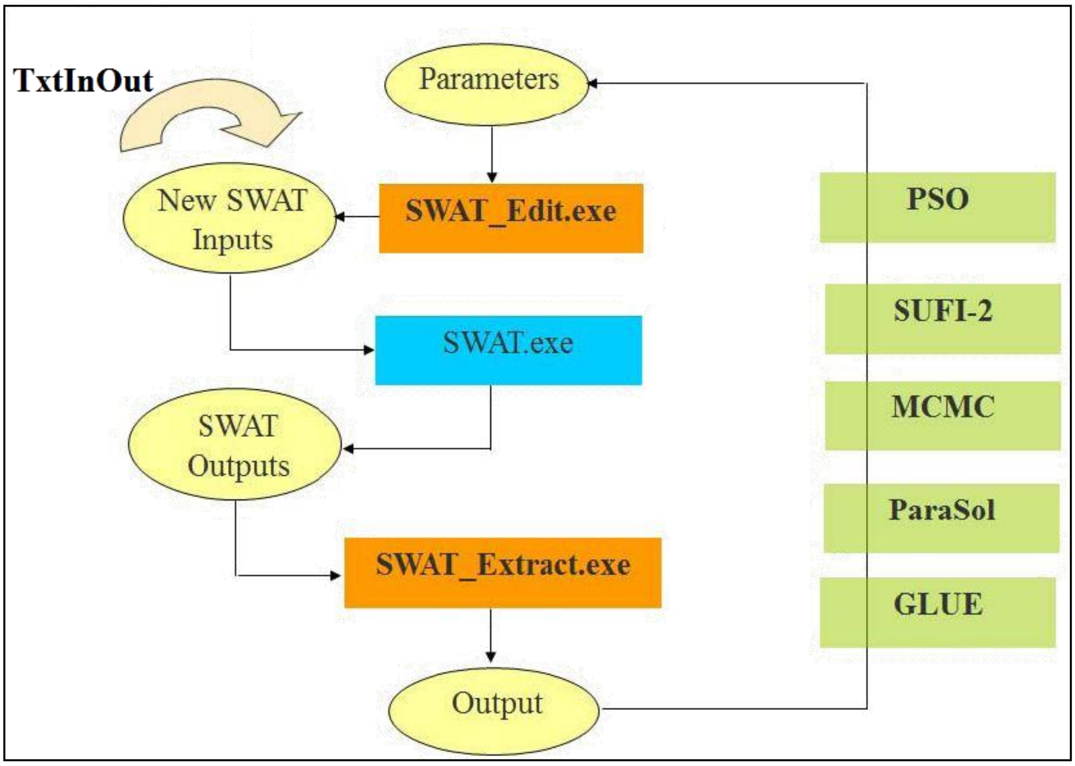


Figure 3: Communication system between SWAT and the five Optimisation Programmes in SWATCUP.
Source: Abbaspour (2015:20).

Uncertainty analysis in SUFI-2 ranges from conceptual model errors (such as bank slides, landslides, wind erosion, building constructions in catchment, dump sites, ditches in the catchment that trap water, etc.) errors in measured input data especially rainfall, discharge and none uniqueness of input parameters (e.g. rainfall intensity, distribution, quantity, groundwater delay and changes in water table, etc.) (Abbaspour, 2015). Uncertainties in the input parameters inevitably lead to uncertainties in the model outputs, which according to Abbaspour (2015), are depicted as 95 Percent Prediction Uncertainty (95PPU) computed at 2.5 percent and 97.5 percent of accumulated dispersion of variable output triggered by spread of uncertainties using Latin Hypercube Sampling.

The philosophy behind SUFI-2 95PPU is to envelope as many measured parameters in a system as possible so that if those measured parameters were correct, then all other variables leading to such observations are correct (Abbaspour, 2007; Yang *et* *al.,* 2008). To this effect, Abbaspour (2007) recommends inputting as many variables as possible in the Objective Function (statistical method that computes performance of the model in SWATCUP) so as to minimize erroneous processing.

In order to calculate the fitting between simulated data and observed one within in the context of 95PPU, p-factor and r-factor statistics are considered. The p-factor simply refers to the percentage of measured variable captured or enveloped by the 95PPU whereas the r-factor refer to the thickness of the 95 PPU band width (Abbaspour *et al*., 2007). Whilst there are no hard numbers existing as to what must constitute p and r factors, Abbaspour (2015) proposes a p-factor as closer to 1 as possible and r factor as closer to zero as possible.

When p-factor is 1 and r factor 0, it means that there is a perfect fit between predicted and measured data (Abbaspour , 2015). A p-factor of ≥70 and r value around 1 are considered to be good enough for discharge, however, smaller p and *r* factors are acceptable for sediment modelling (Abbaspour, 2015; Arnold *et al*., 2012). As iterations of simulation are done in SUFI-2, the parameters range keep changing zooming the narrower and better range, this eventually tends to reduce the p and *r* factor's values. It is therefore recommended to do at most <5 iterations depending on the general outlook of the model outputs (Abbaspour, 2004). Calibration process helps reduce the gap between simulated and measured data. Validation helps test the predictive power of the model to data sets that are outside calibration period or space. Sensitivity analysis is another important aspect of SUFI-2 as it depicts the most. There are two types of sensitivity analysis namely one-at-a-time and global sensitivity analysis. SUFI-2 carries out automatic sensitivity analysis if the inputted parameters as many in number (>20), but if numbers are fewer, the former has to be done manually. The idea behind is the higher the *t*-stats value and the smaller the *p*-value, the more sensitive the parameter is to the variable under simulation (Abbaspour, 2007; Tejaswini and Sathian, 2018). This means that, any change in such a sensitive parameter will lead to a change in the variable being simulated.

SUFI-2 processing changes the minimum and maximum range of values depending on the type of commanded change needed. According to Abbaspour (2015), the rule of thumb is all spatial data such as soils, curve number (CN2), among others assume relative (r__) method of change, which means that an existing parameter value is multiplied by (1+a given value). None spatial data such as groundwater delay (GW_DELAY) are assigned with a replace (v__) method such that an existing parameter value is replaced by a given value. The other identifier code used in SUFI-2 and SWATCUP in general is (a__), which means that a given value is added to the existing parameter value. It is very important to pay attention to this method in order to assign the right method of required change. SUFI-2 and SWATCUP in general has about 10 Objective Functions (OF), however, the most commonly used are Coefficient of Determination (R^2), Nash-Sutcliffe efficiency (NS), Percent Bias (PBIAS) (Anold *et al.,* 2012). Most if not all recent studies (Moriasi *et al.,* 2007; Yang *et al.*, 2008; Singh *et al*., 2014; Halefom *et al.*, 2017; Tejaswini and Sathian, 2018) have used these OFs, which are used to assess the performance of a model. Moriasi *et al.*, (2007:891) presents various assessment criteria for different parameters. Arnold *et al.* (2012) also present a more concise framework for assessing the performance of SWAT model as shown in Figure 4.

As much as SUFI-2 may be friendly and robust at dealing with complex hydrological data sets, it tends to perform poorly in instances where physically based data is too scanty temporally (Abbaspour, 2018). SUFI-2 applies statistical models embedded in it to run performance statistics. These are as presented in Equations 9 for R^2, 10 for NS and 11 for PBIAS, respectively.

$$R^2 = \frac{\left[\sum_i \left(Q_{m,i} - \overline{Q}_m\right)\left(Q_{s,i} - \overline{Q}_s\right)\right]^2}{\sum_i \left(Q_{m,i} - \overline{Q}_m\right)^2 \sum_i \left(Q_{s,i} - \overline{Q}_s\right)^2} \tag{9}$$

Where:

R^2	Coefficient of determination (model predictive power);
Q	Variable (sediment or discharge);

m Measured;

s Simulated;

i i^{th} measured or simulated data; and

$\overline{Q}$ Mean.

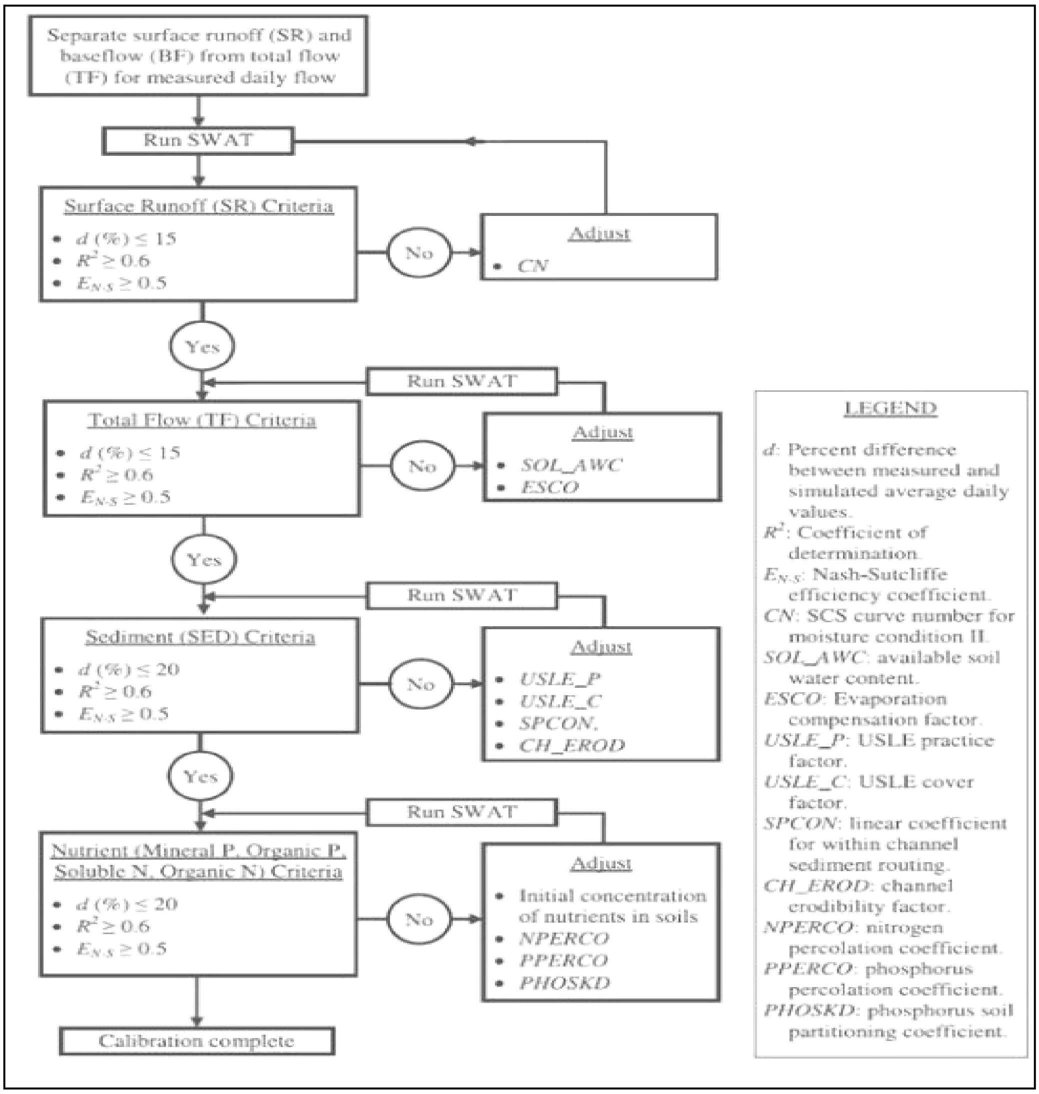


Figure 4: SWAT model performance criteria for surface runoff, flows, sediment and nutrients.
Source: Arnold *et al.* (2012:1495).

(10)

Where:

NS	Nash-Sutcliffe efficiency (Fitting between observed and simulated data (Nash and Sutcliffe, 1970)).
Q	Variable (sediment or discharge);
m	Measured;
s	Simulated;
i	i^{th} measured or simulated data; and
$\overline{Q}$	Mean.

$$PBIAS = 100 * \frac{\sum_{i=1}^{n} (Q_m - Q_s)_i}{\sum_{i=1}^{n} Q_{m,i}} \qquad (11)$$

Where:

PBIAS	Percent Bias (percent);
Q	Variable (sediment or discharge);
m	Measured;
s	Simulated;
i	i^{th} measured or simulated data; and
$\overline{Q}$	Mean.

According to Yang *et al.,* (2008), SUFI-2 is fairly easy to work with, but the challenge is one needs to be familiar with the effect, which each input parameter may have on the variable being calibrated. SUFI-2 is not just user friendly, but it is capable of simultaneously optimising and detecting uncertainties during processing (Abbaspour, 2004). Table 1 summarises some of previous and recent studies that used SWAT to simulate sediment. The current study contributed to the broader field of SWAT simulation through the use of real time sediment depth records which were eventually transcribed to loads and volumes. This stood out differently when compared to earlier studies, which only repeated the same procedures of calibration and validation using pre-observed sediment records documented outside the process of study.

Table 1: Summary of selected case studies that used SWAT to model flows and Sediment

No.	Citation	Main Objective	Place	Model performance		Main conclusion
				NSE	R^2	
1	Pokhrel, 2018	estimate the impact of land use changes on Bagmati river discharge and sediment yield at the Khokana gauging station of the Kathmandu valley	Nepal	0.9	0.88	A very good agreement between monthly measured and simulated sediment
2	Djebou, 2018	assess sediment inflow to a reservoir using the SWAT model under undammed conditions	USA	0.75	0.81	The model was efficient in prediction of sediment
3	Ang and Oeurng, 2018	test the applicability of SWAT model to simulate the stream flow in the Stung Pursat catchment.	Cambodia	0.6		SWAT model fairly well performed in capturing the amount and variability of daily and monthly flows
4	Gull *et al.*, 2017	evaluate the performance of Swat model by comparing its predicted flow and sediment yield with corresponding observed values	India	0.79, 0.86	0.88	Model performed well during both calibration and validation period.
5	Hallouz *et al.*, 2017	model discharge and solid erosion quantification through a small agricultural watershed by applying the SWAT model	Algeria	0.55, 0.88		SWAT model is very efficient in simulating water phenomena and sediment transfer processes.
6	Begou, 2016	make prediction of stream flow hydrographs on the Bani basin to improve the knowledge of water resources availability	West Africa	0.76, 0.84	0.79, 0.87	The model efficiently predicted the flows.
7	Amam *et al.*, 2016	Model the hydrology of ungauged catchment	Vietnam	>0.70	>0.70	A regionalization approach was useful to predict discharge with the aid of SWAT.
8	Duru *et al.* 2018	Estimate suspended sediment yield in a semi-arid watershed	Turkey	0.81	0.93	Based on SWAT outputs, the model performed well

No.	Citation	Main Objective	Place	Model performance NSE	R²	Main conclusion
9	Ghoraba, 2015	Simulate the stream flow to Simly Dam in order to help the managers to plan and handle this important reservoir	Pakistan	0.79, 0.85	0.80, 0.93	Model successfully modelled runoff than sediment
10	Nasrin *et al.*, 2013	Simulate the watershed basin sediment and inflow	Persian Gulf	0.7	0.76	Simulated flow and sediment were generally in agreement with measured data.
11	Qui *et al.*, 2012	Test the feasibility of SWAT on runoff and sediment load simulation	China	0.53, 0.63	0.79, 0.82	Comparisons of observed and simulated data were within acceptable range although underestimations were noted
12	Muzumara, 2012	Apply remote Sensing and a GIS-based SWAT to estimate river discharge to address the challenge of water resource management	Zambia	0.87	0.93	modelled results showed good correlation with observed data
13	Ndomba *et al.*, 2008	Validate the Soil and Water Assessment Tool (SWAT) model in data scarce environment in a complex tropical catchment	Tanzania	0.55, 0.68		The SWAT simulation was moderately satisfactory
14	Bouraoui *et al.*, 2005	Test applicability of SWAT model to the river basin	Tunisia	0.53	0.75	Model moderately successful in prediction of flows.

It was noted that the above listed studies on simulation were mainly focusing on flows and not sediment and that, they did not provide enough physical conditions about the geographical areas where simulation was done.

2.5.1.3 Overview of factors influencing sedimentation, water flows and quality

Factors that influence rates of reservoir sedimentation, water flows and water quality are very widely documented Imanshoar *et al.* (2013). Imanshoar *et al.* (2013) classify these factors into anthropogenic and biophysical factors (Table 2).

Table 2: Summary of factors influencing reservoir sedimentation, water flows and water quality

Factors influencing sedimentation process		**Literature consulted**
Physical factors	Surface runoff	Tejaswini and Sathian (2018), Abbaspour (2015), Leopold *et al.* 1995.
	Groundwater hydrology: water table, flows and quantity.	Viessman and Lewis (2012), Abbaspour (2015)
	Soil: type, bulk density, erodibility, composition, particle sizes and chemistry.	Rubey (1933), Colby (1963), Krumbrein (1942), Abbaspour (2015), Baishya and Sahariah (2017), Singh *et al.* 2014, Derbyshire *et al.*(1979)
	Physical characteristics of catchment such as size, declivity angle, bank characteristics, locations, surface form, stream density, distance to the water body, vegetation cover and parent rock.	Rubey, 1933, Goudie and Pye (1983) Leopold *et al.* 1995, Walling *et al.* (2002), Abbaspour (2015),
	Channel characteristics: bank and channel cover, slope, erodibility factor, stream length and width.	Brune (1953), Chiti (1987), Viessman and Lewis (2012), Abbaspour (2015), Leopold *et al.* 1995, Walling *et al.* (2001)
	Climatic factors: Type of precipitation, rainy days, quantity, storm direction and rainfall distribution, antecedent rainfall events and timing, wind speed, temperature and humidity	Langbein and Schumm (1958), Chiti (1987), Leopold *et al*. (1995), Sichingabula (1996), Sichingabula (2000), Viessman and Lewis (2012), Heidi *et al*., 2016; Theresa *et al*., 2016; Srinivasan *et al.*, 2016
Human Factors: landuse such as bank agriculture, grazing, irrigation, type, urbanization and sand mining.		Leopold *et al*. 1995, Sichingabula (2018) Sichingabula *et al.* (2014), Da Silva *et al.* (2016), UNESCO (2011), Heidi *et al*., 2016.

2.6 Sedimentation and water quality

Reservoir sedimentation affects water quality in many ways; the most obvious visual effect is that of increasing turbidity (Grobler, 2011). This often affects light penetration resulting into extensive loss of reservoir productivity (Grobler, 2011). Chemical effluents and metals that are usually part of the Total Sediment Load

(TSL) also affect the quality of water making it unsuitable for crop irrigation, household use and livestock (Grobler, 2011). On the other hand sediment is one of the important sinks for pollutants in the reservoir environment and provides certain minerals that are useful to humanity, but under certain circumstances pollutants can be remobilized through scouring depending on the characteristics of the storm events (Sichingabula, 1999). Sediment may be contaminated by excessive levels of nutrients such as urban and agricultural phosphorus, which create algal blooms that reduce dissolved oxygen and life of aquatic micro-organisms (Castro and Reckendorf, 1995). For example, the draining of Halligan Reservoir in Colorado was accompanied by the release of approximately 6400 cubic metres of clay to gravel sized sediment that had accumulated in the reservoir. The immediate effect of the sediment release was a massive death of aquatic organisms, as reported by the Colorado Division of Wildlife (CDOW), which estimated 4,000 dead fish along the ten miles of channel immediately downstream of the reservoir (Castro and Reckendorf, 1995). Over a long term, the continuing presence of excess fine sediment along the channel inhibited re-colonization by aquatic insects and fish due to reduced water quality (Castro and Reckendorf, 1995).

Water quality studies have been widely documented at diverse spatial and temporal scales (Braul and Kirychuk, 2001; Kithiia and Mutua 2006; Ougang, 2005; Kapungwe, 2013; Kamtukule, 2008; Mudyazhezha and Kanhukamwe 2014; Sracek *et al*. 2012; Linn, 2013; Chomba and Sichingabula, 2015, Korkanc *et al*., 2017; Song *et al*. 2017; Kandler *et al*., 2017; Lu and Yu, 2018; Cui *et al.* 2018; Wijesiri *et al.*, 2018). The main limitation noted in most of the studies was that, some of them were simply based on one off and single sampling point, which did not present a very clear picture of spatial-temporal hydro-chemical dynamics. The most visible limitation was emanating from little or no prior analysis of physico-chemical characteristics of soils and or sediment within catchments. Water quality study cannot be complete without first understanding the chemistry of sediment or soils being deposited in water (Sichingabula, 2018).

Other studies used piper plot analysis in combination with other statistical techniques. A piper plot is a tool that visualizes the chemistry water, soils or rock samples (Dauda, 2015). In its lower left is a ternary diagram which represents cations, and on its lower right is another ternary diagram which represents anions. The rhombus plot also known as diamond plot represents combination of the two (Dauda and Habib, 2015; Usman *et al*., 2014). In their case study in the Santiniketan-Bolpur-Sriniketan zone, Birbhum District, West Bengal-India, Manoj *et al*., (2013) used a piper diagram to classify water samples, they concluded that the waters were predominantly Mixed (calcium-sodium-carbonate) Type'. They found no variation in water type hinting out that the water bodies had stable compositions of ions. Another Indian case study by Tiwari *et al*. (2015) used a piper diagram for analysis and evaluation of surface water in Pratapgarh District. It showed that, most of the surface waters in the district were mainly controlled by rock weathering, followed by agriculture and other anthropogenic activities. The water was predominantly mixed with calcium, magnesium, carbonates as well as chlorides as major hydro-geochemical compositions.

The piper method has been successfully used in other areas such as Malaysia by Shamsuddin *et al*. (2016) who noted that calcium carbonate water was the most predominant water type. Talabi *et al.* (2013) also used a similar method in assessing quality of surface water in the Central Part of Ekiti-State in Nigeria. Their study concluded that 70 percent of the surface water was mixed constituting calcium, magnesiun and chloride, 20 percent was sodium chloride and 10 percent was calcium chloride. There are other case studies (Baumle *et al.* 2007; Dano, 2010) that have successfully used this technique to understand the hydro-geochemistry of water. Whilst piper method of water analysis offers several advantages such as being able to analyze several water samples at once, it also has one limitation as it renormalises the concentration of chemical elements to an extent that it cannot incorporate waters with minimal quantities of anions and cations (Dauda, 2015). However, the method offers flexibility for adaptation in order to accommodate other anions that are not represented by default. It was also noted that, inter-seasonal piper analysis of water chemistry was poorly attended to or that little or no attention was given to inter-seasonal comparisons of hydro-geochemical faces of studied hydrological systems.
Although it is generally believed that characteristics of water in reservoirs are uniform, this needs a rethink because factors such as depth, size, time and place may actually create some variations within the same hydrological body. The current study

not only delved into determination of concentration levels of selected physical and chemical parameters, but also demonstrated how such parameters varied across the reservoir from intra-inter spatial and temporal contexts.

2.7 Summary of reviewed literature

The Bathymetric studies that were reviewed focused on instantaneous measurement without taking into consideration the inter-seasonal hydrological regimes. Moreover, they only focused on the physical dimension of the science of hydrology without linking it to the social dimension. Sedimentation is indeed a major factor in reservoir's volumetric change, but it is not the only one that affects the volume, there are other physical factors such as temperature, evaporation, humidity, among others that seasonally affect the bathymetry, but were not adequately explored in previous studies. Previous studies reviewed in this research estimated annual sedimentation based on classic approach of dividing the current total load by the age of the reservoir, but this method is flawed with lack of accuracy as it presents sedimentation as a linear phenomenon, but that is never the case. This study however, overcame this limitation by determining real time measurement of sedimentation at hourly time interval using SediMeter SM3A. Studies that used the latter method were scarce if not none existent especially in African context. This was a foundational approach also in the calibration of sedimentation using SWATCUP.

Generally, in Zambian context, there were barely any scientific studies on use of SWAT to model sedimentation; the closest study by Muzumara (2012) only used it for simulating discharge in Kabompo, North-western Province of Zambia. It was therefore, worthwhile to delve into this path to determine not only sediment loading into the Makoye Reservoirs, but also other parameters such as erosion hazardous areas and sources of sediment within the reservoir's subbasin. The use of real time physically measured sedimentation was overarching contribution to the general field of fluvial geomorphology and sediment simulation and calibration using SWAT and SWAT-CUP, respectively. The main limitation noted in most of the water quality-based studies reviewed above was that, many of them were simply based on one off and single sampling point, which did not present a very clear picture of spatial-temporal hydro-chemical changes. The most visible limitation was emanating from little or no prior analysis of physico-chemical characteristics of soils and or sediment, which influenced water quality for animal consumption. Water quality studies are incomplete without first understanding the chemistry of sediment or soils being deposited in water (Sichingabula, 2018). Therefore, the current study enhanced understanding of this least considered aspect of understanding water quality especially from Zambian context. Generally, all the limitations noted in previous studies as summarised above, motivated the current study, which also developed a 3D model, which would be researches can adapt.

CHAPTER THREE: SELECTION AND DESCRIPTION OF THE STUDY AREA

This chapter describes the physical and socioeconomic characteristics of the study area with the aid of maps. In the closing section of this chapter, reasons for adopting Makoye Reservoir of Monze East will be outlined.

3.1 Physical characteristics of the study area

3.1.1 Location and size

Makoye Reservoir is found in Njola area of Monze East in Southern Province of Zambia. 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 (Figures 5 and 6) (MLF, 2016). Makoye Reservoir is situated about 20 Km East of Monze Town in Njola area and is surrounded by Chikankata in the East, Tonga and Magoye in the North-West, Chula in the North-East as well as Chisekeshi and Gwembe in the South-West. The approximate spatial extent of the Makoye Reservoir is 60,499 m^2 and its basin size is 66.82 Km^2 size is (Survey Department of Zambia, 2014).

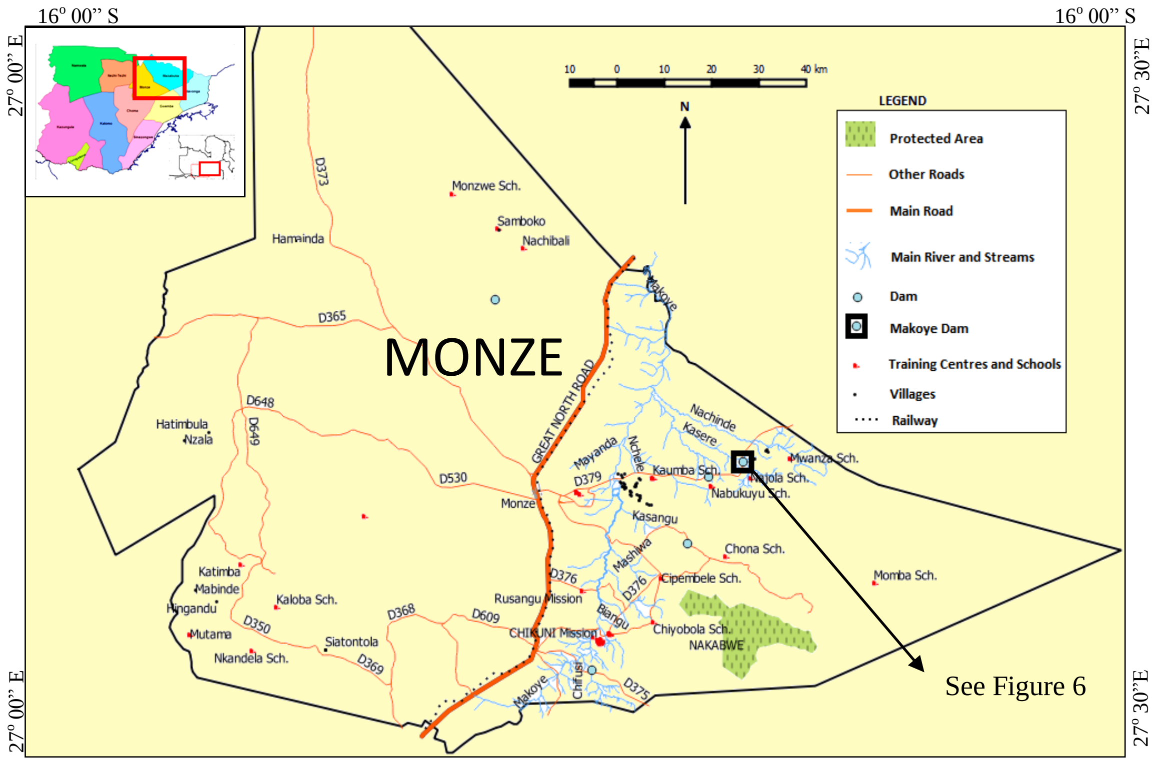


Figure 5 : Location of Makoye Reservoir in Monze District, Zambia.
Adapted from SDZ (2014).

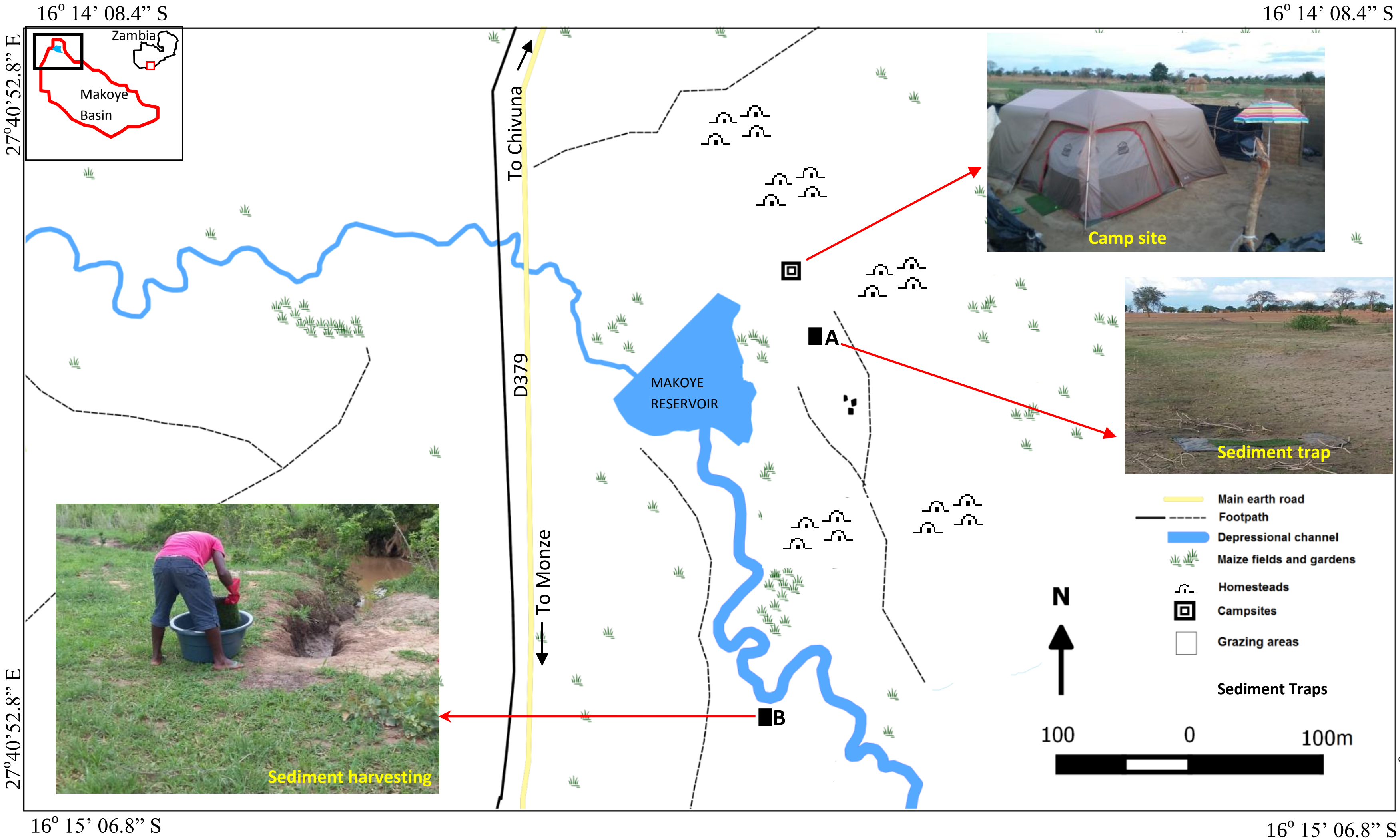


Figure 6 : Specific geographical setup of the immediate environment of Makoye Reservoir in Monze District, Zambia. Field Mapping (2016).

3.1.2 Ecological zoning and Climate

Makoye Reservoir catchment is located in ecological region-IIa (Figure 7) where the annual rainfall ranges between 200 mm and 1000 mm with mean annual rainfall of about 617mm (ZMD, 2013). It has three main seasons namely, cool-dry from May to August, hot and dry from September to October and the hot-wet from November to April (ZMD, 2004). The average midday maximum temperatures are generally high (31^oC-45^oC) in October especially in the southern fringes (ZMD, 2004). Average midday minimum temperatures oscillate about 4^oC to 20^oC in June (ZMD, 2004). Some arid conditions especially in the south-eastern fringe are evident because it is near the ecological Zone-I where arid conditions with annual rainfall below 800 mm are prevalent (Ministry of Tourism Environment and Natural Resources (MTENRs, 2007:2). Figure 8a-b respectively presents rainfall and temperature trends of the study area.

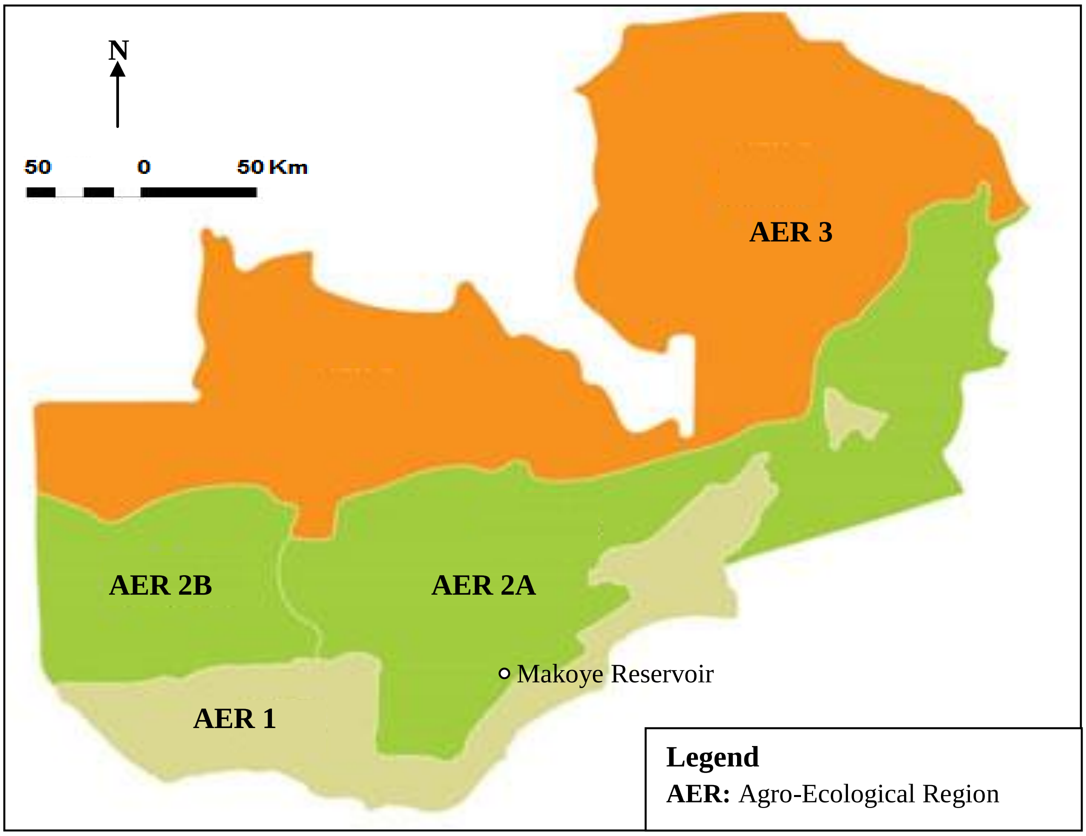
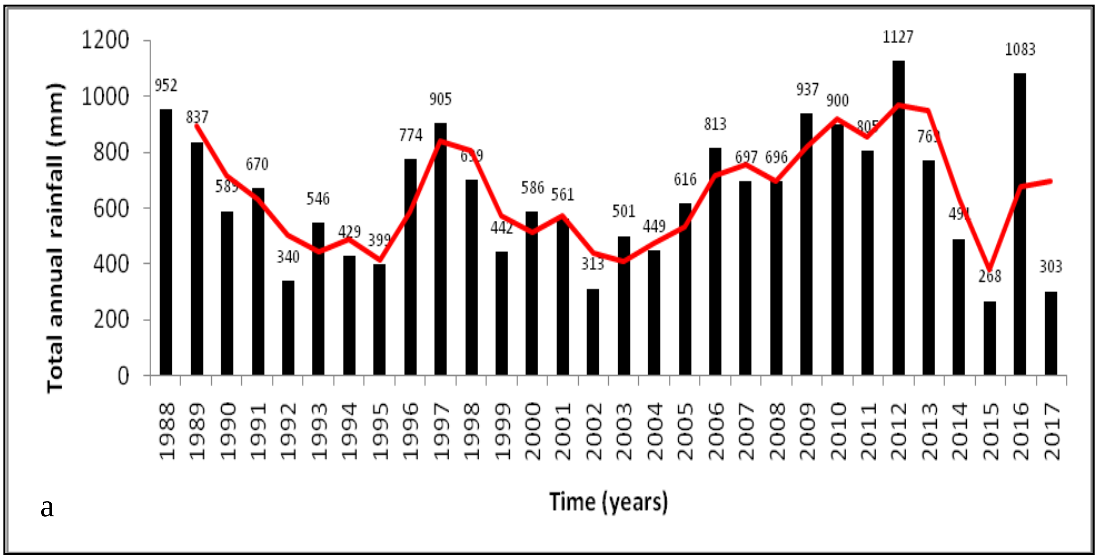


Figure 7: General location of study area in the Zambia's agro-ecological zone.
Adapted from MTENR (2007:2)



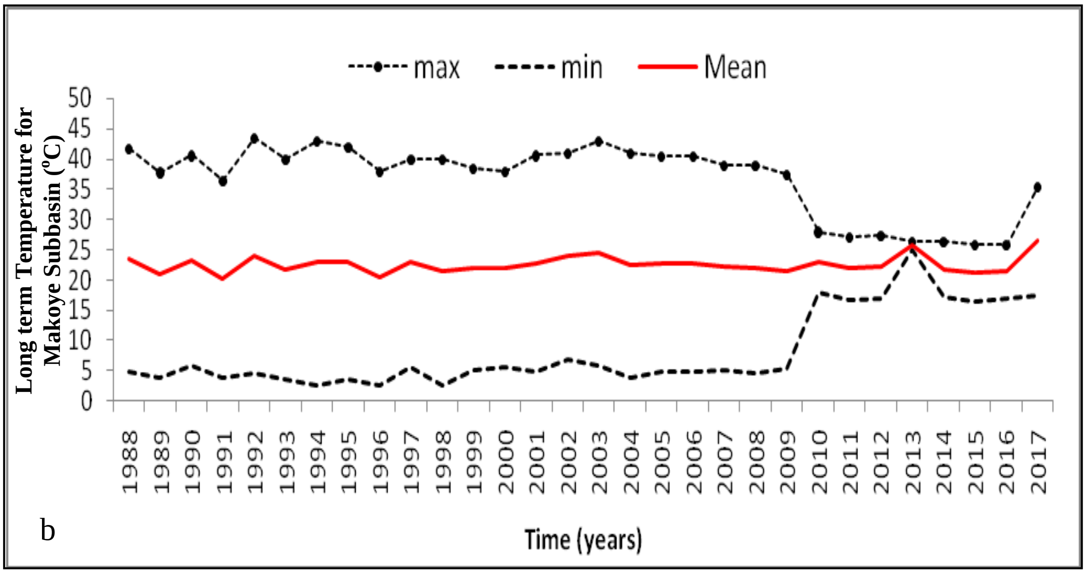


Figure 8: (a) Total annual rainfall and moving averages and (b) average annual max (maximum)- and min (minimum) temperature and moving average trends for Makoye subbasin. (NASA, 2017).

3.1.3 Hydrology

According to Sichingabula (2018), there are over 96 reservoirs in Monze District (Figure 9 and Appendix A) with varying sizes ranging between 40,000 m^2 and 90,000 m^2. Makoye Reservoir is located on the Rusangu natural depression channel, one of the tributaries of Magoye River (main drainage system) within the Magoye catchment (Department of Water Affairs (DWA), 2014).

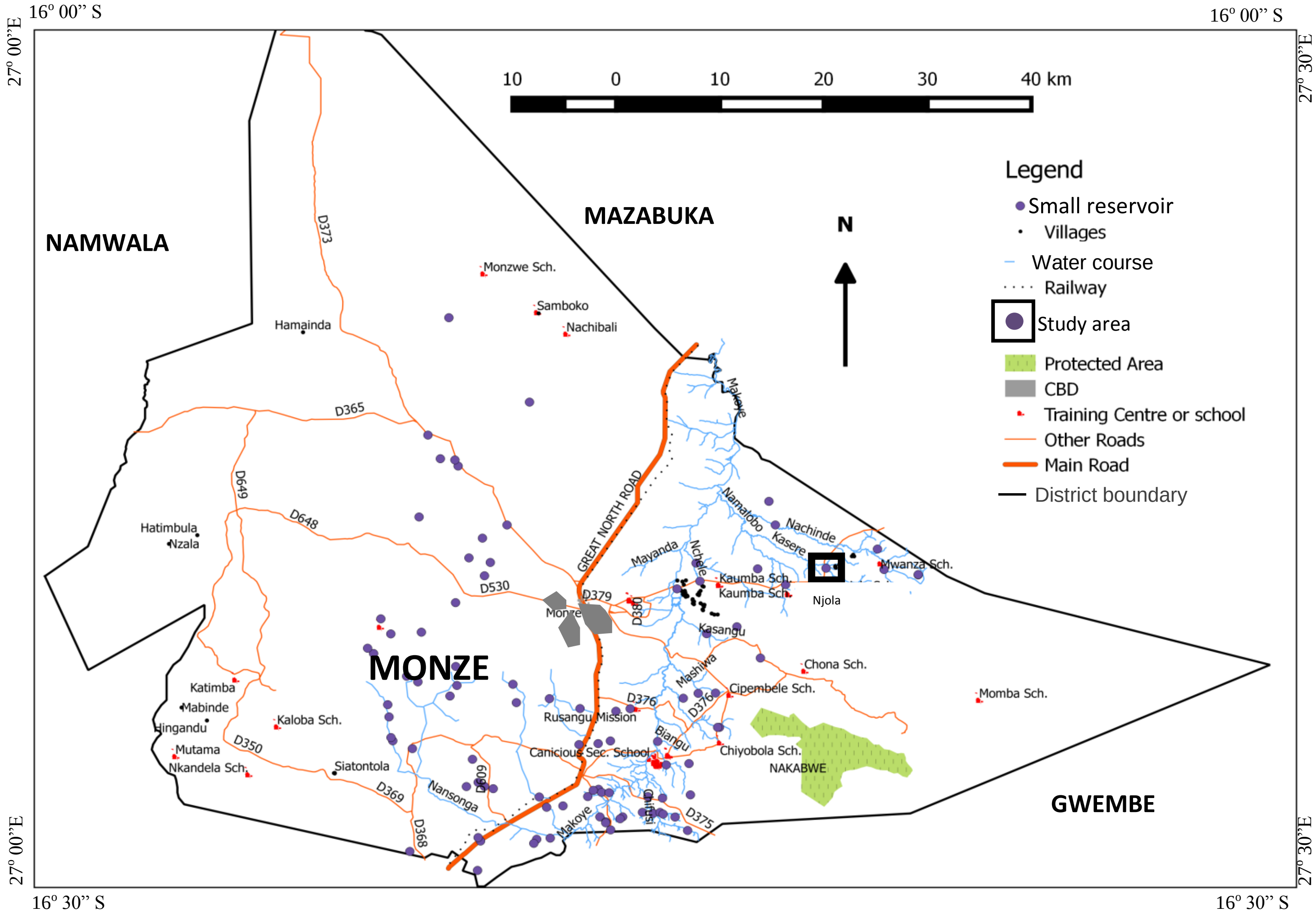


Figure 9 : Distribution of small reservoirs in Monze District. Adapted from Sichingabula *et al.* (2014).

3.1.4 Geology

The general geological structure of the study area is predominantly underlained by the Zambezian Belt in the north, north eastern, south and central parts. It also constitutes the Middle Peterozoic that is made up of the metamorphosed pelites, micaceous and psammites (Figure 10) (Geological Department of Zambia (GDZ), 2013). The eastern, southern and much of the western parts are covered by Palaeozoic to Recent geological characteristics. The south is underlain by metamorphic pre-Cambrian Basement rocks intruded by granites, Karoo (Permian-Triassic) sedimentary and basalt rocks, Pleistocene deposits, ferricrete and alluvium (Money, 1978). The south-eastern fringe also has some traces of the Karoo supergroup, which includes Upper Carboniferous to Jurassic continental clastic sediment (Geological Department of Zambia (GDZ), 2013). The mean altitude above sea level of the study area ranges between 1070 m and 1166 m (GDZ, 2013).

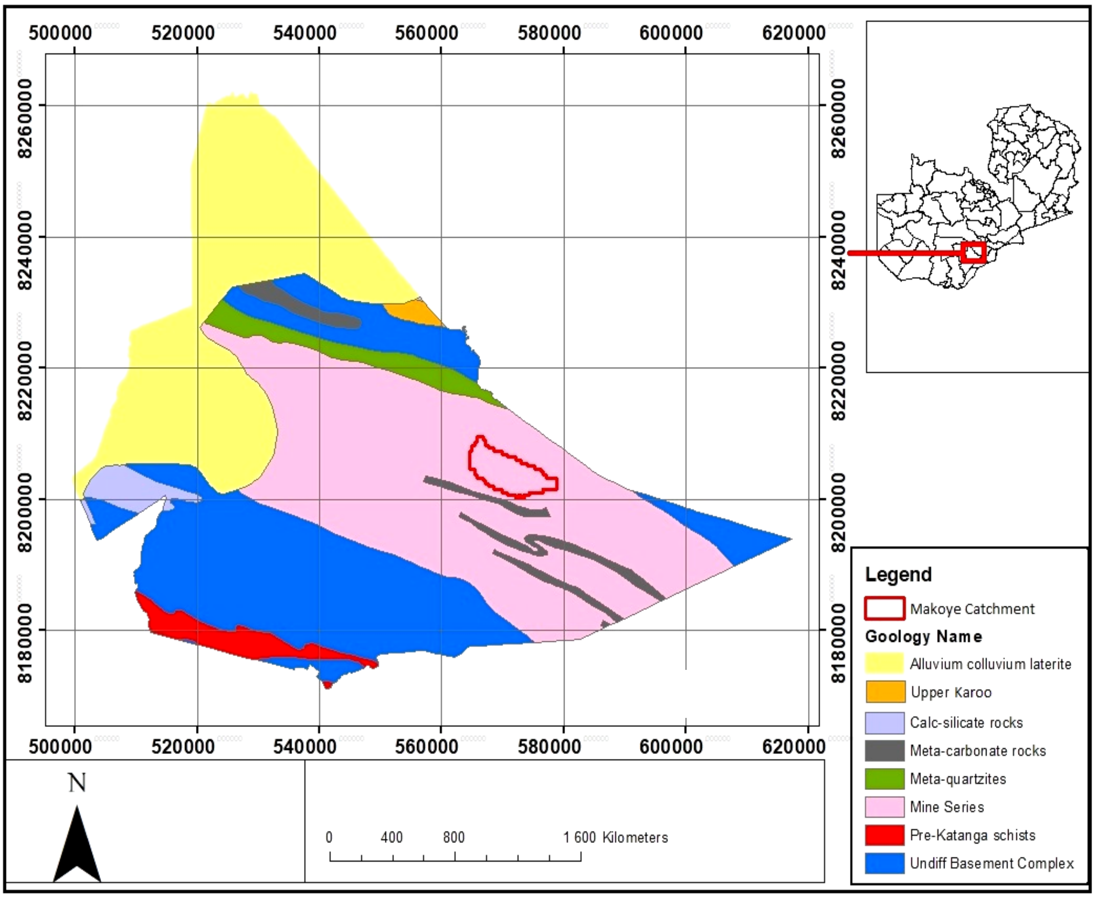


Figure 10: General geological orientation of Makoye Catchment in Monze District, Zambia. Digitised from GDZ base map (2013)

3.1.5 Soils

Pedogenic system of the study area is made up of two soil types namely, Orthic ferralsols and Chromic Luvisol (FAO, 2007; Zambia Agriculture Research Institute (ZARI), 2016). About 10 percent of the Makoye subbasin is covered by Orthic Ferralsol, which means that Chromic Luvisol is the most spatially distributed (90 percent or 59.94 km^2 of the subbasin) (Table 3).

Table 3: Main characteristics of the soils in the Makoye Reservoir subbasin, Monze District, Zambia

Soils	Main characteristics and Susceptibility to Land Degradation
Orthic Ferralsols	classic red soils of the tropics
	high in iron content sandy loam to a clay
	low supply of plant nutrients and favourable infiltration rates
	not therefore impacted greatly by erosion
	have strong acidity and with good porosity and permeability
	have low resilience and moderate sensitivity
	low levels of available phosphorus
	easily lost topsoil organic matter
Chromic Luvisols	most used by small farmers because of its ease of cultivation and no great impediments.
	but they are greatly affected by water erosion
	easily lose fertility.
	nutrients are concentrated in topsoil
	low levels of organic matter.
	moderate resilience to degradation
FAO (2007)	moderate to low sensitivity to yield decline.

3.1.6 Vegetation and landuse change

The study area is covered by *Brachystegia Julbernardia* and *Isoberlinia* collectively known as southern Miombo (Muyombo) Woodland (Fanshawe, 1971). It is also endowed with Zambezian Woodland and Mopane Woodland *(colophospermum)* (Storr, 1995; Fanshawe, 1971). In the southern fringes of the area, there are some xerophytic plants such as Baobab (*Adenosine digitata)* adaptive to arid conditions (Storr and Storr, 1995). C*olophospermum* covers the low-lying Zambezian Belt with Acacia species such as *nigrescens, polyacantha, albida, sieberana* dominating in selected parts of the west and southwest. Other species include *borassus aethiopum* (fan palm) and others. The catchment is generally a grassland area and forms the range lands where animals graze (Fanshawe, 1971; Storr and Storr, 1995). Between 1990 and 2017, land use of the Makoye catchment has undergone changes with vegetation reduced by 47 percent, wetlands by 98 percent and grassland by 93 percent due to settlement and domestic agricultural expansion (United States Geological Survey (USGS), 2018), which may have punctuated sediment generation, transportation and deposition into reservoir and other water bodies (Figure 11).

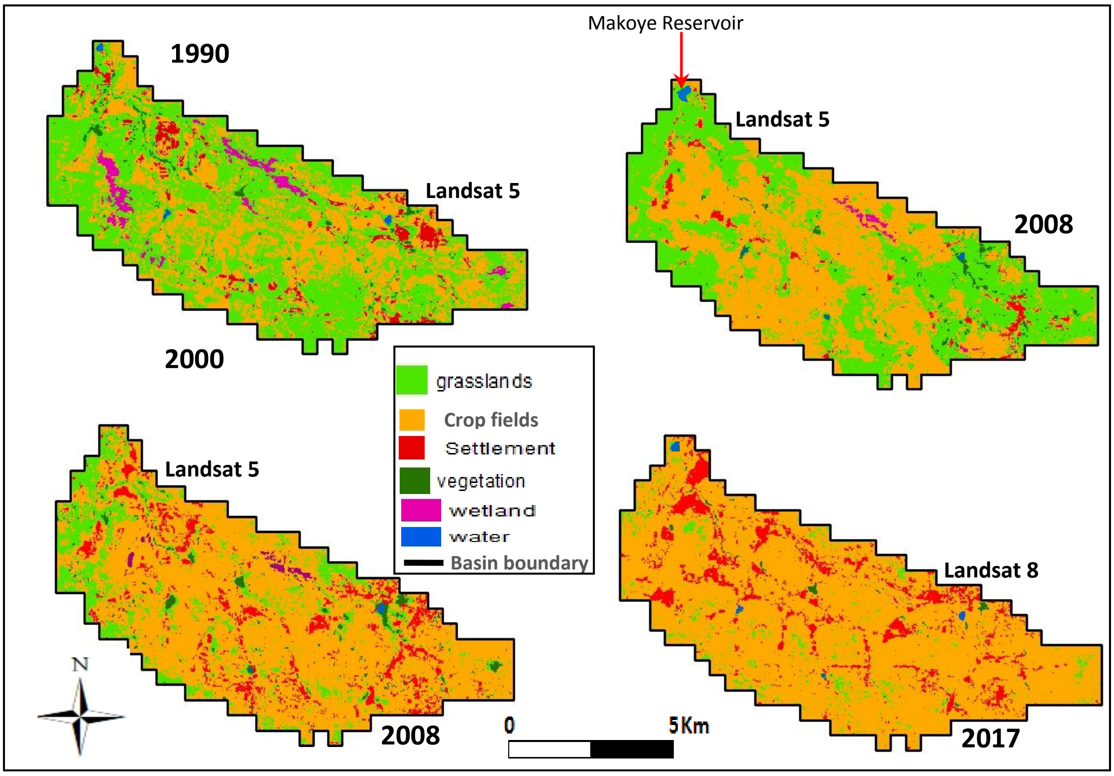


Figure 11: Landcover changes of the Makoye Basin from 1990 to 2017 using Landsat Satellite images
USGS (2018)

3.2 Socio-economic characteristics

The population of households that depends on the Makoye Reservoir is about 474 and most of the settlements are either dispersed or linear in nature (MFL, 2016). About 90 percent of households in the basin depend on livestock farming, keeping about 10,000 cattle that depend on the Makoye Reservoir during most parts of the year (MLF, 2016). Other households are engaged in crop farming, market gardening ad brick moulding (MLF, 2016). This means that the reservoir must be conserved from excess sedimentation to ensure sustainable supply of water.

3.3 Justification for selection of study area

Sichingabula (1997) recommended further detailed quantitative study of sedimentation problem. The catchment areas does not receive sufficient rainfall because of being partly located within Ecological Zone-I, which is prone to drought conditions coupled with rapid large-scale sedimentation. Since all households depend on Makoye small reservoir for their livestock, surveying the levels of sedimentation provided baseline for decision making on rehabilitation, maintenance and management of the reservoir and safeguarding the livelihood of the local people. Moreover, Makoye Reservoir serves all its surrounding catchment during water stressful period.

3.4 Chapter Summary

Chapter Three has presented the physical and socio-economic characteristics of the study area. The chapter has shown that Makoye Reservoir is found in Njola area of Monze East in Southern Zambia between 16°14'08.4" South to 16°15'06.8" South and 27°40'52.8" East to 27°42'49.8" East. Makoye Reservoir catchment is domiciled within the Magoye Catchment in the south-eastern part in ecological region-IIa with some erratic rainfall conditions. The mine series is the main underlining geological system. Pedogenically, about 10 percent of the Makoye subbasin is covered by Orthic Ferralsol and 90% of Chromic Luvisol within the 59.94 km^2 of the Makoye Basin. The study area is covered by *Brachystegia Julbernardia* and *Isoberlinia* collectively known as southern Miombo. Pastoral farming was the main socio-economic activity. However, small scale market gardening and maize farming were also a source of livelihood. The Makoye Reservoir Basin had undergone drastic landcover change between 1988 when it was first renovated and 2017 during which the bathymetric and sedimentation measurements were done. Much of the land within the basin had been taken by farming activities, which inherently punctuated sedimentation in the Makoye Reservoir.

CHAPTER FOUR: PHILOSOPHY OF SCIENCE, RESEARCH METHODOLOGY AND METHODS

This chapter describes methodological approaches that were used to collect, process and analyse the data. It will start by briefly explaining the philosophy of science behind the proposed study as well as the main research design used. Thereafter, particular emphasis will be placed on population, sample and sampling methods. It also shows the methods and tools used to collect primary and secondary data just before the subsection that shows method of analysis as well as methods of data validation and study limitations, respectively.

4.1 An overview of philosophy of science behind the study

An important part of academic research process involves ensuring that the methodology and methods used are consistent with the ontological and epistemological assumptions of a particular philosophy of science (Guba, 1990). Saunders *et al.* (2007:100) add that, "questions of research design and methods are secondary to questions of paradigm or philosophy". Philosophy of science or paradigm is defined as the basic belief system or world view or philosophical perspectives that guide scientific investigation, not only in choices of methods, but also in ontologically and epistemologically fundamental ways (Saunders *et al.*, 2007; Muchanga, 2020). The methodological framework of this study was guided by a research paradigm known as Critical Empirical Analytic. It developed out of merging of 20th Century work on the logical foundations of mathematics with work on foundations of the physical sciences (Harvey, 1969; Sheppard, 2001). The empirical dimension in Empirical Analytic refers to the goal of inquiry which includes definition, prediction, control and scientific explanation of physical phenomena (Reeves, 1996). The analytic aspect of this paradigm reflects a belief in deterministic reality whereby parts can be separated from the whole, and cause and effect relationships among parts can be revealed (Reeves, 1996; Harvey, 1969). Empirical Analytic is a school of thought that promotes use of quantitative methods and techniques in understanding phenomena because it stems from a reliance on measuring variables and analysing relationships among them using appropriate mathematical models and/or statistical techniques. However Critical Empirical Analytic does not embrace rigidity that is found in pure positivism because it is a post-positivist paradigm that allows for control of variables and integration of some elements of qualitativity so as to obtain desired results (Rodgers-Bridges, 2013; Lotz-Sisitka, 2013).

4.1.1 Epistemological assumptions

Epistemology is the philosophical and theoretical study of how knowledge is acquired (Makumba, 2009). The epistemological assumptions of the study were as follows:

i. Knowledge should be generated based on the principles of determinism. Determinism means that phenomenon (for example, state of water quality) are caused by other circumstances (landuse, soil or sediment chemical properties), and hence, understanding such causal links is necessary before arriving at scientific conclusions (Lotz-Sisitka *et al.*, 2013).

ii. The knowledge being generated should be approached with critical empiricism, which means collection of verifiable pieces of evidences in support of claims and conclusions. For example, bathymetry of the reservoir was iteratively and inter-seasonally measured five times (two at peak flow, two at medium flow and one at low flow) in order to improve the accuracy of the conclusion about the bathymetric state of the reservoir.

iii. Knowledge should be created in a parsimonious way possible. This means explanation of the phenomenon in the most precise and straightforward way possible (Cohen *et al.*, 2000).

iv. Knowledge should be generated premised on rationality, which is the scientific principle that, knowledge should be based on objectivity of thought (Cohen *et al.*, 2000). As far as possible, the knowledge created in this study was generated with humanly possible objectivity so as to minimise any personal biases.

4.1.2 Ontological Assumptions

Ontology refers to nature of reality that emerges from a science and how it must be viewed (Lotz-Sisitka *et al.*, 2013). The ontological assumptions of this study were as follows:

i. The reality behind the knowledge generated in this study is material meaning that it is observable by other would be researchers. For example, any other scientist should be able to observe that Makoye Reservoir has lost its storage capacity due to sedimentation. However, this should not mean that the findings are rock solid and not challengeable by studies that may be done afterwards. For example, results such as concentration levels of selected chemical and physical parameters of water are stochastic and may undergo some changes within shortest laps of time and change in landuse. Nonetheless, as long as the basin characteristics remain the same, almost the same levels of chemical concentration should be observable.

ii. The nature of reality in this study should be treated as independent of the researcher's subjective notions. This means that no individual opinions of what reality should be influenced the creation of that reality but the measured data brought out the existing reality. Even some social perspectives that were solicited from the reservoir users were those which would resonated with those physically measured.

iii. The other ontological assumption of the study is that, reality generalisable and not only confined to one specific context (Lotz-Sisitka *et al.*, 2013). Knowledge in this study was created based on the principle of generality which refers to the process of generalizing the observation of the particular phenomenon to the world at large (Reeves, 1996). For example, one of the final products of this study such as the synthesis 3D conceptual model is applicable and adaptable to other contexts outside the study area as long as they share similar characteristics. Even the reservoir management strategies generated in this study apply to other reservoirs and basins that share similar characteristics.

The rationale for using empirical analytic as a guiding philosophy of science in this study was based on its flexibility to support a systematic and quantitative knowledge generation process and analysis which is essentially to enhance objectivity in the description of variables and the discernment of the relationship among them. Going by Rodgers-Bridges (2014), the other advantage of using critical empirical analytic unlike pure empiricism is that, it allow parametric controls so as to improve outputs and allows simultaneous use of qualitative and quantitative strategies where necessary. For example, in selected instances, SWAT-based regression models were improved by eliminating outliers so as to optimise predictive power of the models. Moreover during the preliminary generation of population of reservoirs some qualitative sampling strategies were employed whilst still remaining within the framework of empirical analytic. A critically engaged philosophical exposition is presented after discussion of all results so as to establish the nexus between the philosophy of science adopted and the study findings.

4.2 Research design

This study was guided by quantitative research approach, particularly, Analytical Experimental Design (AED) (Gray, 2004). AED is defined as a research design that seeks to understand physical phenomena using mathematical models or functions, statistical techniques and models in order to confirm relationship among such phenomena being investigated (Gray, 2004). Gray (2004) further argues that, what determines whether a study is analytical or descriptive; is either the size of parameters to be measured or analytical methods and techniques adopted. AED was instrumental in carrying out field experimental analysis of multiple parameters in view of reaching conclusions (Gray, 2004).

4.3 Target Population

The initial target population included 96 small reservoirs (Appendix A) in the Magoye catchment of Monze District of Zambia. The reason was based on an observation by Sichingabula (1997) that most small reservoirs in Southern Province and particularly Monze District are at risk of losing their useful life due to sedimentation.

4.3.1 Generation of the general target population

At the beginning of the study, the actual number of small reservoirs was not known. To generate it, reconnaissance survey of small reservoirs in Monze was conducted with the aid of the SASSCAL 109 Research Team (Sichingabula, 2012). Exponential Non-Discriminative Snowball Sampling (ENDSS) technique was used to generate the database of small reservoirs. Castillo (2009) defines ENDSS as a non-probability sampling process where a identified member provides reference of at least two or more similar objects or subjects. This way, the size of the sample grows exponentially and a large population or sample size can be achieved after reaching a saturation point. Applied in context, a reservoir was being identified together with key informant (its owner or stewards) who would provide information about it. Thereafter, key informants were requested to refer the researcher and assisting team to other known small reservoirs so that the number would increase exponentially. This was significant in order to generate the entire population of reservoirs in the catchment. During this phase of populating reservoirs, all reservoirs referred to were recorded. Figure 12 illustrates how 96 reservoirs were generated using ENDSS.

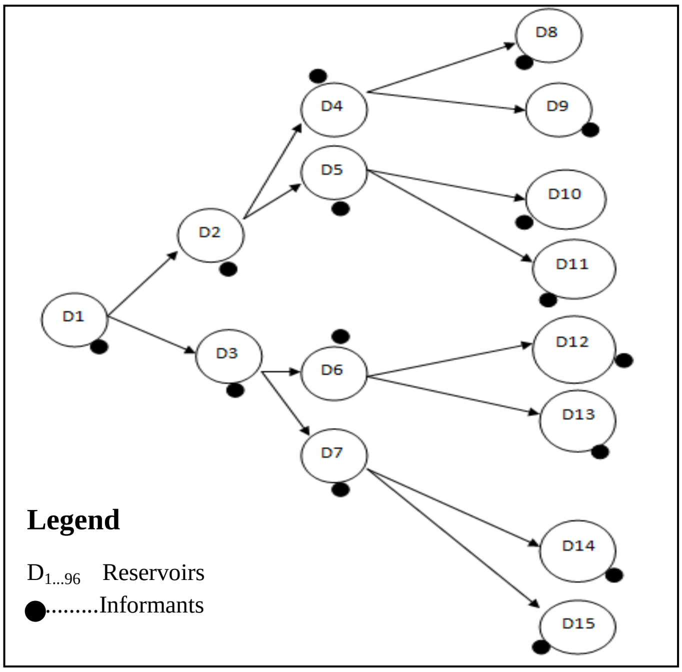


Figure 12: Illustration of how the general target population was generated.
Adapted from Castillo (2009).

4.3.2 Generation of the specific target population

After mapping 96 small reservoirs through ENDSS, Exponential Discriminative Snowball Sampling (EDSS) technique was applied to separate small reservoirs that were annual (dried up during hot-dry seasons (Table 4) from those (86/96) which were perennial. Castillo (2009) defines EDSS as a process where initially one sample is identified and thereafter provides opportunity for identification of two or more references of similar subjects or objects, out of which at least one subjects or object must be selected for further investigation, whilst the others are put aside. EDSS was essential because it enabled putting aside (discriminating) all perennial small reservoirs and to focus only on those which were annual, which finally constituted the final target population. EDSS therefore, provided opportunities to put aside (discriminate) 86 small reservoirs that did not meet the criteria. The suitability criteria was based on reservoir's susceptibility to drying up during hot-dry season because achieving objective two of the study (to determine the long term quantity of sediment deposited in the reservoir) required complete drying up of the reservoir since there was no equipment (sediment corer) that could sample sediment depths whilst water was still in the reservoir. The 10 small annual reservoirs (Table 4) constituted the final specific target population from which the sample was taken. The essence of using snowball sampling was to record as many reservoirs as possible into the target population, which was initially not known.

Table 4 : Specific target population of annual small reservoirs

No.	Name of small reservoir	Geographical Coordinates	
		South (^{o})	**East (^{o})**
1	Chuuka	16.25937	27.66139
2	Nampeyo	16.32823	27.63896
3	Chokole	16.2102	27.78112
4	Choombwa	16.21518	27.75028
5	Gilbert	16.25611	27.58404
6	Makoye	16.24397	27.69791
7	Kaumba	16.22603	27.74431
8	Choobe	16.45792	27.53704
9	Kaya	16.08838	27.43014
10	Moonzwe	16.96706	27.38322

Field Surveying (2013-2014)

4.4 Sample size

The study focused on one small reservoir which was randomly selected from among those reservoirs listed in Table 4. The reasons for sampling only one reservoir were as follows: firstly, there were too many parameters which this study investigated in details, such that doing more than one would fiscally and methodologically prove futile. Moreover, one of the methods of sampling sediment using grass carpets (Szmytkiewicz and Zalewska, 2014) required full warm-wet season camping on site and recording for various storm events. It was therefore, not practical to do other reservoirs because rainfall events took place at different times and sometimes at the same time within or outside the big catchment. The methodology used to measure real time sediment data input for SWAT simulation would not allow more than one reservoir. Moreover, available resources and tools would not allow hiring additional support staff to camp at other reservoirs other than the one sampled. The following section describes how one reservoir was sampled.

4.5 Sampling design and techniques used to select a small reservoir

The study employed a probability sampling design. According to Bryman (2008), probability sampling design is sample selection approach where all units have equal probability of being selected into a sample. Specifically, Simple Random Sampling Technique (SRST) (Bryman, 2008) was used to select one small reservoir from among the shortlisted 10. Each of the 10 shortlisted small reservoirs was tagged with a number as shown in Table 4, thereafter simple rotary method was used to select one (Makoye Reservoir) (Bryman, 2008). This technique was cost effective and more user friendly as compared to other techniques. Figure 13 summarises the process.

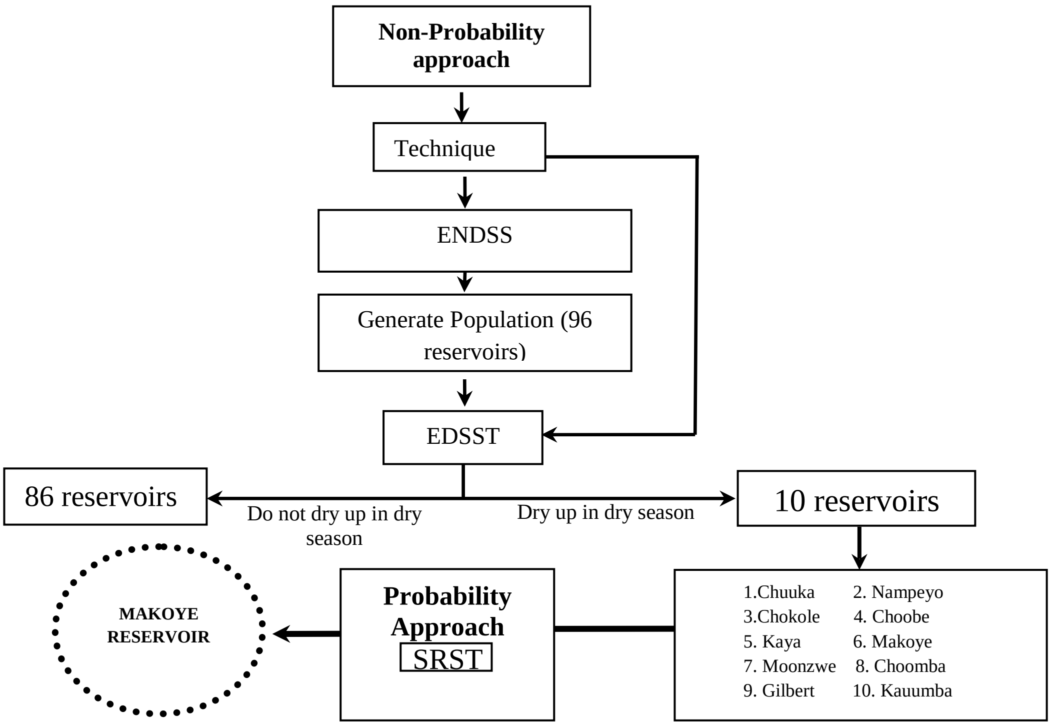


Figure 13: Process of generating specific target population and study sample

4.6 Materials and equipment for collection of different types of primary data

This study gathered different types of primary data in line with the specific objectives. RCHSB Model RC-S2 mounted with Trimble Hemisphere OmniSTAR VBS for DGPS was employed to conduct bathymetric survey of the reservoir so as to measure and collect water depths and bed profile, which were later used to derive water volume, reservoir capacities and hydro-hypsometric curves (Objective 1). The process of setting up the equipment is summarised in Figure 14a, which also shows how measured bathymetric data was displayed in Figure 14b.

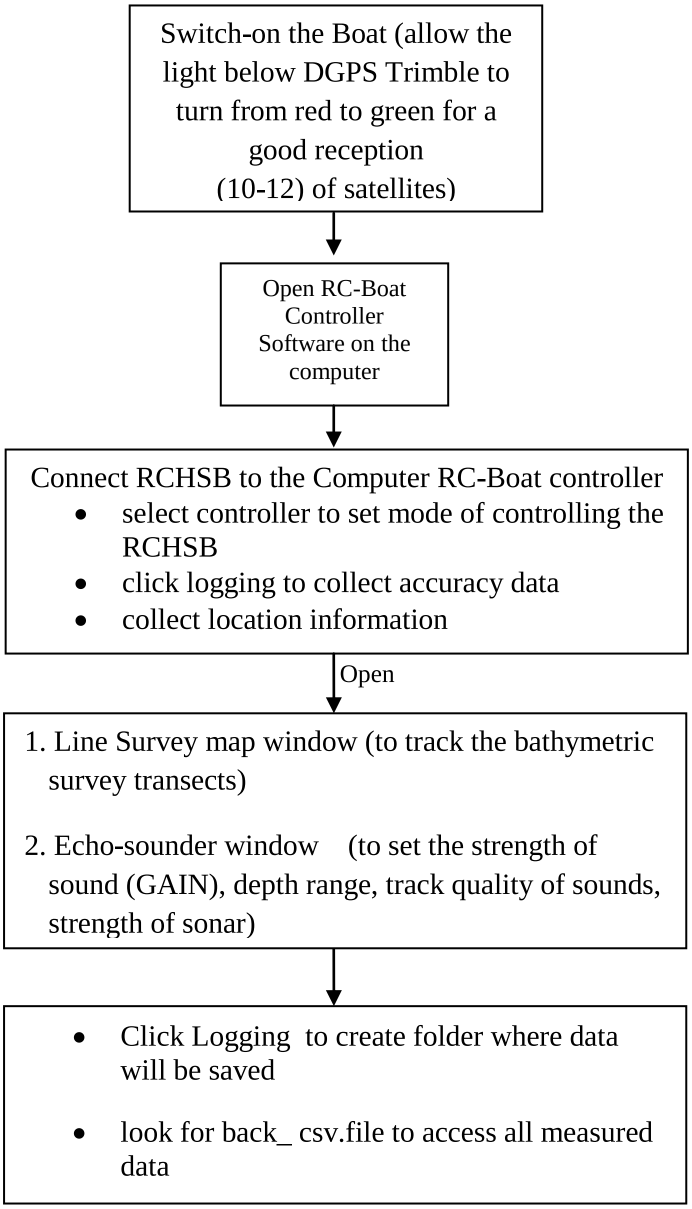


Figure 14 (a): Process of setting up the equipment before deployment for bathymetric survey

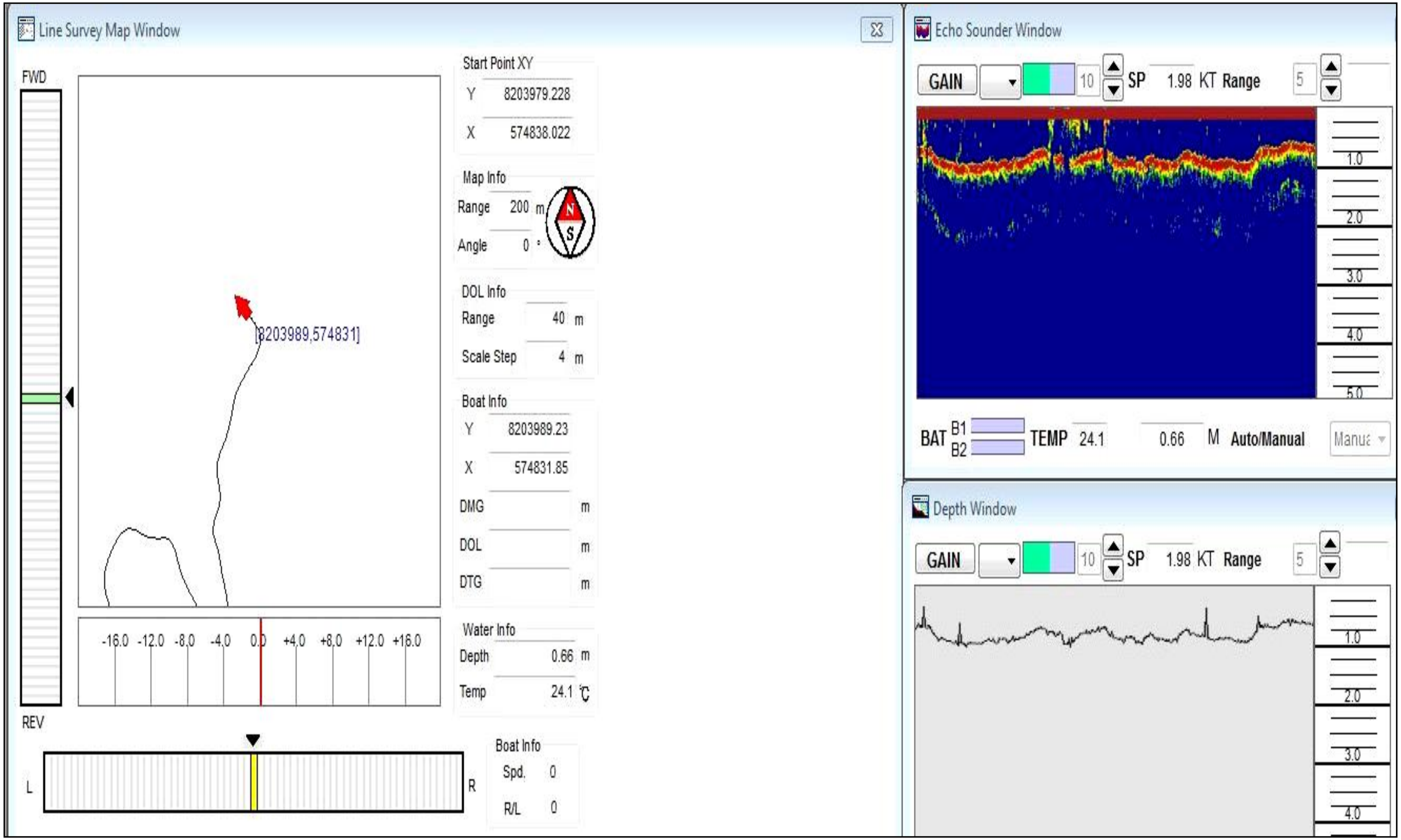


Figure 14(b): Bathymetric survey window. (Eco-sounding window screenshot).

After a successful set up of the RCHSB model RC-S2 boat, XY coordinates were collected using boat's inbuilt DGPS. These coordinates were immediately used to derive location accuracy data using Equation 12 developed in excel spreadsheet template (applicable to a wider context). This was done to ensure that coordinate errors during bathymetric surveys were extremely minimised to centimetres or millimetres accuracy.

$$A= \sum(\sqrt{((X_{i......nth} - XMEAN)^2 + (Y_{i......nth} - YMEAN)^2)})/N \qquad (12)$$

Where:

A	Ground accuracy;
X	All individual X coordinates in UTM;
XMEAN	Mean for X coordinates;
Y	All individual Y-coordinates in UTM;
YMEAN	Mean for Y coordinates; and
N	Total number of paired X and Y coordinates.

After capturing accuracy data, bathymetric survey commenced and this was done by dragging the RCHSB-Model RC-S2 across the reservoir whilst tied to an inflatable boat driven by an outboard engine. Where the inflatable boat could not move by engine, paddling was used and where paddling was impossible because of inaccessibility, RC-S2 was connected to the boat controller software on the tough book laptop so as to remote control it to reach sections which were not possible to reach physically. Bathymetric data of the reservoir was collected five times as follows: twice at full level (3/3/2016 and 17/2/2017), twice at medium level (19/6/2016 and 14/7/2017) and once at its low level (20/8/2015).

Water depths were collected automatically through the inbuilt SONAR of the RC-S2 and were registered in the back_csv.file. After each bathymetric survey, wetted perimeters were measured by walking around the reservoir whilst holding the DGPS on the RCHSB-Model RC-S2 which was automatically sending records of perimeter coordinates to the created folder on the laptop computer. This was useful in determining the boundary of reservoir water extent and in the final analysis using

Arc-Geographical Information System (ArcGIS). RCHSB-Model RC-S2 was very instrumental in this study because it is designed for quick deployment and use in shallow waters and hard to reach areas of water bodies like Makoye Reservoir. It was also temporally and economically cost effective because it drastically reduced the time that would otherwise be needed if traditional manual methods of bathymetric surveying were to be used (CODEN, 2014). Plates 1a-b show some visual impressions of bathymetric data collection.

Plate 1: (a) Eco-sounding of water depth and bed morphology and (b) collecting water perimeter at Makoye Reservoir, 2017.

Data collection process on Objective 2 (to quantify the long-term sediment deposited in Makoye Reservoir) involved two phases. The first phase (2014) involved collection of sediment depths (Z-data) by digging pits along various transects across the bed of reservoir during dry season during which it dried up. The process involved making transects (4-5m apart) across the dry bed of the reservoir with the aid of ranging poles and measuring tapes.

Universal Transverse Mercator (UTM) XY coordinates were recorded for each pit on the dry bed of the reservoir using the DGPS on the RC-S2 boat. A total of 195 sediment pits were dug at each point using picks, augers, and shovels. Depth (Z data) of each pit was measured using a measuring tape carefully aligned to the ranging pole. Being a tedious process, assistants from surrounding community were hired to help in the digging of 166 pits across the reservoir bed at five metres intervals.

In the second phase, all measurements (XYZ data) were recorded on the sediment data collection form and later transferred into Microsoft excel spreadsheet before volumetrically and gravimetrically quantifying sediment. Objective 2 also required collection of sample of a section of undisturbed fully compacted deposited sediment using iron sediment corers and a hammer. This was useful in determining the bulk density of sediment and eventually to estimate the weight of sediment based on its volume. Deposited sediment core was also useful for physico-chemical characterisation of sediment deposited in the reservoir and particle size analysis. Sediment coring method has been widely used in previous studies (Brunner, 2012; Sichingabula *et al.*, 2014) and it proved to be cost effective and readily available for this study.

To capture eight samples of sediment transported by surface runoff, PVC grass carpets were used, Winchell *et al.*, (2013) earlier used this method. This was done during the two warm-wet seasons of camping at the study site. Grass carpets were overlaid on industrial plastics (at runoff entry points to the reservoir) with the aid of cap nails. After each flood event, grass carpets were collected from where they were installed and thoroughly washed in a bucket full of water so as to remove sediment. The sediment suspended in water was left to settle down and afterwards, water was decanted to harvest settled sediment which was regularly transported for laboratory storage. These samples were useful in physico-chemical characterisation of sediment in motion and later, in the analysis of the relationship between physico-chemical properties of moving and deposited sediment and those of water in the reservoir. The chemical and physical properties of selected moving sediment samples were measured at the Soils Science Laboratory of the University of Zambia.

Water scooping was another method used to capture samples of moving sediment for physico-chemical parameter analysis in the laboratory and further comparisons with other samples. Water was scooped from the channel at the point where it deposited its water into the reservoir's throwback. After settling of sediment on the bottom of the scooper, water was decanted and sediment allowed to dry and safely kept for laboratory analysis of chemical and physical properties. The idea behind this was to compare and contrast physico-chemical properties of sediment that entered the reservoir and to establish their sources. This necessitated soil profile sampling around the subbasin at 50cm depth. Given the uniform characteristics of soils and landuse in the subbasin, three samples of soil were collected from the agriculture fields, grazing areas and another section with mixed land use (grazing and crop farming). Physico-chemical properties were measured in the laboratory so as to compare them with those of sediment for final establishment of the sources of sediment. Plates 2a-b partly present a pictorial view of how the data on Objective 2 was collected.

Plate 2: (a) Digging pits to determine sediment depths on the dry bed; and (b) collection of a sediment core sample from the Makoye Reservoir bed.

Data on Objective 3 (to determine sediment settling rate in the Makoye Reservoir) was collected using a Sedimeter-SM3A. The SediMeter is a "sediment meter" that measures vertical sedimentation profile - using 36 Optical Backscatter Detectors (OBD) - through the bottom, and calculates the level with resolution of 0.001 mm (Erlingsson, 2018). Its deployment involved turning it on and setting up the date and time it would start measuring, as well as temporal interval of measurement with the aid of its accompanying software installed on the laptop. Whilst Figure 15 illustrates the process involved to use the equipment, Plate 3a-f presents a pictorial view of sedimeter installation and data view window, respectively. Due to clayish and muddy reservoir bed, the sedimeter was tied to the angle bar (instead of drilling it into the bed as prescribed in the manual) deeply inserted in the reservoir bed with aid of a heavy duty hammer.

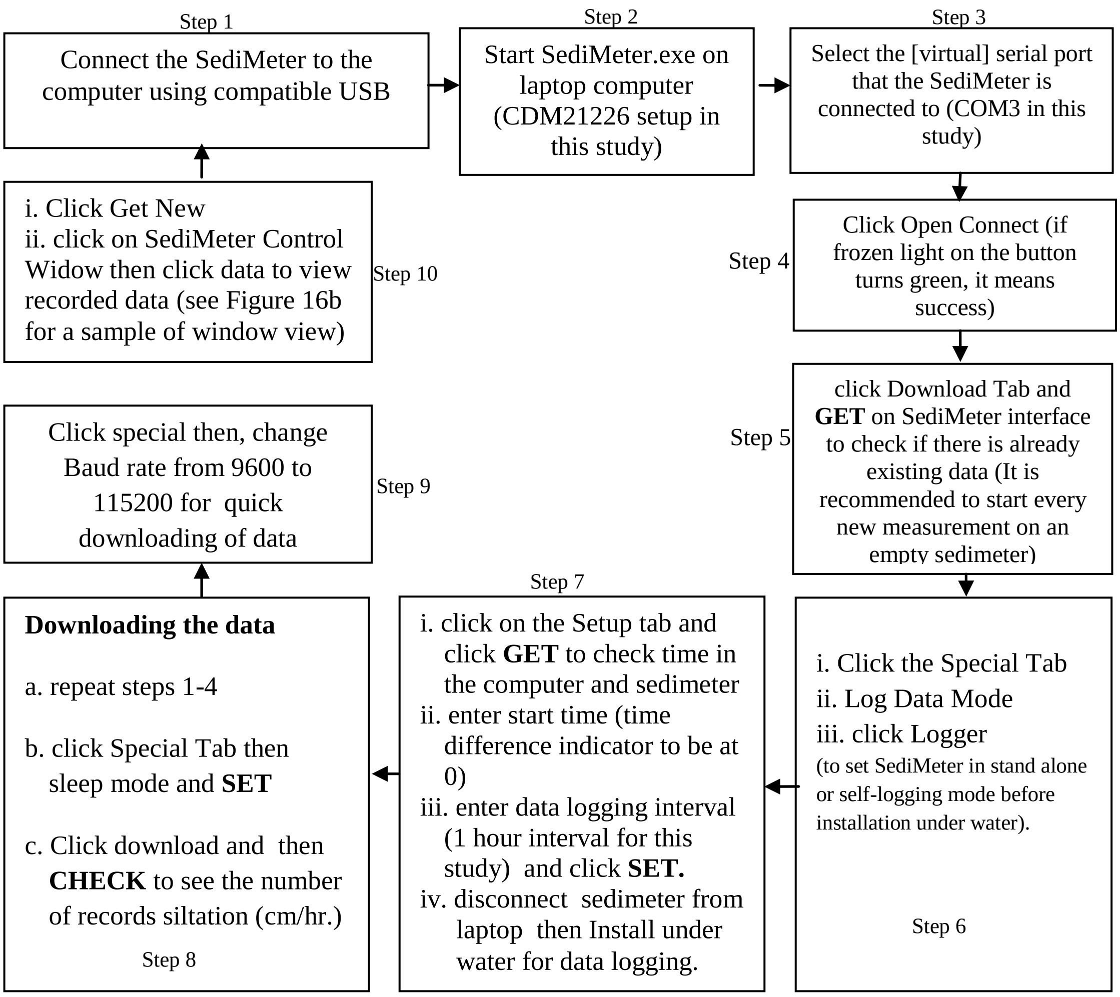
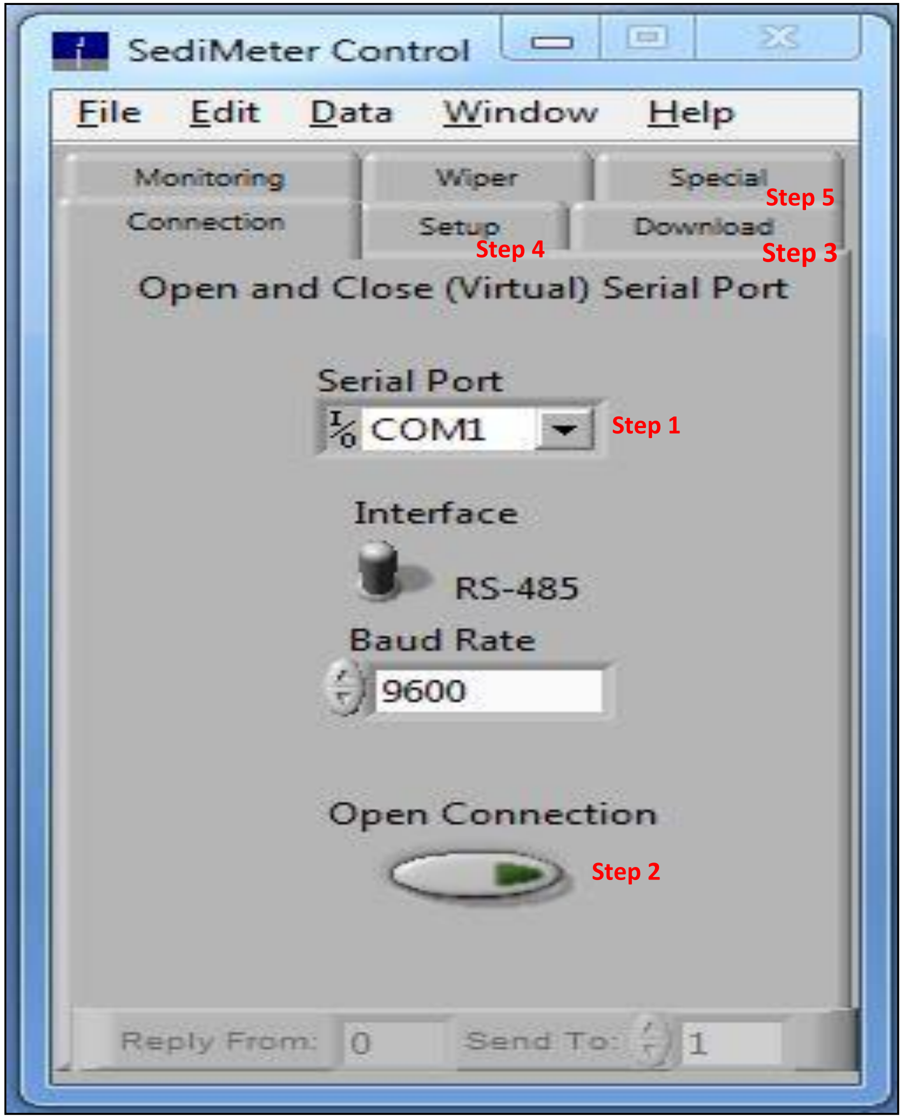


Figure 15: Illustration of how the sedimeter was setup for real time sediment depth measurements.

Plate 3: (a) Candidate preparing SediMeter for deployment as Supervisor looked on;
(b) Deploying the Sedimeter under water ; (c) Getting from under water after successful installation of the sedimeter; (d) Inspecting the recorded data after the measurements at Makoye Reservoir.



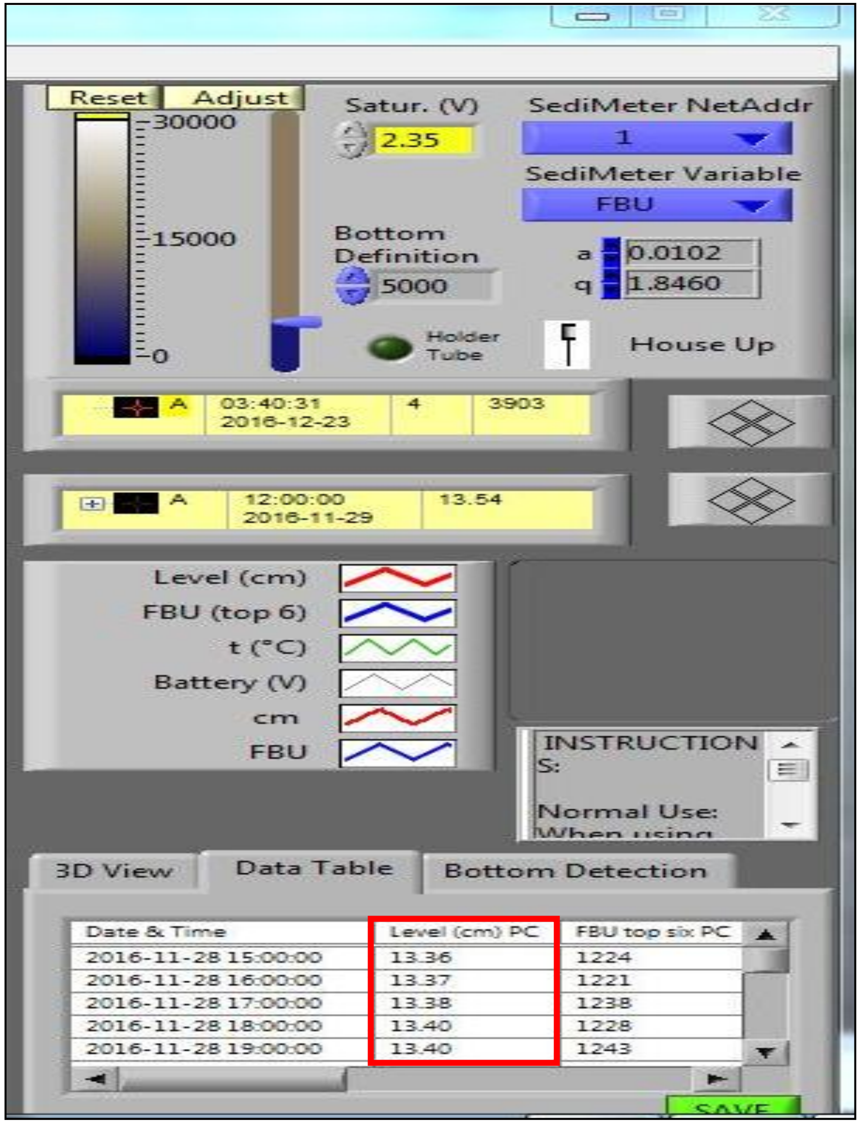


Plate 3: (e) SediMeter Control Window; and (f) SediMeter data view Window.

Physical diving under water was prerequisite in order to properly tie and fix the equipment. During the first camping rainy season (2015/2016), the tool was centrally installed for four weeks as soon as the level of water reached a depth of >1 m in order to protect equipment from heat, and it was under the guardianship of two research assistants. During the second phase of camping, the equipment was installed in the reservoir for 13 weeks, from 22 November, 2016 to 17 February, 2017). This tool was very useful for this study because it helped to monitor hourly sediment settling rate or accumulation in real time.

The other merit with this equipment is that even though data is not downloaded instantly, it stores it internally for up to over a year during which the data would have been downloaded for analysis. It also helped in collection of extra data on temperature and turbidity levels in the vertical column of subsurface water. Had it not been for this equipment, it was going to be impossible to capture short term sediment depth data, which was used to compute volumes and loads (initially not existent) for SWAT model calibration and validation using SUFI-2 in SWATCUP2012 (Abbaspour, 2004).

In order to collect data on Objective 4 (to examine concentration levels of selected physical and chemical parameters of water in Makoye Reservoir), many stages were involved. Firstly, the researcher together with research assistants camped on the site for the whole of 2015/2016 warm-wet season. The team identified section on the reservoir and throwback from where to collect water samples on selected days. A total number of 24 samples of water were collected from a specific point of the using water sampling bottles. At the peak of the warm-wet season, 10 water samples were collected across the reservoir once on 3 March 2016 with the aid of an inflatable boat, the Global Positioning System (GPS) and a note pad for taking coordinates.

In all instances of water sampling, all bottles of water samples were clearly labelled in order to avoid mixing them up prior to laboratory analysis. Whilst collecting water samples, sampling bottles were completely immersed under water surface and closed tightly whilst still completely submerged in water. This was done in order to evacuate air out of sampling bottles so as to prevent chemical reactions. All collected water samples were then taken to the Environmental Engineering Laboratory at the University of Zambia so as to determine concentration levels of selected parameters.

During phase two of camping in the 2016/17 warm-wet season, the above described procedure was repeated, although it did not involve collection of samples across the reservoir. A total of 36 samples of water were collected because this camping season started earlier than the previous one due to early onset of rains. In the third phase, 13 water samples were collected using the same procedure, but did not involve camping and it was done during the cool-dry season. During phase three, spatially distributed water sampling was also done at the same 10 sampling points using DGPS. During the fourth phase in the warm-dry season, only two samples were taken on the 1st and 30th days of October, 2017. Inter-seasonal sampling was useful in enhancing understanding of inter and intra-seasonal variations and trends in concentration of selected physico-chemical parameters. Plate 4a-d presents a pictorial view of the data collection process.

Plate 4: (a) Soil sampling process on the upstream of reservoir; (b) Preparing Sediment core for shipping to the Laboratory; (c) Onsite extraction of trapped sediment an; (d) preparing for water sampling on the Makoye Reservoir's throwback

4.7 Secondary data and sources of literature

For the purpose of calibrating the hydrological component of the SWAT model, secondary data on river discharge were collected from DWA. Weather data was collected from NASA weather data portal. The DEM was collected from USGS.

The study consulted diverse sources of literature such as journal articles (Lu *et al*., 2013, Adwubi *et al*., 2009; Born *et al.*, 2009; Abbaspour, 2007; Boardman *et al*., 2009; Walling *et al*., 2001, Meade, 1982; etc), books (Gray, 2004; Derbyshire *et al.*, 1979; Goudie and Pye, 1983), and reports (Nissen-Petersen, 2006; Sichingabula, 1996) were consulted. Secondary data that were in line with themes of the study were useful in supplementing primary data and helped in continuous shaping of research ideas (Bryman, 2008). Reviewing of these sources involved critiquing where necessary, comparing and contrasting ideas, methods, approaches and identifying existing gaps in earlier documented works (Leedy and Ormrod, 2001).

Data inputs to simulate sediment (Objective 5) included 90m x 90m Shuttle Radar Topography Mission Digital Elevation Model (STRM-DEM) because it was the one that had accurate variable unlike 30 x 30 m, which failed to process. Soils map was extracted from the 2007 FAO soils map for Africa whose spatial scale was 1:5,000,000. Landuse map was extracted from the raster version of the GlobCover landuse map (GLOBCOVER_L4_200901_200912_V2.3.tif) of 2009 (Louvain University, 2010). Its spatial resolution was 300 m because of its spatial extent. Weather input data (daily rainfall, temperature, humidity, solar and wind speed) were initially collected from ZMD, but due to too many errors and wide data gaps, they were replaced with weather data sets from the NASA web portal (power.larc.nasa.gov/common/Agroclimatology) whose temporal resolution was from 1988 to 2017 (National Aeronautics and Space Administration (NASA), 2017).

The rainfall data captured on site (Plate 5) during 2015/16/17 warm-wet seasons was used to test the suitability of the weather data sets from the NASA web portal. The coefficient of determination was found to be good (r^2=0.61) (Appendix B) between NASA rainfall records and the ones measured onsite (Appendix C) from 2015 to 2017. Since rainfall is influenced by other weather parameters (most of which were not physically measured onsite due to lack of instruments) (Henderson-Seller, 1998), it was assumed that such parameters were also correct by default because of a good r^2 value obtained for the rainfall parameter. Hence, NASA weather data sets were adopted.

Plate 5: Onsite portable rain gauge at the Camp Site- Makoye Reservoir, Monze District, Zambia

The immediate subbasin of Makoye Reservoir did not have a gauging station and even though attempts were made to determine flows using the current meter, it was impossible as water flows were almost always stagnant due to a very gentle slope and poor rainfall. To this effect, the researcher adopted discharge input data which were measured downstream (about 20 Km from the Makoye Reservoir) at Chimbumbu Farm Gauging Station using regionalisation method (Begou, 2016 in West Africa, Amam, 2016 in Vietnam). Although this gauging station also had many discharge data gaps, the gauge heights were up to date (1970-2015 from DWA) and (2016-2017 based on onsite gauge height measurement). The onsite measured gauge heights were used to compute missing discharge based on the long term rating curves. Sediment data used to calibrate the sediment model was derived using real time sediment depth with the aid of a regression model developed from the hypsometric relationship curve between long term sediment depth and volume. Data for Objective 6 was based on Objectives1, 2, 3, 4 and 5.

4.8 Data analysis

Bathymetric data (Objective 1) was analysed using 3D Spatial Analyst Tools (3DSATs) in ArcGIS 10.3. The input data included water depths (Z), XY coordinates measured using Universal Transverse Mercator (UTM) WGS84 format and perimeters of the reservoir at different temporal scales. The reservoir's boundaries (perimeters) were 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 levels, 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.

At last, the best results (with a very strong r^2) display of one of the techniques at 15 to 42 cm intervals was adopted to ensure good interpolation. 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, polynomial hydro-hypsometric curves were created 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 graphs created (Kwast, 2018). The study also considered understanding how bathymetry fluctuated due to processes other than sedimentation. To do this, direct evaporation and evapotranspiration were computed so as to determine how the two processes influenced bathymetric state of the reservoir at different temporal scales. The analysis adapted the FAO (2015) protocol to determine 3-years evaporation from the reservoir as shown in Equation 13.

$$Ev = ET_o \times A \times 10^{-6} \quad (13)$$

Where:

Ev	Dam reservoir evaporation in volume (km^3/year) [2]
ET_O	Reference evapotranspiration in depth (specific to each dam) (mm/year)
A	Reservoir surface area (specific to each dam) (km^2)

ET_O was determined using Penman-Monteith equation in excel template (PMday.xls, accessible at: biomet.ucdavis.edu/Evapotranspiration/PMdayXLS/PMday.xls). This is a very smart and user friendly tool, which helped to reduce the tedious processes of calculating ET_O manually.

Further analysis was done using multiple regression analysis in Microsoft Excel so as to determine the influence of selected climatic parameters (radiation, humidity, temperature, among others) on reservoir evaporation at different times. This was necessary so as to determine the extent to which bathymetric fluctuations could be explained through a diverse climatic factors influencing evaporation.

Data on objective 2 (to measure the long term quantity of sediment deposited in Makoye Reservoir) was analysed using 3DSATs in ArcGIS 10.3. The Input data (XYZ) included the UTM coordinates, sediment depths (m) and boundary of Makoye Reservoir bed. The reservoir bed's boundary coordinates were converted to points and a default Z value of zero was assigned to them. The created reservoir bed's boundary point data were afterwards merged with the sediment depth data using the merge tool in ArcGIS 10.3. The next step involved interpolating a continuous raster surface using raster interpolation tools in 3-D Analyst in ArcGIS 10.3. Sedipleth maps representing sediment distribution were generated for the Makoye Reservoir at 0.2 m intervals to ensure good extrapolation. Sediment Volume (SV) was computed using mix of interpolation tools such as IDW, TIN and NN. Since these produced slightly different results, but within acceptable magnitudes, their averages were computed and used as final figure. Further analysis involved generation of hydro-hypsometric curves in Microsoft excel spreadsheet in order to determine depth-area and volume relationships. Since the reservoir's boundary had zero values representing the reservoir bed surface, the plane height was set to zero and all the sediment depths converted to negative values in meter units. The area and volume was computed at a 20 cm (0.2 m) interval from the surface to the deepest point using the AVT under ArcGIS 3-D Analyst (Kwast, 2018). The computed area and volume associated with each depth were finally organised into tables and hypsometric graphs using Microsoft Excel spreadsheet. In order to compare sediment volume computed using the 3DSATs in GIS Environment, the current study devised an empirical Equation 14. This was useful in the analysis of sedimentation volume by Elevation Change Method (ECM), assuming a V-shaped reservoir.

$$SV = A\left[\frac{((W_e - D_{se}) - M_{wd})}{3}\right] \qquad (14)$$

Where:

SV	Sediment Volume (m^3)	M_{wd}	Maximum water depth near the Crest (m) ;
W_e	Water Surface elevation of reservoir (m)	3	Constant (derived by Sawunyama (2005)) ;
D_{se}	Downstream elevation (m)	A	Total surface area of the bed (m^2).

The volume of sediment obtained through Equation 14 was within acceptable magnitude as the one obtained through GIS 3DSATs. hence the average was considered as the final volume of sediment settled on the bed. In order to determine the gravimetric quantity of sediment in the reservoir, bulk density (weight of sediment per unit volume (United States Department of Agriculture (USDA, 2014)) analysis was first carried out. This was determined using equation 15.

$$\rho_b = \frac{W_d}{V} \qquad (15)$$

Where:

ρ_b	Dry bulk density of sediment (kg m^{-3});
W_d	Weight of oven-dried sediment at 105°C (kg); and
V	Volume of core cylinder (m^3).

Sediment volume obtained through the above method was eventually used in analysis of derivative data on long term sedimentation rate, reservoir storage capacity and useful life based on Anyekulu *et al*. (2013) Equations 16, 17 and 18.

$$SR = SV/y \quad (16)$$

$$LE = RSC/SR \quad (17)$$

$$SY = SV*dBD/y \quad (18)$$

Where:

SR	rate of sedimentation (m^3y^{-1});
y	age of reservoir (year);
LE	useful life or life expectancy of the reservoir (year);
RSC	the reservoir storage capacity (m^3);
SY	sediment yield ($t\ y^{-1}$);
dBD	dry bulk density ($t\ m^{-3}$) (sediment dried at 105°C); and
SV	Sediment Volume (m^3).

After calculating the bulky density, the gravimetric quantity of sediment was computed using Equation 19.

$$S_l = C_w \left(\frac{M_v}{C_v} \right) - W_{wrs} \quad (19)$$

Where:

S_l	Sediment load (tonnes);
C_W	Weight of oven-dried sediment core at 105°C (tonne);
M_v	Measured volume of sediment in the reservoir (m^3);
C_v	Volume of sediment in a core cylinder (m^3); and
W_{wrs}	Weight of water impounded in reservoir sediment (tonnes).

For the sake of estimating the actual weight of sediment deposited on the reservoir bed, the total weight of water impounded (W_{wrs}) in the Makoye Reservoir sediment was computed using the following Equation 20 devised by this study. This was later used to compute the weight into volume as illustrated, later on.

$$W_{wrs} = W_{wsc}\left(\frac{M_V}{C_V}\right) \quad (20)$$

Where:

W_{wrs} Weight of water trapped in the volume of sediment (tonnes);

W_{wsc} Weight of water trapped in the volume of sediment core (tonne);

M_v Measured volume of sediment in the reservoir (m^3); and

C_v Volume of sediment in a core cylinder (m^3).

To estimate the quantity of water required to saturate the total volume of sediment in the reservoir, a fully dried sediment core sample was carefully ground and thereafter, tightly packed in a transparent container. A known volume of water (0.0023 m^3) was continuously and slowly added to the sediment packed in a container until saturation. At this point, the volume of water required to saturate the sample sediment core was estimated. Thereafter, the amount of water that would be required to saturate the total quantity of sediment that accumulated in the reservoir was arithmetically estimated using Equation 21 devised by this study.

$$V_{wsrs} = W_{sc}\left(\frac{M_V}{C_V}\right) \quad (21)$$

Where:

V_{wsrs} Volume of water required to saturate total sediment in water before accumulation of water (m^3);

W_{sc} Volume of water in the sediment core sample (m^3);

M_v Measured volume of sediment in the reservoir (m^3); and

C_v Volume of sediment in a core cylinder (m^3).

The settled sediment in the core cylinder (50cm high) was divided into five equal parts (10cm each). After a laboratory determination of concentration of physico-chemical parameters of settled sediment at each depth, descriptive statistics (Ebdon, 1985) was used to communicate analysed results. Coefficient of Variation (CV=Standard Deviation/Mean) (Jhunjhunwala, 2008) was also used in order to determine variations within and between the different depths along the vertical profile of sampled settled sediment. Sediment core analysis was also useful in ascertaining the landuse changes upstream over the years. Particle analysis also helped to determine the mode of sediment delivery into the reservoir over the years. A similar laboratory procedure and analytical technique of presentation was followed for the soils samples and sediment in-motion harvested using grass carpets. Analysis of soils and moving sediment was useful in establishing relationship between soils-moving sediment chemistry and water-settled sediment in the reservoir. These relationships were determined using multiple regression method in Microsoft Excel. They also helped in tracing the possible sources of sediment that was entering the reservoir. All analyses were done at the Soils Science Laboratory of the University of Zambia.

Before analyzing data on objective 3 (To determine real time sediment settling rate in the Makoye Reservoir), the raw records were transferred into Microsoft Excel to clean out all outliers. In order to obtain the rates of sedimentation in depth per hour, two consecutive level values computed in the sedimeter software were being subtracted in order to determine the difference between them. The resulting differences constituted the absolute depth of sedimentation per hour. The polynomial equations derived from sediment coring method were afterwards used to calculate volume and load of sediment per day and to compute cumulative values from 2014 (when sediment coring was done) to 2016/17 during which real time sediment depths measurements were done. Thereafter, time series in form of trend line graph and bar graphs in Microsoft Excel spreadsheet were used to visualize the data graphically. Regression technique was also used to establish relationship between sediment depths, volume and load. Regression method was further used to establish relationship (Ebdon, 1985) between daily rainfall and real time loading of sediment in the reservoir. This was done in order to project real time sediment loading based on daily rainfall.

To analyse data on concentration levels of selected physical and chemical parameters in the Makoye Reservoir in view of addressing Objective 4, laboratory analysis of collected water samples was done at the University of Zambia Environmental Engineering Laboratory. Laboratory results were further processed using descriptive statistics where data was summarized into thematic tabular matrix prior to running coefficient of variation and standard deviations from where the discussion and conclusion were derived. Some data sets were graphically analysed using Microsoft Excel so as to present quick impression of changes over time. For selected parameters such as TSS and Turbidity, regression analysis was carried to determine relationships not only between them, but also to determine how they related to rainfall events. The turbidity measured in real time using Sedimeter SM3A in the water subsurface (near the bed and near the water surface) was analysed based on the regression model derived from the relationship between laboratory-measured turbidity and TSS of the subsurface water. Differences between daily average levels of TSS were computed in order to determine specific daily quantities of TSS entering the reservoir. The daily average TSS were correlated with daily rainfall so as to develop empirical mathematical models for prediction of daily TSS through daily rainfall in real time.

In order to show how the concentration levels of selected physico-chemical parameters were spatially changing and distributed across the reservoir, 3-D Spatial Analysts tool in Arc GIS 10.2 was used, to be specific, IDW Raster interpolation tool was used. The input data into the GIS Arc Map interface included sampling points; XY coordinates, levels of physico-chemical concentration which were considered as Z data and reservoir's boundary coordinates. This analytical process was useful as it provided visual impression of how spatially distributed some physico-chemical parameters across the reservoir in ArcGIS. Physico-chemical analysis maps were produced for selected parameters. The procedure of creating these maps was similar to that of creating bathymetric maps or sediment map described above, only the inputs were different.

In order to determine the classes and types of water in the reservoir based on the geochemistry of sediment, the hydro-geochemistry of water samples was done using the Piper diagram in combination with descriptive statistics. This method of analysis has been successfully used in recent studies (Manoj, 2013; Shamsuddin *et al.,* 2016; Tiwari *et al.,* 2017). The chemical concentration of selected cations and anions were converted to percentages of the total constituents.

The GW_Chart software was used to input percentage values so as to visualize the general chemistry of water, chemical mixing and the most prominent type of water that was entering the reservoir. The Piper method of analysis was not only useful in the hydrochemical regime analysis, but also in the historical analysis of different landuse that were taking place within the subbasin. Inter-seasonal (warm-wet and cool-dry seasons) Piper analysis was useful in determining seasonal variations in the hydro-geochemical regimes of the reservoir. Percentages were arrived at by dividing each type of mix with the total for all mixes multiplied by 100 percent. In the final stage, the relationship between the chemistry of moving sediment-soils and water chemistry was done using multiple regression analysis in Microsoft Excel spreadsheet so as to establish the extent to which water chemistry was influenced by sediment/soil chemistry and to trace also the sources of sediment.

Analysis of data on Objective 5 (SWAT modelling of sedimentation) was done in several phases. During the first phase, the SWAT project setup in ArcGIS 10.3 was done. Thereafter, watershed delineation window interface was opened in order to input the DEM and to inspect its spatial resolutions earlier mentioned. Within the watershed delineation window interface, the gauging station location (later selected as a final watershed outlet) was added in form of XY data followed by masking the watershed area of interest from which the catchment was to be delineated (Abbaspour, 2004). After the masking, flow directions and accumulation were automatically determined followed by automatic creation of stream networks and outlets. This created nodal points of the catchment, which determined the outlet junctions of main river/stream paths, watershed boundary and define Hydrological Response Units (HRU) (areas within watershed that respond hydrologically similar to given input (Shourie, 2012)) with respect to their sub-basin. Available weather data base for the catchment were stored in the SWAT data base through SWAT's weather data input interface.

The whole watershed outlet definition and catchment delineation were respectively, done automatically, followed by subbasin parameter calculations. In the second phase, HRU analysis was done were rasterised landuse/cover and soils maps were inputted followed by a slope definition, respectively. A great deal of time was spent preparing soil input data extracted from FAO soil data base for Africa. Soil erodibility factor (USLE_K) was automatically analysed using Williams (1995) Equation as presented in Equations 22, 23, 24, 25 and 26. Finally the HRUs were defined and reports automatically generated based on the inputs.

$$K_{USLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgc} \cdot f_{hisand} \quad (22)$$

$$f_{csand} = \left(0.2 + 0.3 \cdot \exp\left[-0.256 \cdot m_s \cdot \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (23)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (24)$$

$$f_{orgc} = \left(1 - \frac{0.0256 \cdot orgC}{orgC + \exp\ 3.72 - 2.95 \cdot orgC}\right) \quad (25)$$

$$f_{hisand} = \left(1 - \frac{0.7 \cdot \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \cdot \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (26)$$

Where:

K_{USLE}	Soil erodibility factor;
f_{csand}	factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soil with little sand;
f_{cl-si}	factor that gives low soil erodibility factors for soils with high clay to silt ratios;
f_{org}	factor that reduces soils erodibility for soils with high organic carbon content;
f_{hisand}	factor that reduces soil erodibility for soils with extremely high sand contents;
m_s	percent sand content of a layer;
m_{silt}	percent silt content of a layer;
m_c	percent clay content of a layer; and
o_{rgC}	percent organic content of a layer.

The third phase involved writing of the input table where the weather data in text format (.txt) were inputted and saved following a prescribed format in the software (Appendix D for sample of full input data sets and formats for 1988).

After finalising the SWAT input table, warm up years (1979-1989) were set, desired parameters to be simulated were also set, then SWAT model was run for a period of 30 years skipping only (1988-2017). The model outputs were checked for any early warnings by running a SWAT Check. Afterwards, the SWAT results were saved in the TxtInOut folder in the mother folder called Scenario where all other processes involved in the running of the model were also saved for reference purposes. Figure 16 illustrates analysis process in SWAT.

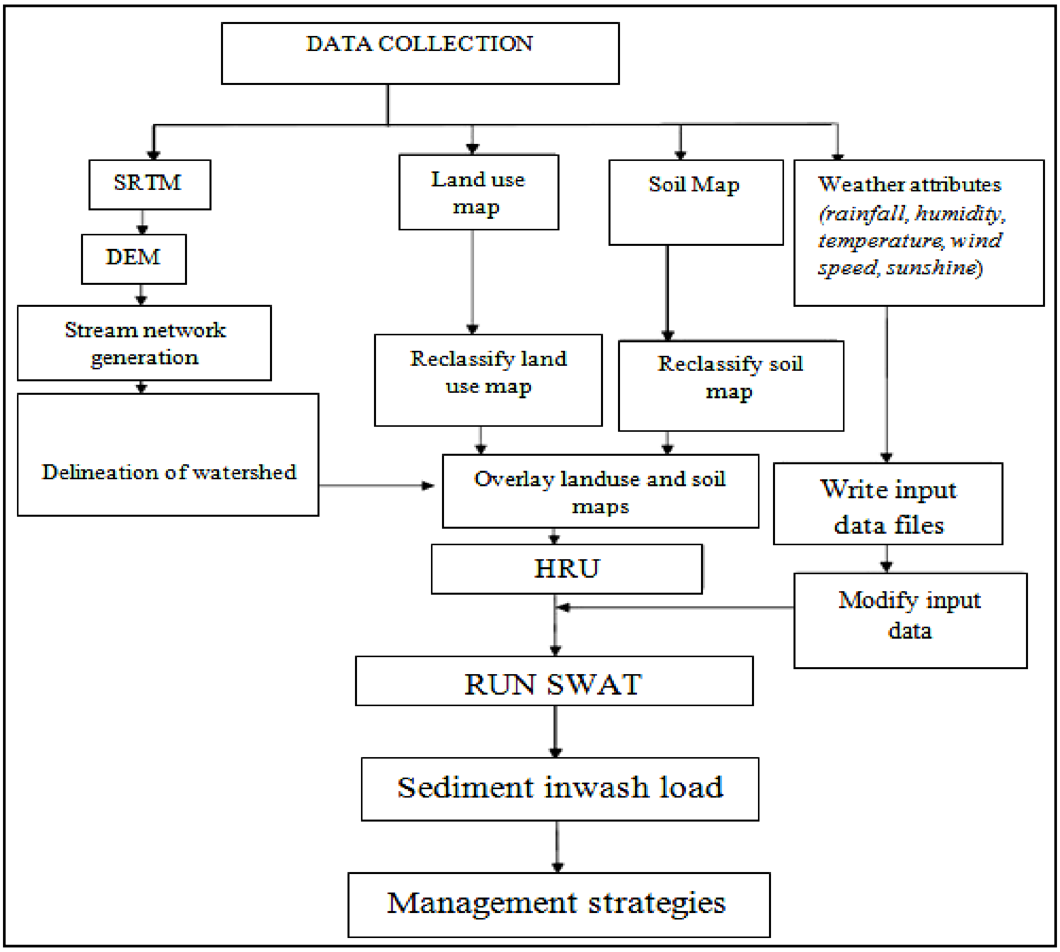


Figure 16 : Analytical process of modelling reservoir sedimentation using ArcSWAT (Shourie, 2012)

In the fourth phase of data analysis for objective 5, SUFI-2 algorithm in SWATCUP was used to calibrate the model initially created in ArcSWAT. The reason for using this was to finally compare simulated sediment with measured one so as to calibrate, validate and evaluate the performance of the SWAT model in accurately predicting sedimentation especially in ungauged catchments with scanty hydrological database. As earlier mentioned, the specific area that was being studied did not have a gauging station so the calibration of discharge was done at another subbasin (subbasin 1 in this study) downstream which had a gauging station (Abbaspour, 2004; Arnold *et al.*, 2012).

The watershed generally showed similar characteristics in terms of slope, landuse, soils and climatic conditions. It was therefore assumed that if the calibration of discharge at such a subbasin was correct, then the calibration at the main study site would be correct too. Regionalisation approach based on spatial similarities have been used in studies by Emam *et al.* (2016); Begou (2016), Halefom *et al.*, (2017); among others. The calibrated discharge was therefore a mirror of what would most likely transpire at the study site. Since sediment calibration and validation were only for two years during which data was captured, this study only took interest in calibrating reflective discharge for two years (2016-2017) at the gauging station so as to have an impression of the possible hydrological process at actual study site. Moreover, the goal was to simulate sediment, not flows. The general assumption was that, if the model was hydrologically correct at the gauging station downstream, it would be correct also on other outlets in the upstream sub-catchments. Flow calibration and validation were done from the month January to December, 2016, and January to December, 2017, respectively. A pre-calibration simulation was carried to pre-inspect outliers in simulated discharge data as compared to measured data. Parameterisation for pre-calibration only included *SFTMP*, which according to Abbaspour (2007) does not change anything in the simulated values. After a satisfactory pre-calibration check, actual parameterisation was done in *Par_inf.txt* windows interface of SUFI-2 SWATCUP. The *Par_inf.txt* was loaded with 39 *optimisation* parameters which were likely to influence routing of flows taking into consideration their default minimum and maximum values in SWATCUP and of parameterisation method.

The number of simulations were set to 1000 both in *Par_inf.txt* and *SUFI-2_swEdit.def.* In the File.cio, the period of calibration and validation was set to 2016 and respectively in order for SWATCUP to only consider such periods. The *observed_reach.txt* was opened in order to set the number of variables, name of variable to be simulated from the SWAT model as well as number of data points for the variable (discharge) to be simulated. The format for measured input data for calibration and validation was as follows: *FLOW_OUT_001_2016 4.7* (Appendix E), representing variable name, first julian day number, year of simulation and value of observed flow data, respectively.

Measured daily flows for 2016 were transferred to *observed_reach.txt.* Extraction command was set in order to name the variable to be calibrated, set the number of variables to capture (1 in the current case) and set the variable column number in the swat output file from which SUFI-2 was going to extract the values. Also recorded in the *SUFI2_extract.txt.def* windows of SWATCUP were the following: the total number of reaches (subbasins) in the watershed, reach number from which to extract the variable, the duration of simulation, as well the time step for simulation (daily time step in the current study). Afterwards, the Objective Function (OF) was set to Nash-Sutcliffe (NS).

Abbaspour (2015) says that the best objective function for discharge is NS because it promotes better fit between simulated and observed values. As per SUFI2 requirement, the name of the variable to be simulated was re-entered, followed by percentage error of measurement which was set to be prescribed 10. Last but, not the least, measured discharge data set for 2016 was also re-entered and saved. After a re-inspection of all entries, calibration was initiated and was iterated three times. In order to validate the resulting model, the same process described above was followed except that during validation, 2017 simulated and measured data were used and that, the best range of parameters in the last iteration (Iteration 3) were the ones used to validate the model. The resulting data was presented using automatically created time series graphs of simulated and measured data as well as the 95PPU. Regression analysis of measured and simulated discharges was done for both the calibration and validation period so as to determine the strength of the relationships. Resulting values for the OF including the means and standard deviation were summarised using tabular matrix.

Global sensitivity analysis was done automatically by SUFI-2 in SWATCUP and the results were presented using graphs and tables. Uncertainty analysis was done by describing the extent to which the model captured factors that influence discharge. The p-factor was mainly used as default criteria for uncertainty analysis. Lastly, the performance of the reflective hydrological model was done based on the NS, R^2 and P-BIAS, which are the most, if not universally acceptable OF for evaluating performance of SWAT Model. The analytical procedure described above is exactly the same one used to simulate sediment, except discharge values were replaced by sediment values. Moreover, 33 optimization input parameters in the *Par_inf.txt* were those deemed to be sensitive to sediment. The sediment model was simulated 500 times and iterated three times so as to enhance its accuracy. The objective function used was NS. However, in the performance evaluation, R^2 and PBIAS were factored in. Figure 17 summarises the procedure involved in calibration of sediment using SUFI-2 algorithm in SWATCUP 2012 based on adaptation from Abbaspour (2007).

SWAT was used to simulate sedimentation because it was capable of generating geo-hydrological data sets even in sub-basins that did not have any gauging stations like it was in Makoye Reservoir's subbasin. SWAT simulation also facilitated erosion mapping within the basin so as to detect areas that required improved management to reduce generation of excessive sediment. Moreover, SWATCUP proved to be a very robust tool in handling bulky daily simulation. It is endowed with statistical packages that facilitate efficient computation.

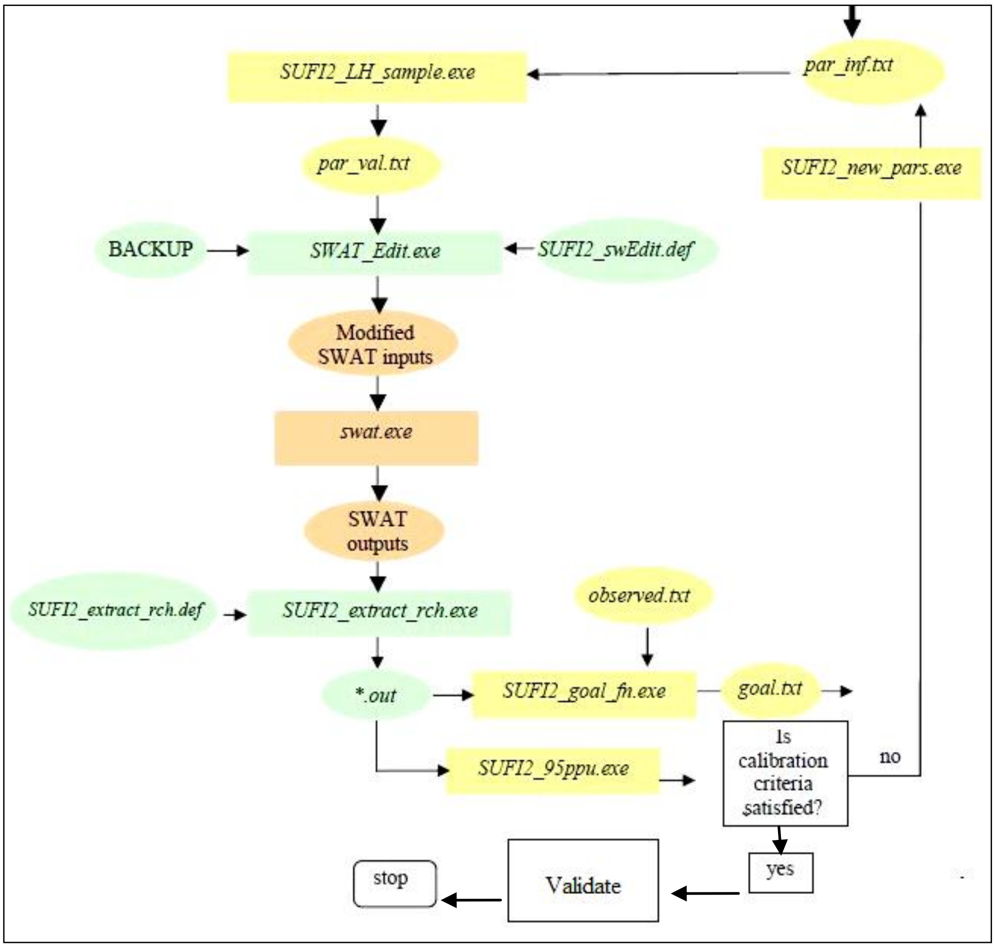


Figure 17: Illustration of the process of creating SUFI-2 setup for calibration and validation in SWATCUP input files. Adapted from Abbaspour (2015:21)

SWAT also offered best stochastic procedures for understanding a complex and stochastic hydrological system such the Makoye Reservoir subbasin. The developed conceptual block model was based on results from objectives 2-4 and adaptation from Abbaspour (2007). To give it a theoretical meaning, it was hermeneutically explained in terms of its uniqueness, replicability and applicability to understanding reservoir sedimentation and simulation in small ungauged reservoir catchments in Zambia. Table 5 summarises method and analytical techniques used.

Table 5: Sets of Primary data collected and some analytical techniques used in this study

Primary collected	Study objectives	Materials and equipment for data collection	Analytical techniques
Bathymetric data: water depth, bed to topography, Sampling coordinates. Water wetted perimeter	1	Field measurements using Hydrographic survey boat RC-S2 with DGPS and VBS Omnistar service.	3D spatial Analyst tools (Triangulated Irregular Network (TIN), Inverse Distant Weighted (IDW), Krigging, Natural Neighbour (NN)) in ArcGIS 10.3 and Hydro hypsometric curves
Quantity of Sediment Soils and sediment samples	2	Field measurements using DGPS and Omnistar, Measuring tapes, Sediment corers, ranging poles, shovels and picks. Field measurement to collect soil samples using picks, spades, collection containers and measuring gauges, sediment traps (grass carpet)	3D spatial Analyst tools TIN, IDW, Krigging, NN) in ArcGIS 10.3. ECM. Laboratory procedure for chemical analysis in soils.
Real time sediment settling rate	3	Field measurements using Sedimeter SM3A	rating curves and line/bar graphs
Water samples and coordinates for analysis of (Total Dissolved solids Total suspended sediment Turbidity, Chlorides Ammonium, pH, Nitrates, phosphates, Total Dissolved Oxygen.	4	Water sampling across the reservoir using sampling bottles and DGPS	Laboratory analysis standard procedure IDW in ArcGIS 10.3 Piper technique Descriptive statistics
SWAT inputs data for sediment simulation namely: Weather data: daily rainfall, relative humidity, sunshine, wind speed, temperature. Spatial data: Landuse, soils, DEM. Hydrological data: Discharge and water depths.	5	For weather data: NASA web portal agro-climatological database and field measurement. For spatial data: By extraction from FAO soils data base for Africa using ArcGIS. Landcover data was acquired by extraction from global land cover map using ArcGIS. STRM DEM	ArcSWAT processing, SUFI-2 in SWATCUP and descriptive statistics in form of tables and graphs. regression methods.
Block Model for enhancing understanding of sedimentation in small catchment	6	Developed based on first Objectives 2-4	Hermeneutics (art of interpretation or meaning making about something) (Alvesson and Skoldberg, 2009).

4.9 Validation and trustworthiness

Different criteria are used to judge research validity in different research paradigms (Ransburg, 2001). In such paradigms such as empirical analytic, there are four key factors that must be taken into consideration to ensure data validity and trustworthiness namely, internal validity, external validity (generalisability), reliability and objectivity (Krefting, 1991).

To ensure internal validity, the internal consistency of research and experimental procedures were constantly checked to minimize errors. For example, iterative simulation process to check consistency or changes in emerging values were done. Water sampling procedures were repeated at different temporal scales to check consistency or changes in concentration of parameters. A validation sample of water (with distilled water) was also used for quality assurance of analysis. Bathymetric survey depths were validated using gauge plate to physically inspect what the RCHSB recorded. Accuracy of GPS was always checked using Equation 12 so as to minimise coordinate errors.

External validity refers to the ability to generalize results from internal context to a wider context (Ransburg, 2001). This was achieved by carefully executing data collection, analysis and interpretation so as to allow replicability in other contexts with similar catchment characteristics. For example, during calibration of sediment in SWATCUP, care was taken during the analysis in order to strengthen model predictive power to temporal and spatial scales outside the calibration. Scientific scrutiny was also embraced and in this context, it implied distancing any destructive subjectivity or feelings from the researcher.

The researcher aimed at being neutral ensuring that all biases in data collection were as far as possible eliminated or minimised. For example, during calibration and validation of sediment model, a stochastic analytical approach was used rather than a deterministic one so as to avoid try and error method, which many a time, brings about biasness (Abbaspour, 2015). However, where outliers were too imposing, they were eliminated so as to end with a stochastic model without outliers. To ensure reliability of findings, methods were applied in an objective way possible so that it would reliably yield almost the same results even if other researchers questioned or tested them at different times.

As far as possible, ambiguity was avoided so that results could be interpretable in the same way by all end users in the scientific community. Methodological triangulation (involving a combination of different methods to check consistency during data collection and analysis), specifically between-method triangulation (which involved the use of different methods in combination) was used (Denzin, 1970). For example, the researcher used different techniques to determine the volume of sediment and to come up with good averages. Laboratory pre-test of real time sediment depth measurements to pre-check the validity and accuracy of instrument was done. Iterative measurement of bathymetry was carried out and analysed with a mix of techniques so as to arrive at representative averages.

4.10 Ethical considerations

Griffith (2008) recommends that all geographical researches be conducted in a ethical way possible. The following were the ethical considerations which the study adhered to:

i. Before commencing the study, the research proposal was submitted for ethical clearance by the University of Zambia Natural and Applied Science Research Ethics Committee IRB (Appendix F);

ii. The researcher got prior permission from the Village head of the area to camp at the reservoir. This was done by presenting the ethical clearance letter and an institutional headed letter of introduction explaining the purpose of the study;

iii. Self regulation was also adhered to by sticking to the objectives of camping at the reservoir site;

iv. All the cited sources were acknowledged in the list of references; and

v. Transparency in data collection and management was adhered to in the most possible way to ensure quality.

4.11 Limitations of the study and mitigation strategies

Like any study, the current one also had some inherent limitations, which had to be minimised using different strategies. Table 6 provides summary of study limitations and mitigation strategies. Figure 18 presents a general process followed to carry out the study from its planning phase up to its completion phase.

Table 6: Summary of study limitations and mitigation strategies

No.	Limitations	Mitigation strategies
1	None availability of sediment data prior to the study	Real time sediment data was generated using Sedimeter, but on short term basis.
2	Sediment simulation using SWAT was not well documented if none existent in Zambian context.	A number of related literature was consulted outside Zambian context and the dearth of literature was used as an opportunity to advance knowledge and justify the current study.
3	Poor rainfall during the 2015/2016 season partly affected the collection of sediment data.	During the 2016/17 warm-wet season fairly lengthy sediment data was collected.
4	Sediment simulation was done only based on short term data. Abbaspour (2018) says model which are calibrated for one year only are weak in most cases.	The calibration was carefully carried out so as to produce desired calibration results.
5	Validated Sediment model was weak due to limited sediment data.	The validated sediment model was drastically improved by bracketing outliers.
6	Limited scientific literature on use of SediMeter in African context	Related literature from outside Africa was still consulted.
7	Computation of real time sediment (tonnes) was only dependent upon the regression model from the coring method or accuracy of computations from objective 2	The computations in of sediment depth-load relationship and bulk density was carefully done so as to ensure strong *p-Value*, which gave confidence to use the developed regression model.
8	During the 2015/16 rainy season, low accumulation of sediment was caused by scanty rainfall punctuated by El-Nino, hence, results cannot be generalized to the whole rainy season as they were only restricted to individual rainfall events.	Maximising real time measurement in the 2016/17 warm-wet season during which La Nina was experience punctuating early and heavy rainfall
9	Use of satellite weather data due to lack of properly documented ones from local context.	Part of Satellite data (2015-2017) from NASA was validated with what was physically measured onsite during the 2015/16/2017 warm-wet seasons.
10	Unlike 90m DEM used in this study, 30m DEM would have been the best for small catchment	Simulation was done at a larger scale through regionalisation, Makoye Basin was just part of the bigger catchment. The 90m DEM had very accurate had accurate variable than 30m DEM.

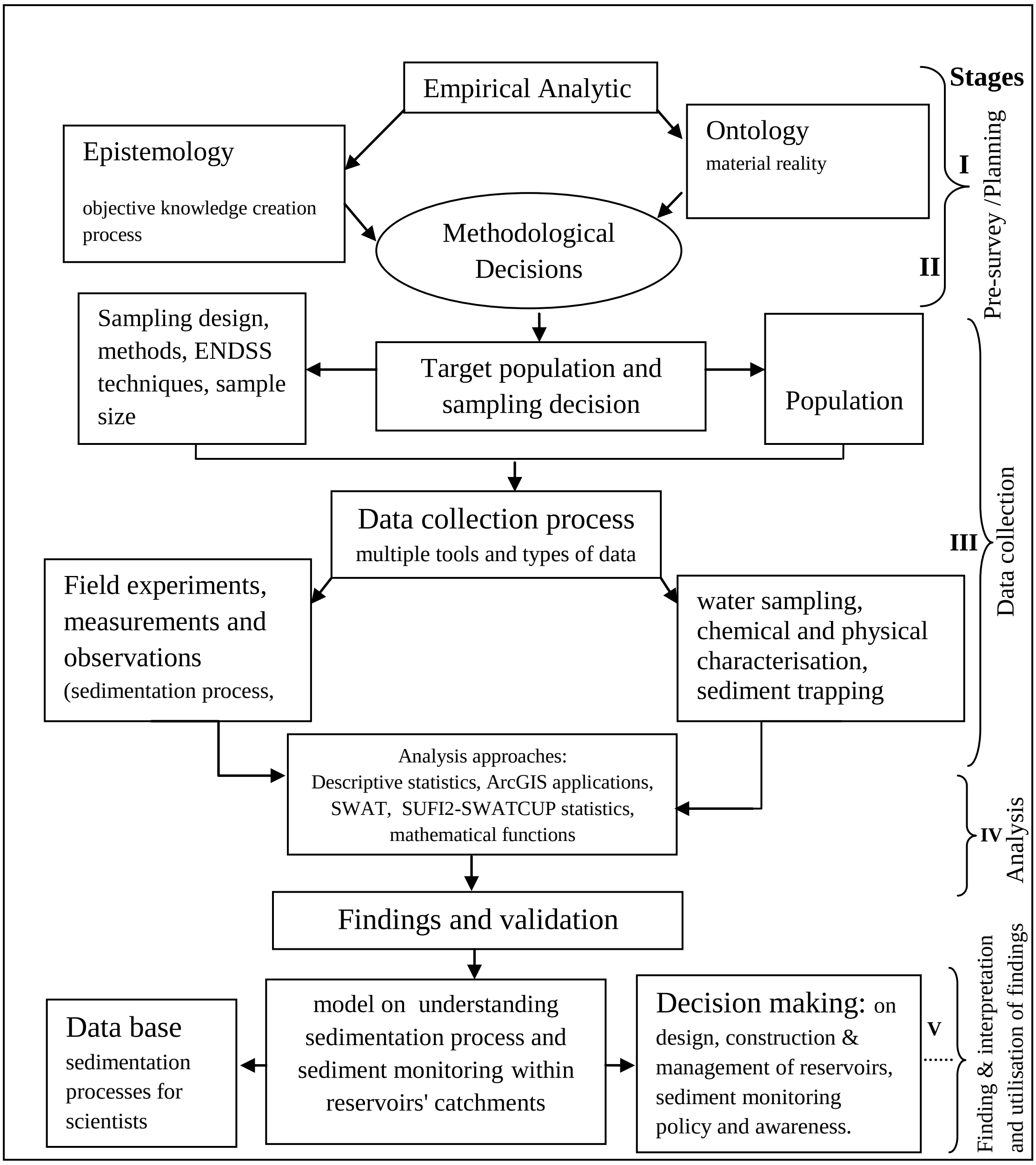


Figure 18: Research conduct flow model of the study

4.12 Chapter summary

Critical Empirical Analytic formed the philosophical logicality of the study with analytical experimental research design being the main research framework. Five bathymetric surveys were conducted using a Remote Controlled Hydrographic Survey Boat whereas sediment coring was done across the reservoir to determine depths, data sets for both were analysed using 3DSATs in ArcGIS 10.3. Real time sediment depth was measured using SediMeter SM3A and analysed using time series and descriptive statistics. Water sampling was done across the reservoir for water quality analysis in the laboratory based on FAO standards for livestock water. Sediment was simulated and calibrated using ArcSWAT and SUFI-2 in SWATCUP.

CHAPTER FIVE: BATHYMETRY OF THE MAKOYE RESERVOIR

This chapter presents and discusses results based on the first objective whose focus was on bathymetric mapping, water volume computation and determination of relationships between water volume and depth as well as, reservoir's hydrological regimes.

5.1 Depth, water volume and hydrological regimes of the Makoye Reservoir

Inter-seasonal bathymetric survey results (Table 7) indicated that the water volumes oscillated between 24,830.93 m^3 and 75,974.21 m^3 during the warm-dry and warm-wet seasons, respectively. Generally, the reservoir was characterised by drastic inter-seasonal variations in water depths, volumes and surface areas. Based on results in Table 7, Figures 19a-h respectively show bathymetric maps and survey pathways for Makoye Reservoir at different water capacity levels and seasons.

Table 7: Depths, surface areas and volumes of water in the Makoye Reservoir at different seasons between 2015 and 2017

20 August, 2015			3 March, 2016			19 June, 2016			17 February, 2017			14 July 2017		
Low Capacity			Full Capacity			Medium capacity			Full Capacity			Medium Capacity		
Water Depth (m)	Water Surface area (m^2)	Volume of water (m^3)	Water Depth (m)	Water Surface area (m^2)	Volume of water (m^3)	Water Depth (m)	Water Surface area (m^2)	Volume of water (m^3)	Water Depth (m)	Water Surface area (m^2)	Volume of water (m^3)	Water Depth (m)	Water Surface area (m^2)	Volume of water (m^3)
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
0.75	38171.76	19105.16	1.82	60499.4	67283.64	1.05	44950.05	33750.90	2.03	57144.06	61459.61	1.12	49403	29661.9
0.6	38171.75	13379.39	1.68	60361.85	58828.72	0.90	44950.04	27008.39	1.78	56687.55	46953.33	0.84	41635.25	16466.34
0.45	37629.99	7653.56	1.54	59950.69	50385.22	0.75	44950.03	20265.89	1.52	52900.38	32978.35	0.56	29569.95	6220.41
0.3	26820.94	3070.92	1.4	57445.43	42162.43	0.60	40539.72	13752.99	1.27	44450.65	20576.47	0.28	7119.91	324.91
0.15	7828.99	342.96	1.26	54945.52	34284	0.45	33845.09	8157.64	1.02	36610.09	10312.77	0	0	0
0	0	0	1.12	51134.01	26843.62	0.30	27208.42	3568.29	0.76	23571.33	2408.87			
			0.98	46761.1	20004.12	0.15	13090.79	276.87	0.51	435.89	22.6			
			0.84	41097.53	13799.72	0	0	0	0.25	20.66	4.54			
			0.7	32987.05	8562.5				0	0	0			
			0.56	26474.59	4418.05									
			0.42	17473.48	1244.93									
			0.28	1460.33	46.17									
			0.14	20.2	0.2									
			0	0	0									

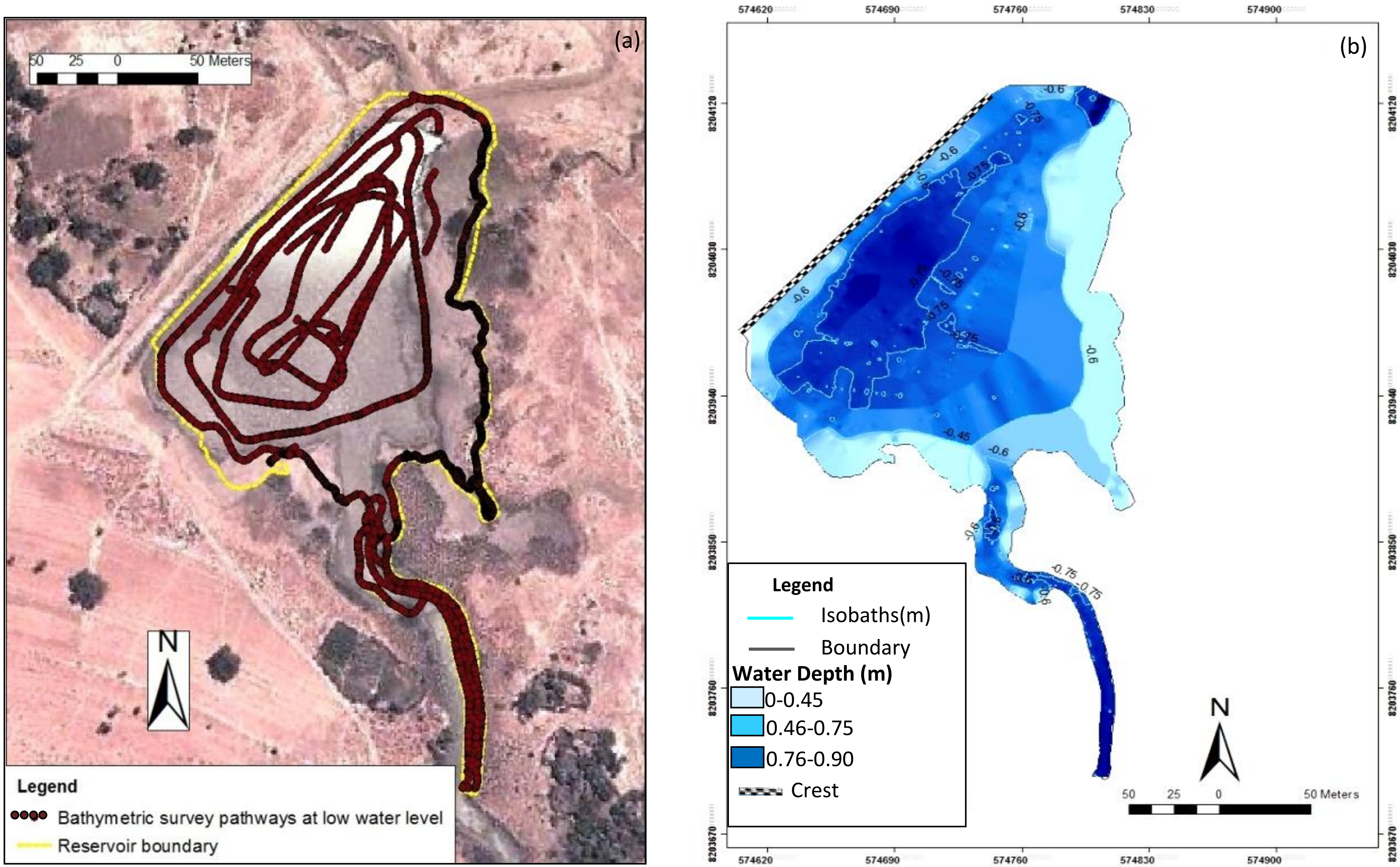


Figure 19: (a) Bathymetric survey pathways and (b) Bathymetric Map of the Makoye Reservoir at its low water level (20/7/2015)

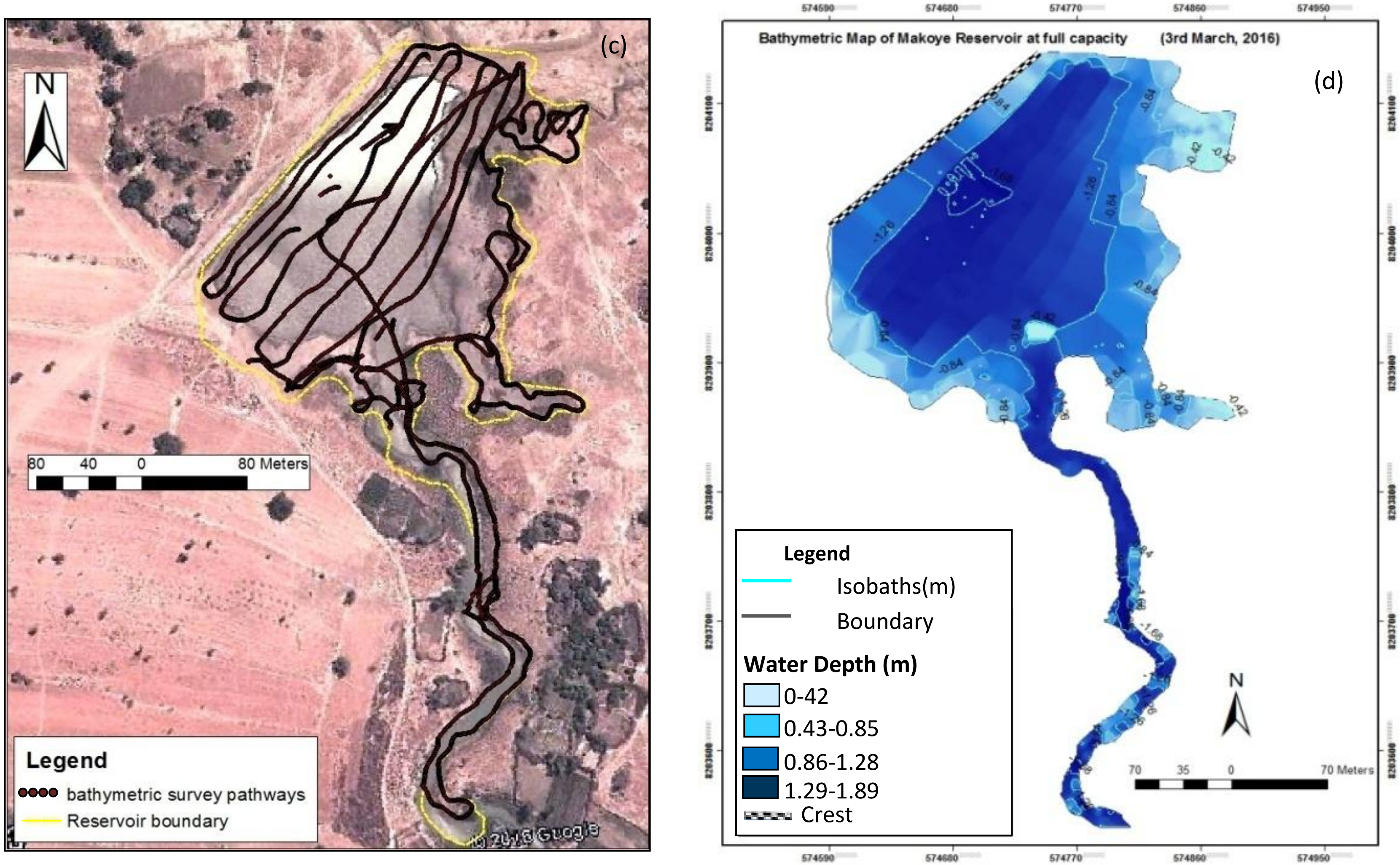


Figure 19: (c) Bathymetric survey pathways and (d) Bathymetric map for Makoye Reservoir at its full water level (3/3/2016).

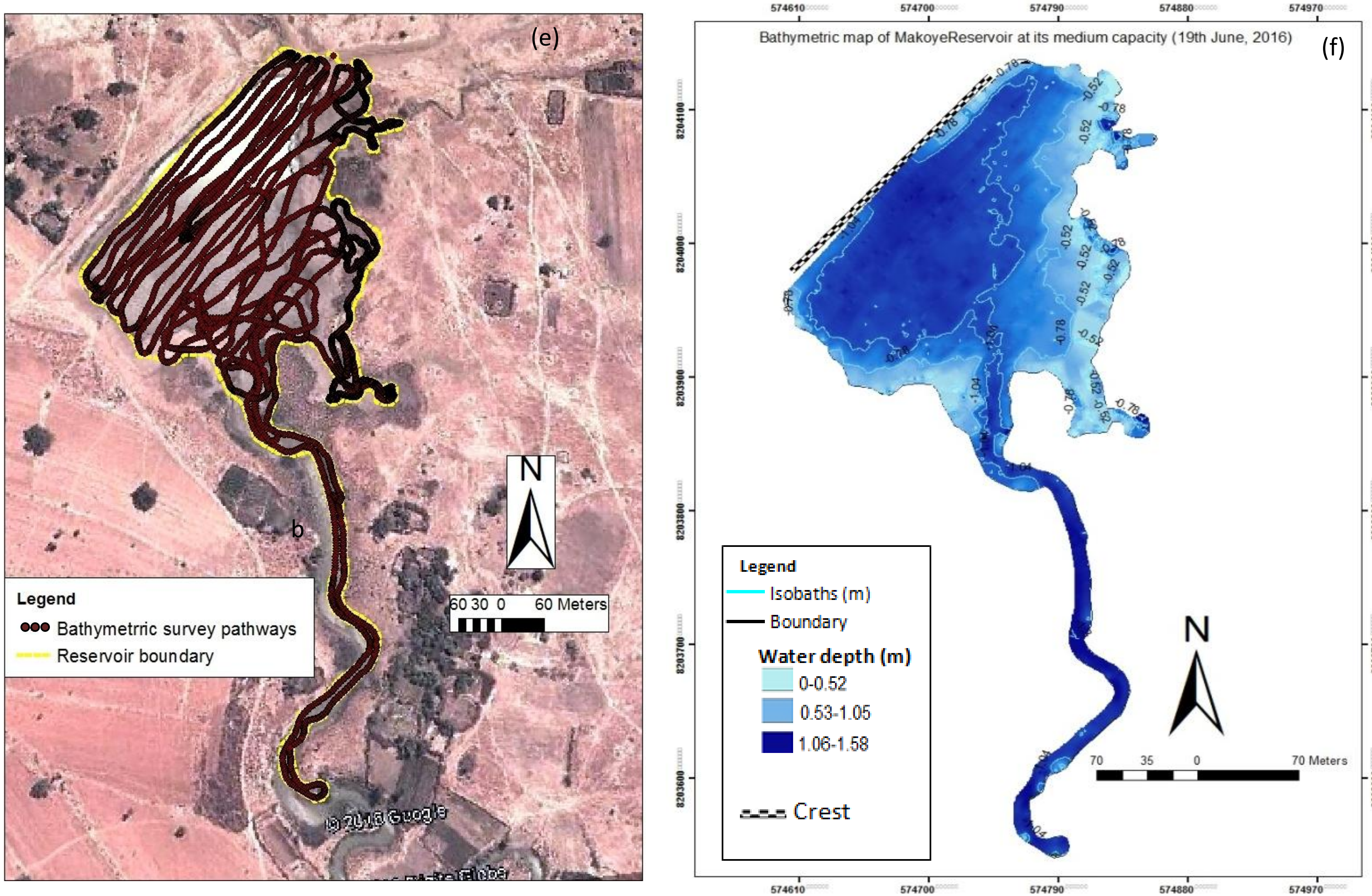


Figure 19: (e) Bathymetric survey pathways map and (f) Bathymetric Map for Makoye Reservoir at its medium water level (19/6/2016).

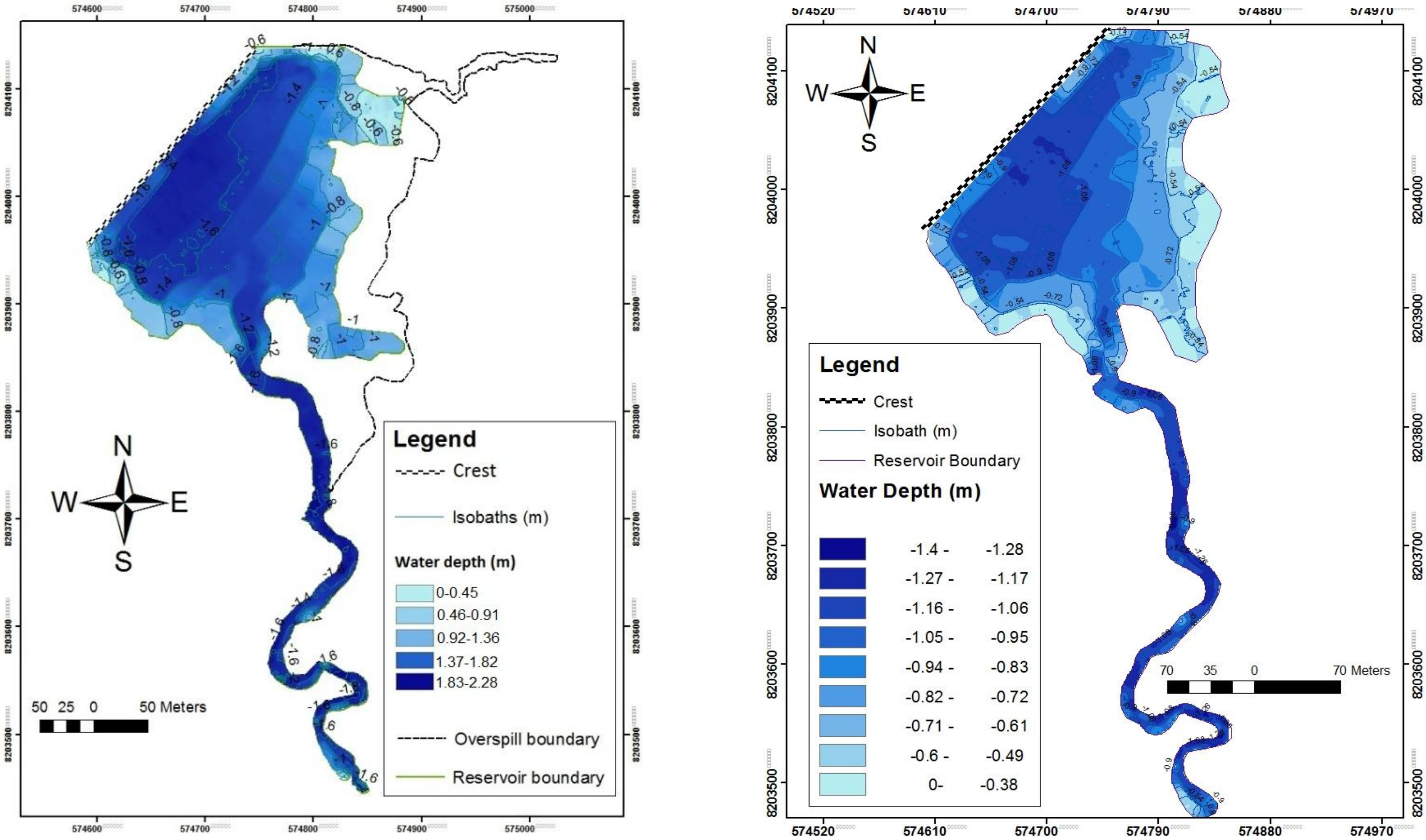


Figure 19: Bathymetric maps of Makoye Reservoir at full water level on 17/2/2017 (g) and medium water level on 14/7/2017 (h)

At all capacities (low, medium and full), the volume of water was almost perfectly (r^2 = 0.99 on average) dependent on the depth (Figure 20a-e) and inter-seasonally in unstable equilibrium as illustrated by hydrological regimes of the reservoir (Figure 20f).

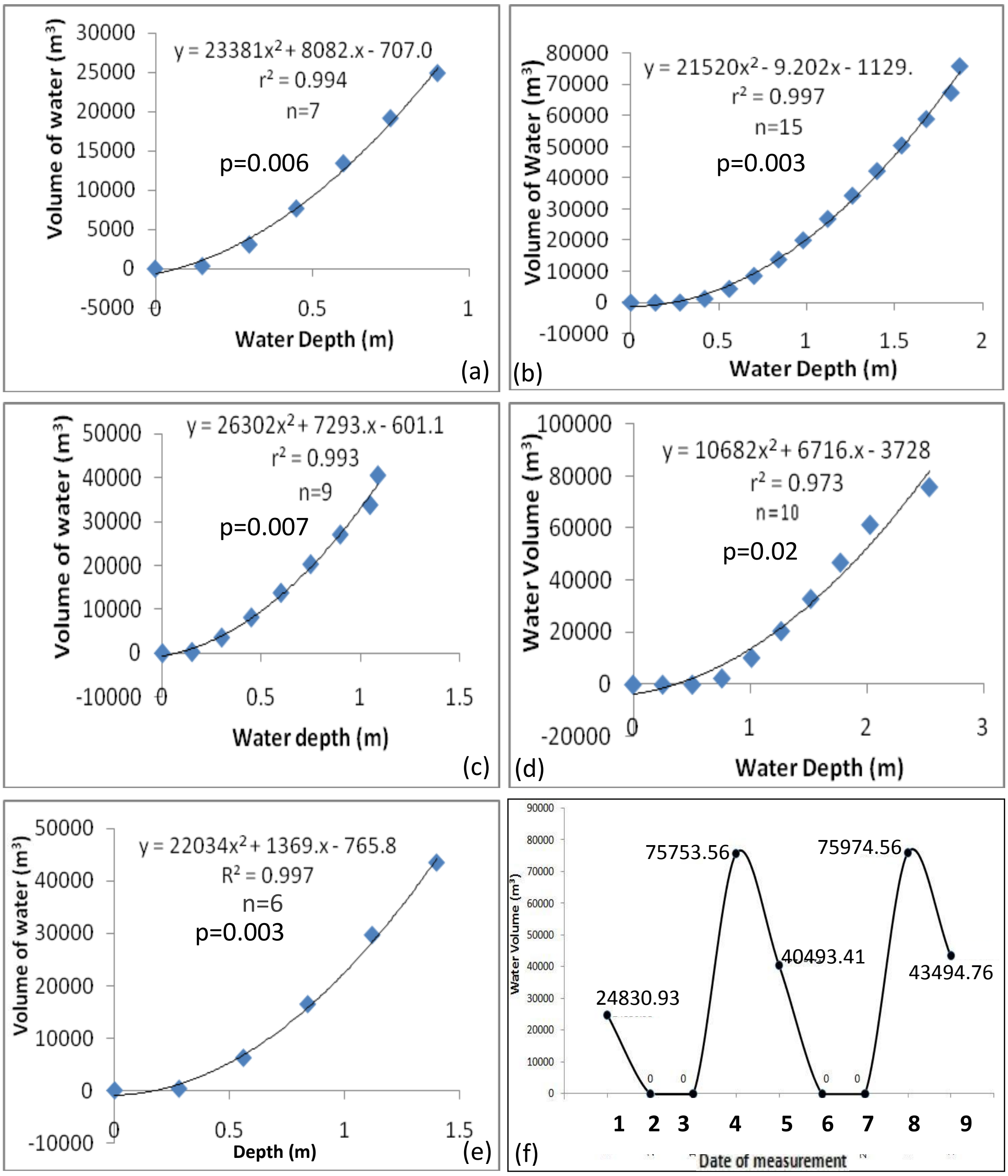


Figure 20: Hydro-hypsometric curves showing non-linear relationships between water depths and volumes at (a) low water level (20/8/2015) (b) full water level (3/3/2016) (c) medium water level (19/6/2016) and (d) full water levels (17/02/2017) (e) medium water level (14/7/2017) capacities; (f) hydrological regimes of Makoye Reservoir.

Key for timings in Figure 20f: 1=(20/8/15); 2=(28/9/15); 3=(18/1/16); 4=(3/3/16); 5=(19/6/16); 6=(16/9/16); 7=(26/11/17); 8=(17/2/17); 9=(14/7/17)

Similar to earlier studies by Dalu *et al.* (2013); Khaba and Griffiths (2017), the current study noted that, the unstable bathymetry of Makoye could be attributed to high average sedimentation rate (>5,000 m^3 yr^{-1}) reducing its water holding capacity by 54 percent. This finding also resonates with what Sawunyama *et al.* (2006) as well as Ajith (2016) earlier observed that, sediment accumulation affects the mean depth of water basins and eventually, the quantity. The current study estimated that about 56,400.096 m^3 of water was infiltrated in settled sediment before reaching its asymptotic limit where sediment is fully saturated such that, water would start accumulating in the reservoir (Leopold *et al.*, 1995). Had there not been excess sediment in the reservoir, this quantity of infiltrated water would have been available for animal consumption and would have drastically reduced the water-stress period. This means that, sediment does not only reduce the reservoir's water volume, but also widely sack part of the water that should otherwise to be accumulated in the reservoir.

The drastic volumetric changes in water interseasonally implicitly pointed to reservoirs reduced water holding capacity. 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 20f) above showing a highly compromised water holding capacity of the reservoir. A similar observation was also made by Vyleta *et al.* (2017) and Busker *et al.* (2018), in their study of Vrbovce reservoir in western Slovakia, Muela reservoir in Lesotho, and multiple reservoirs across the globe, respectively. Makoye Reservoir continued to be in a dry state from 28 September, 2015 up to 18 January, 2016. This long water stressful period was punctuated by delayed onset of rainfall during the 2015/2016 warm-wet season when Southern Africa and Zambia in particular experienced El Nino Southern Oscillation (ENSO), well known for triggering drought conditions and long dry spells (Viessman and Lewis, 2012).

Moreover, during the 2016/2017 warm-wet season, Zambia experienced La-Nina (ZMD, 2016), which led to heavy rainfall and flash floods such that, the reservoir almost filled to full capacity in a single storm. Other other reduced reservoir storage capacity, this was caused by antecendent rainfall events that were experienced before the main rainfall event thereby, reducing the infiltration capacity within the catchment. 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 percent of the measured volume at full capacity) was not in the reservoir. This drastic plummation could not only be attributed to sedimentation but also to seapage, animal watering and evaporation due to atmospheric processes (Figures 22 and 23). During this period, the reservoir overflowed by 15 December, 2016 just about 20 days from onset of rainfall on 26 November, 2016. However, over time, water level receded slightly below the spill way until late December, 2017. This rapid filling of water into the reservoir within such short temporal intervals showed that, the reservoir had lost its water holding capacity (Kamtukule, 2008). When the reservoir delays to fill up, it increases water stressful period and conversely, when it fill up quickly, it may lead to downstream flooding of crop fields, gardens, homestead and water loss during heavy storms (Dalu *et al.*, 2009). 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 has implications on social livelihood for water-dependent economic activities such as pastoral farming.

The measurement at full capacity for 2016/2017 warm-wet season were done on 17 February, 2017 and the volume of water was determined at 75,974.21 m^3. This bathymetric measurement showed a slight higher volume (by 220 m^3) of water during the latter season than the former one (Tables 7 above). This slight volumteric increase was due to that, during the first measurement at full capacity, the throwback along the stream channel was shorter than during the 2016/2017 full capacity measurement during which high rainfall was received as compared to the former warm-wet season. At its low water leveld (water depth at 0.73) in the 2015/2016 warm-wet season, Makoye Reservoir's water surface area was 38,171.77 m^2, but at its full capacity when water depth was 2.2 m, it rose to 60,499.41 m^2 which represents 37 percent increase (Table 7 above).

At medium capacity when water level was about 1.1 m to 1.4 m, the surface area was 44,950.06 m^2, which represents a 26 percent decrease from the water surface area at full capacity. During the 2016/2017 warm-wet season, water surface area at full capacity of the reservoir showed a slight decrease by about six percent compared to 2015/2016 measurement at full capacity (Table 7). These statistics imply that, timing in seasons may cause flunctuation in surface areas covered by water and eventually, water acessibility.

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 (about 44 percent of capacity remaining by 2017) because the actual boundaries of the reservoir seem to be obscured by water inundation such that, a portion of the water pupported to be part of the reservoir was in the actual sense supposed to be excess or simply an over spill, thereby posing a challenge to compute the areal extent.

Based on evidence in Figure 20a-e above, water volume was dependent on the depth as demonstrated by very strong relationship (r^2 = 0.97-0.99) at all different seasonal scales. The current finding corroborate with earlier findings by Curtarelli *et al*. (2015) in the Amazonian reservoirs, Mavima *et al*. (2015) in Zimbabwe as well as Chomba Sichingabula (2016) in Lusaka East, Zambia.

As a matter of fact, it was noted that the volume of water was increasing towards the deepest point and vice versa. This entails that water depth has a very strong influence on the amount of water likely to be found in a reservoir at all times and spatial scales. A finding which was also noted by Sichingabula (2018) in his bathymetric surveys of reservoirs in Southern Zambia. Therefore, if the reservoir was to be deepened 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.

5.2 Selected physical processes influencing bathymetric dynamics

Apart from sedimentation, there were other physical processes that partly contributed to the unstable equilibrium of the reservoir bathymetry namely evaporation, temperature, radiation, atmospheric pressure and wind speed (Figures 21a-d and 22a-d whose actual data is presented in Appendix $G_{(i-ii)}$). The influence of these physical processes on reservoir volume dynamics have been widely documented by FAO (2015).

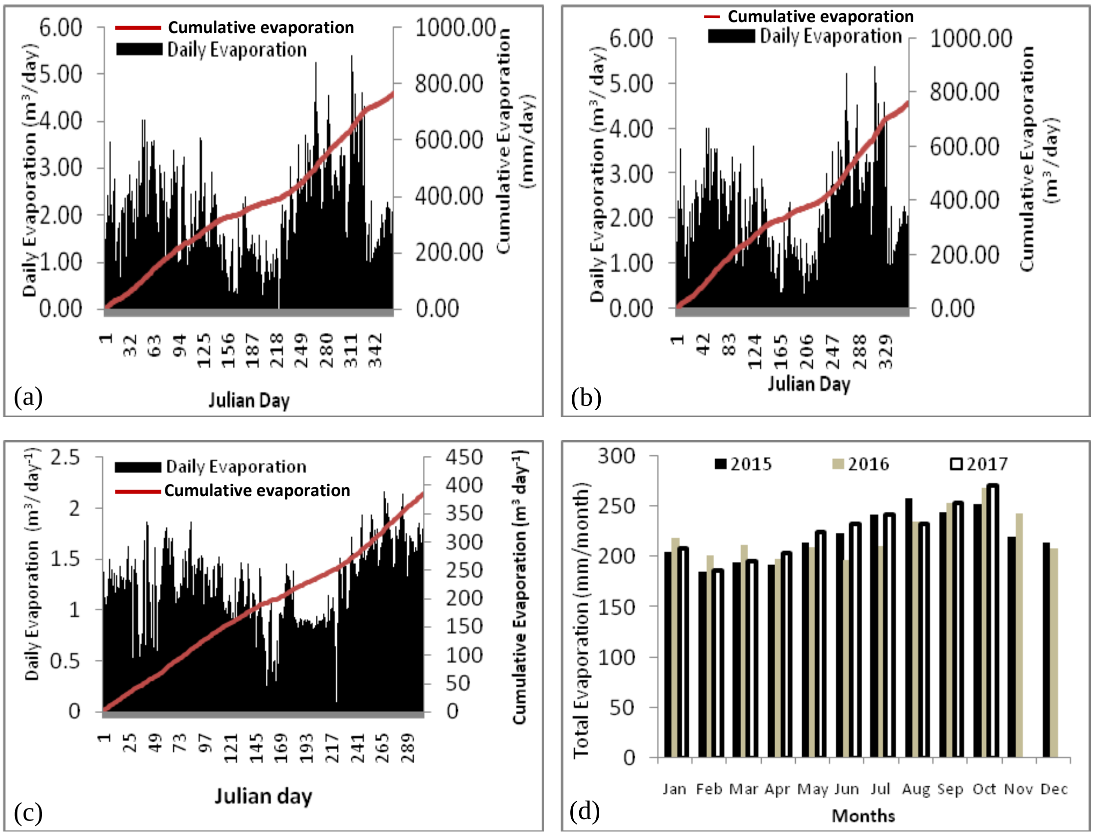


Figure 21: Daily actual and cumulative evaporation from the Makoye Reservoir in (a) 2015 (b) 2016 (c) 2017; and comparison of total monthly evaporation for 2015, 2016 and 2017.

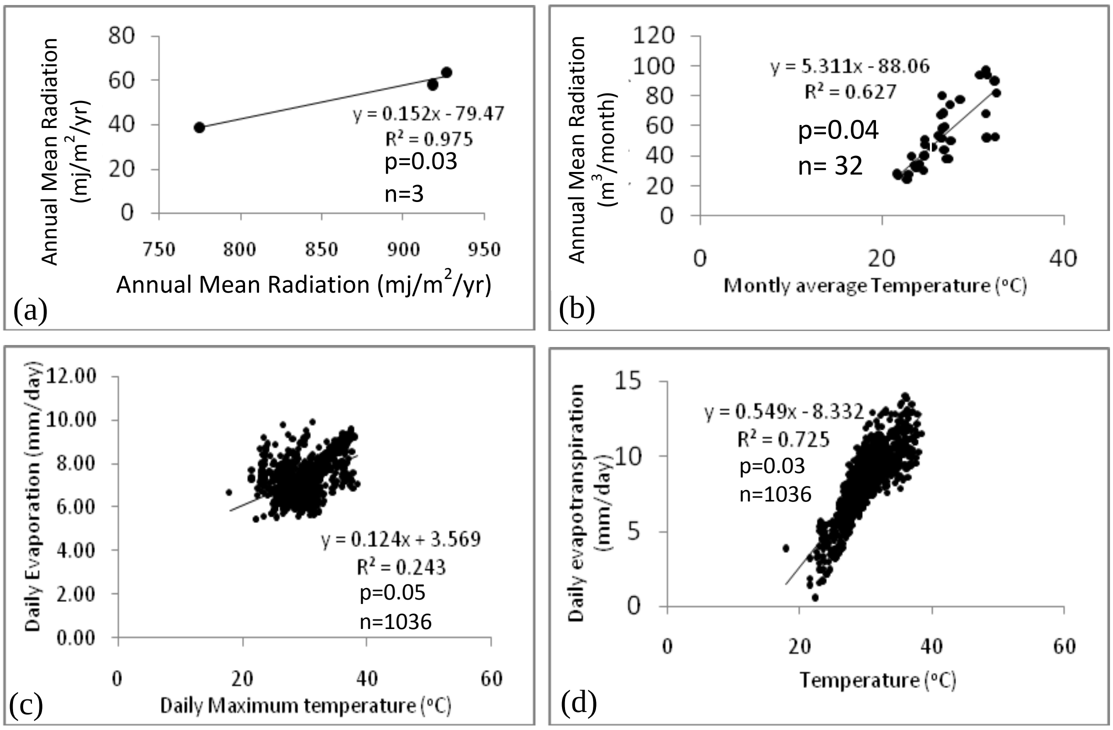


Figure 22: Relationship between (a) annual mean radiation and annual mean evaporation (b) monthly mean temperature and total monthly evaporation (c) daily maximum temperature and daily evaporation; (d) daily maximum temperature and daily evapotranspiration observed, 2015 to 2017.

Makoye Reservoir recorded the highest evaporation during the 2016 hydrological year, which tallied with dry spells recorded during the same year (Table 8).

Table 8: Annual average and total evaporation rates from the Makoye Reservoir (2015-2017)

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) and whose resulting multiple regression model for Makoye Reservoir Evaporation was $15.70+0.01x_1-0.22x_2+0.04x_3+0.12x_4$ (Table 9).

Table 9: 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						
Multiple R	0.55					
R Square	**0.30**					
Adjusted R Square	0.19					
Standard Error	0.62					
Observations	31					
ANOVA						
	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				
	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	**0.11**	0.07	1.67	**0.11**	-0.03	0.27

A strong positive relationship ($r^2 = 0.97$) between annual mean radiation and annual mean evaporation of water from the reservoir was noted (Figure 22a above). Figure 22b above shows a strong positive relationship ($r^2 = 0.63$) between monthly average temperature and monthly average evaporation from the reservoir. Figure 22d above also confirms that daily maximum temperature had a strong influence on daily evapotranspiration from the Makoye Reservoir. Although weak ($r^2 = 0.24$), a positive relationship was also noted between daily maximum temperature and daily evaporation of water from the reservoir (Figure 22c above). The influence of the afore mentioned physical processes on reservoir bathymetry have also been earlier noted by Tanny *et al.* (2011) at Eshkol reservoir in Israel; Abtew and Melesse (2013); Friedrich *et al.*, 2018 in Western United States of America, among others, which confirm the universality of these factors in influencing bathymetric dynamics. FAO (2015) as well as Viessman and Lewis (2012) have also conceptually documented how such natural climatic processes affect evporation. In volumetric terms, the annual average water losses from the Makoye Reservoir through evaporation ranged between 38.59 and 63.61 m^3 for the three year period from 2015 to 2017.

Some of the hydro-geomorphometric parameters could have also intrinsic contributed to the unstable equilibrium of the bathymetry of Makoye Reservoir (Derbyshire *et al.*, 1979). For example, the stream order of 2, sinousity of the main natural depressional stream, low stream density and frequency all partly and indirectly contributed to the unstabile reservoir bathymetry as they generally tend to influence the quantity of water reaching the reservoir downstream as already documented by Das and Saika (2009), Derbyshire *et al.* (1979) and Leopold *et al.* (1995). High sinuousity as observed for drepressional channel of the Makoye Reservoir combined with low gradient, low stream density and frequency tend to delay water delivery to the reservoir (Leopold *et al*., 1995; Ajith, 2006; Das and Saika, 2009). In the context of the current study, water in the main stream was almost always stagnant due to high sinuosity and low gradient thereby slowing the peak up and stability of the reservoir's hydrograph. At all temporal scales, the computed average volume of water in the Makoye Reservoir was 48,879 m^3, this was found to be lower than the average amount of water that was infiltrated into sediment before reaching its assymptotic limit. Generally, Makoye Reservoir exhibited marked seasonal fluctuations in water level between February and October similar to the behaviour of Malilangwe reservoir earlier studied by Dalu *et al*. (2013).

5.3 Socio-hydrogeological perspectives and implications of reservoir bathymetry on livestock

Sudden changes in water volumes within short temporal scales as illustrated in the reservoir's hydrological regimes (Figure 20f above) implies that, over 10,000 cattle domesticated by 474 households (MFL, 2016) would not have a adequate supply of water from mid-March to August during which reservoir utilisation is most critical. During interviews with 140 informants, 73 percent of them testified that the most water-stressful period in the catchment ranged from September to January (Appendix H) (also refer to Figure 21a-c, which shows that daily evaporation from the reservoir were highest during afore mentioned period). This water stressful period refers to the time when all the reservoirs in proximity are dry and Makoye Reservoir, which is usually the last to dry up, has completely dried up or almost completely drying up.

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 and farm works) and age (MFL,2016). In the context of the current study area, such water requirements for a cow per day, translates into over 400, 000 litres (400 m^3) 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 (146,000 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, excluding those from other nearby catchments.

There was a deficit of almost 50 percent compared to the quantity of water annually required by all the cattle. As ealier noted, the long term average of water quantity indicated a wide deficit in supply compared to the demand. This is a threat to water security especially that, during onset of water stressful period, hundreds of heads of cattle from other distant catchments like Chuuka (5-7 km away) come to drink from the Makoye Reservoir. This explains why the majority of respondents (55 percent) thought that water was not readily available in the catchment (Appendix G). Given the highly variable bathymetric and volumetric states of the water, water scarcity in the Makoye Reservoir's subbasin could be said to be chronic as it was found to be incapable of fully meeting the livestock's water demands. Such a situation may also trigger other challenges such as water-based conflict, travelling long distances (by both animals and people (especially women and children (MFL, 2016)) 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).

Based on the findings on Objective 1 and in line with the aforementioned issues, bathymetric studies need not only to be more related to fundamental science of hydrology (as was the case in most reviewed studies: Tharp 1999; Dierssen and Theberge, 2014; USACE, 2009; Ajith, 2016), but must also be linked to social hydrology, which ventures into understanding pressing societal problems such as water insecurity, conflicts, and other that may be linked to hydrology. Similarly, Thorndycraft *et al.* (2008) recommends that fluvial geomorphology needs not only be related to fundamental and technical scientific issues which are just understood by technocrats, but also to solving pressing societal problems such as those that emanate from sedimentation in small reservoirs such as Makoye (Muchanga *et al.*, 2019). 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 for learning about sediment control measures and water resources amidst climate (Muchanga, 2013).

In order to help water managers especially in Zambian context, participatory social hydrology would play an integral part, otherwise, the water-based societal problems such as those articulated by some respondents (animals getting stuck in mud when water dries out, delayed dipping of livestock, women travelling longer distances to fetch water, among others (Appendix H)) would persist in affecting socio-economic livelihoods whilst water scientists presumptuously claim that they are doing everything possible scientifically, when in the actual sense, these sciences cannot be understood by many policy makers in developing countries such as Zambia to guide their decision making. Therefore, to improve understanding of hydrological science and solution it offers to societal problems, 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. Social hydrology is currently one of the main concepts being debated in the community of hydrologists and some studies (Heidi *et al*., 2016; Theresa *et al*., 2016; Srinivasan *et al.*, 2016) are evolving, but in Zambian context, it is still quite very scanty.

5.4 Chapter summary

Regarding the bathymetric state of the reservoir, the study found that Makoye Reservoir's bathymetric state was unstable with multi-temporal coefficient of variation of 44 percent due to various physical processes especially sedimentation. Unstable bathymetry also implied that, the reservoir's water holding capacity was insufficient to meet the water demands for animal consumption and this would implicate negatively on the current and future water security within the subbasin. Redredging of the reservoir or possibly constructing another one down stream would offer a solution to this challenge, but as earlier hinted out in the context of social hydrology, community awareness and sensitisation would be imperative to raise a conscious in local people to avoid acitivities that propel the generation of sediment and its transportation to the reservoir. For instance, all gardens that are less than 50m away from the reservoir must be demolished and relocated downstream or somewhere else. Moreover, there is a widespread upstream bank cultivation of maize fields and grazing that should be abandoned. Selected upstream banks need to be protected to allow vegetation growth so as to reduce collapse of stream banks, inflow and deposition of sediment which reduces reservoir capacity. More details will be provided in the next Chapter Six.

CHAPTER SIX: LONG-TERM AND REAL TIME QUANTIFICATION OF SEDIMENT DEPOSITION IN THE MAKOYE RESERVOIR

This chapter presents and discusses results based on Objectives 2 and 3 whose main foci were determination of long term and real time sediment deposited in the Makoye Reservoir from 1988 to 2014 and 2015 to 2017, respectively. It starts by providing an overview of the hydro-geomorphometric features of the reservoir and thereafter, presents the main findings in each case, followed by a discussion and chapter conclusion respectively.

6.1 Hydro-geomorphometric characteristics of the Makoye Reservoir and its subbasin

By 2017, Makoye Reservoir was about 30 years old from the time of renovation. Its open dendritic network was found to be in its Second Order and sinuous. Unlike the handheld GPS whose accuracy of measurement is usually 3m, the DGPS widely improved onsite measurement accuracy to the nearest centimetre (0.13) or millimetre (1.3) (Table 10).

The Elongated basin of Makoye was erratically endowed with streams as illustrated by a very low stream density (0.05km/km^2) and frequency (0.04 stream/km^2) (stream segment/km^2). Worth noting from Table 10 is that, by 2017, the reservoir had lost about 56 percent of its original storage capacity. By 2017, the reservoir had a useful life of 23 years. This inherently implied that, if all factors both anthropogenic and physical remained constant, the reservoir may completely be filled up by 2040.

Generally, selected linear and areal aspects of the basin in which Makoye Reservoir is located are summarised in Table 10. All of them have a profound influence on transportation and delivery of sediment.

Table 10: Summary of selected hydro-geomorphometric parameters related to sedimentation in Makoye Reservoir, Monze District Zambia

<table>
<tr><th colspan="3">DESCRIPTION</th><th>VALUES</th></tr>
<tr><td colspan="3">Year of construction</td><td>1940</td></tr>
<tr><td colspan="3">Year of renovation (Dredging and rehabilitation)</td><td>1988</td></tr>
<tr><td colspan="3">Spillway elevation (m)</td><td>1106.700</td></tr>
<tr><td colspan="3">Crest Elevation (m)</td><td>1107.788</td></tr>
<tr><td colspan="3">Crest length (m)</td><td>220</td></tr>
<tr><td colspan="3">Downstream elevation (m)</td><td>1102.61</td></tr>
<tr><td colspan="3">Depression stream order</td><td>2nd</td></tr>
<tr><td colspan="3">Sinuosity of the main depressional channel (Straight <1, Sinuous 1-1.5, meandering >1.5)</td><td>1.4</td></tr>
<tr><td colspan="3">Minimum subbasin elevation (m)</td><td>1070</td></tr>
<tr><td colspan="3">Maximum subbasin elevation (m)</td><td>1145</td></tr>
<tr><td colspan="3">Average elevation of the subbasin (m)</td><td>1107.22</td></tr>
<tr><td colspan="3">Average sediment depth based on 166 pits (m)</td><td>0.72</td></tr>
<tr><td colspan="2" rowspan="2">Projected Useful Life (years)</td><td>by the year 2014</td><td>23.6</td></tr>
<tr><td>by the year 2017</td><td>23.1</td></tr>
<tr><td colspan="3">Subbasin Area (km^2)</td><td>66.8</td></tr>
<tr><td colspan="3">Total distance of streams in the subbasin (km)</td><td>3.22</td></tr>
<tr><td colspan="3">Stream density (length of stream segments/area occupied) (km/km^2)</td><td>0.05</td></tr>
<tr><td colspan="3">Stream frequency = (stream segments/km^2)</td><td>0.04</td></tr>
<tr><td colspan="3">Long term average depth of sediment based on 26 year period (cm)</td><td>2.8</td></tr>
<tr><td>Drainage shape: Elongated</td><td>Drainage pattern: Open dendritic</td><td>Flow type: Unsteady</td><td>Ground Accuracy during measurement: 0.0013m</td></tr>
<tr><td rowspan="3">Total annual measured depth of Sediment in real time using Sedimeter SM3A (cm)</td><td colspan="3">Mode of Sediment transport: Suspension</td></tr>
<tr><td>2015/2016 warm-wet season</td><td>0.688</td><td rowspan="2">Mean: 1.12</td></tr>
<tr><td>2016/2017 warm-wet season</td><td>1.56</td></tr>
<tr><td colspan="3">Difference between long term (1988-2014) and short term average depth of sediment (cm)</td><td>1.68</td></tr>
<tr><td colspan="3">Reservoir Sedimentation (m^3y^{-1}) (26-year period)</td><td>3, 209.86</td></tr>
<tr><td rowspan="3">Reservoir Storage Capacity (m^3)</td><td colspan="2">Original (mean sediment volume (msv)) + (measured water volume at spillway level (wv_{sl}))</td><td>160,689.67</td></tr>
<tr><td rowspan="2">Measured (($msv+mwv_{sl}$)-msv))</td><td>By the year 2014</td><td>75,753.56</td></tr>
<tr><td>By the year 2016-2017</td><td>74,273.71</td></tr>
<tr><td>Storage capacity loss (%)</td><td colspan="3">($msv/(msv+mwv_{sl})\times100\%$: 52% by 2014; 54% by 2017</td></tr>
</table>

$*_{sl}$ *Spillway level*

6.2 Long-term quantity of sediment

Makoye Reservoir was found to have impounded a lot of sediment. The average between sediment quantity determined through GIS techniques (87,163.14 m^3) and the one determined using Elevation Change Method (ECM) (79,749.38 m^3) was 83,456.26 m^3 (Table 11).

Table 11: Computed sediment volume of the Makoye Reservoir based on different techniques

ArcGIS 3DSAT Techniques								**ECM**	**Mean for All techniques**
Inverse Weighted Distance (IDW)			**Nearest Neighbour (NN)**	**Triangulated Irregular Network (TIN)**	**Krigging (K)**	**Mean (IDW, NN, TIN, K)**			
Sediment Depth (m)	**Surface Area (m^2)**	**Sediment Volume (m^3)**	**Volume (m^3)**					**(m^3)**	
2.29	76,437.11	**56,648.09**	95,905.09	95,988.75	100,110.62	87,163.14		79,749.38	**83,456.26**
2.25	76,239.85	45,188.27							
2.1	73,418.30	33,867.18							
1.95	61,264.18	23,881.51							
1.8	49,846.06	15,490.23							
1.65	35,693.08	9,019.48							
1.5	23,449.25	4,517.49							
1.35	12,727.78	1,880.10							
1.2	4,883.82	591.73							
1.05	1,252.66	197.92							
0.9	395.61	98.35							
0.75	220.8	54.35							
0.6	137.52	27.94							
0.45	80.79	11.93							
0.3	39	3.28							
0.15	6.75	0.12							
0	0	0							
CV (%) between the sediment volume computed through GIS Techniques and ECM (difference between sediment maximum depth and downstream depth)									**6**
Average sediment depth (m)*									**0.72**

*The reservoir was assumed to be trapezoidal-shaped

The depth of sediment varies from one point to the other across the reservoir and this also influenced the quantity that can be trapped at each depth segment. Figure 23a-b respectively show how pits and sediment were distributed across the reservoir bed. The depth of sediment (see sample in Table 12 or full raw data in Appendix I) was spatially variable with average depth of 0.72 m (Table 11).

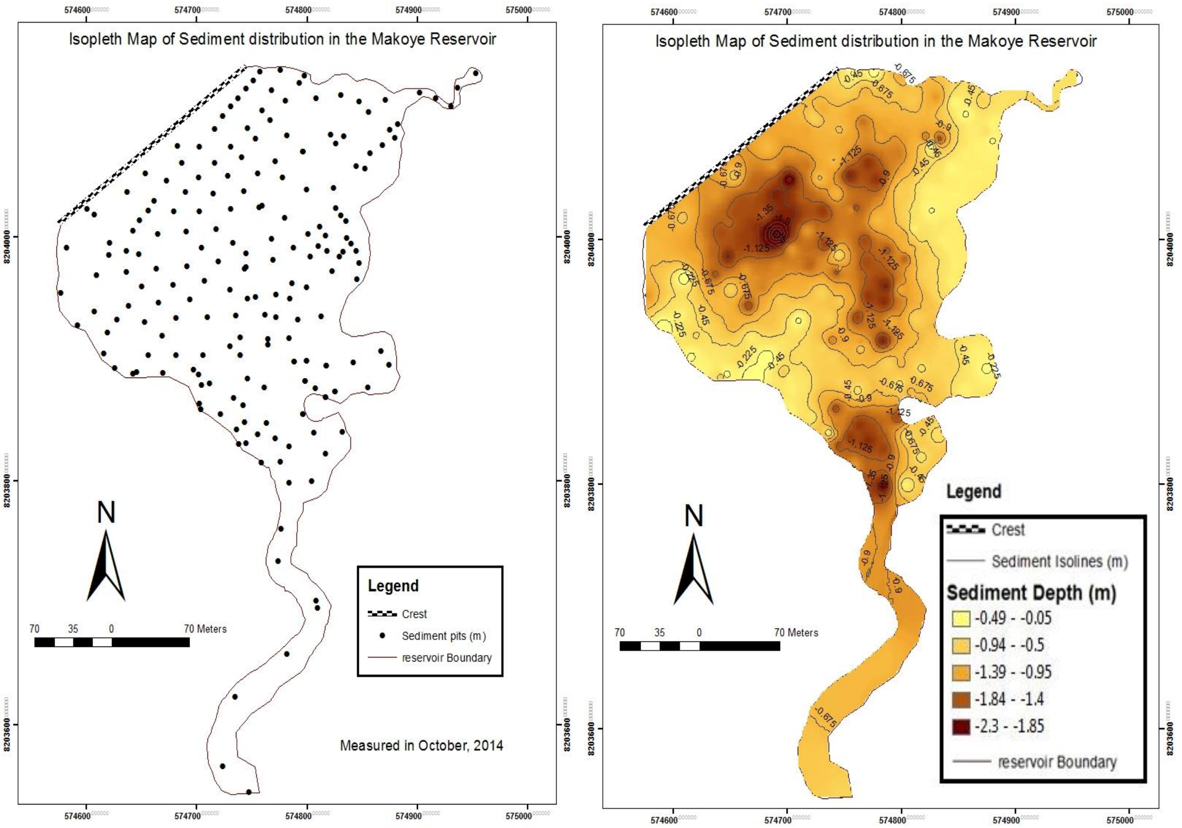


Figure 23: (a) Distribution of sediment pits and (b) sediment depths across Makoye Reservoir.

Table 12: Samples of sediment pits at Makoye Reservoir

Pit no.	Location in UTM		Sediment depth (m)
	X	Y	
1	574591.790	8203927.760	-0.1
2	574609.380	8203968.580	-0.1
3	574620.200	8203985.290	-0.84
4	574636.020	8203988.670	-1.1
5	574642.090	8204005.420	-1.2
6	574648.490	8204013.820	-1.1
7	574655.950	8204022.020	-1.2
8	574661.560	8204029.800	-1.2
9	574672.560	8204046.350	-1.1
10	574686.820	8204060.690	-0.9

The relationship of sediment depth to surface area and sediment depth to volume was found to be very strong (r^2 = >0.90) (Figure 24a-b). This means that if sedimentation continues at the current rate, it will decrease the depth and the surface area which should be occupied by water, would be occupied by sediment.

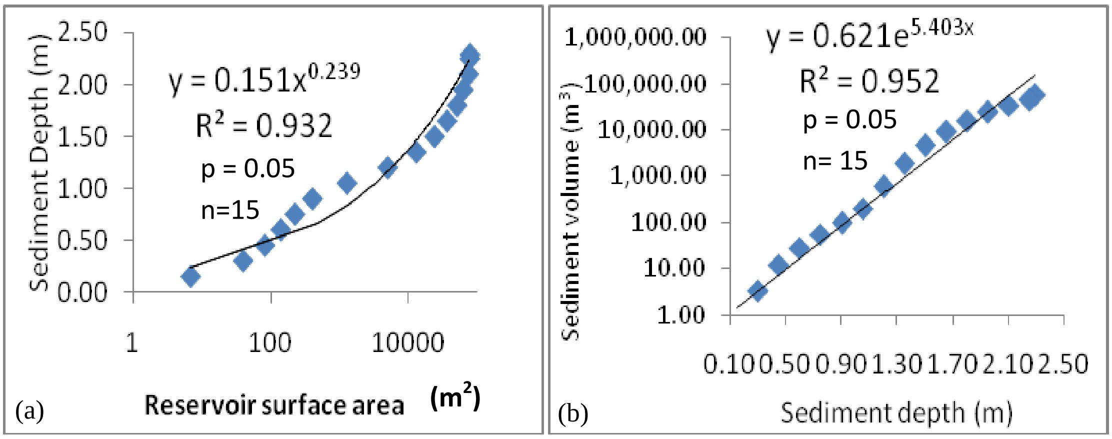


Figure 24: (a) Depth- surface area relationship and (b) depth-volume relationship of sediment.

Sediment was found to be highly compacted as demonstrated by high dry bulk density of 2.06 tonnes/m^3. From 1988 to 2014, the gravimetric quantity of sediment was 172,104.2 tonnes and as earlier mentioned, the estimated amount of water required to saturate it was about 56,400 m^3 (Table 13).

Table 13: Sediment bulk density analysis and related results in the Makoye Reservoir based on radius of sediment core=3.36 cm, Height of sediment sample 50 cm, ∏ = 3.142, SDBD = Sediment Dry Bulk Density

Description of parameters		**Computed values**
	Corer+ Wet Sediment (Kg)	8
	Corer + Dry Sediment (Kg)	7.95
	Corer (Kg)	0.95
	Water content (Kg)	0.05
	Sediment Weight (Kg)	7
	Volume of sediment core sample (m^3)* (V=(2∏r^2)H	0.00335
Bulk Density	Dry bulk density (tonnes/m^3)	2.06
Computed weight of sediment sunken in the reservoir (t) (Sed. Vol. *SDBD)		172.1042 x 10^3
Computed weight of water impounded by sediment in reservoir at the time of measurement kg)		1,229,315.46
Computed volume of water impounded by sediment by the time of measurement (1 m^3 of water:1000 kg) (m^3)		1,229.32
Volume of water used to thoroughly saturate the Makoye Reservoir's sediment core sample in laboratory (m^3)		0.0023
Estimated volume of water required to saturate the total sediment deposited in reservoir (m^3) V=(measured sediment volume/0.00335)*0.0023		56,400.096

(25/10/2014)

6.3 Short-term and real time depth, volumetric and gravimetric sedimentation in the reservoir

In addition to determination of long-term sediment quantity, short term was also done and in real time. A total of 0.02248 m of sediment was deposited on the reservoir bed during the 2015/2016 and 2016/2017 warm-wet seasons. Table 14 presents two sets of first 24 hours of measurements for 2015/2016 and 2016/2017 warm-wet seasons. Appendix J presents all real time daily measurements on which the computations were based using the mathematical model: Sediment Volume (SV) = (20661*(Depth)^2 - 29262 * (Depth) +5905) and Sediment Load = SV*2.06.

Table 14: Extracts of real time sedimentation rates for the first 24 hours in the 2015/2016 and 2016/2017 warm-wet season at Makoye Reservoir

2015/2016 rainy season			**2016/2017 rainy season**		
Date	**Time**	**Sedimentation (m/hr)**	**Date**	**Time**	**Sedimentation (m/hr)**
4/3/2016	14:00:00	0.00002	11/28/2016	15:00:00	0
4/3/2016	15:00:00	0.0007	11/28/2016	16:00:00	0
4/3/2016	16:00:00	0.0001	11/28/2016	17:00:00	0.00003
4/3/2016	17:00:00	0.00045	11/28/2016	18:00:00	0
4/3/2016	18:00:00	0	11/28/2016	19:00:00	0
4/3/2016	19:00:00	0.0002	11/28/2016	20:00:00	0
4/3/2016	20:00:00	0.0001	11/28/2016	21:00:00	0
4/3/2016	21:00:00	0.0001	11/28/2016	22:00:00	0
4/3/2016	22:00:00	0.0007	11/28/2016	23:00:00	0
4/3/2016	23:00:00	0.00045	11/29/2016	0:00:00	0
5/3/2016	0:00:00	0	11/29/2016	1:00:00	0
5/3/2016	1:00:00	0	11/29/2016	2:00:00	0.000004
5/3/2016	2:00:00	0	11/29/2016	3:00:00	0
5/3/2016	3:00:00	0	11/29/2016	4:00:00	0
5/3/2016	4:00:00	0	11/29/2016	5:00:00	0
5/3/2016	5:00:00	0	11/29/2016	6:00:00	0
5/3/2016	6:00:00	0	11/29/2016	7:00:00	0
5/3/2016	7:00:00	0.00001	11/29/2016	8:00:00	0
5/3/2016	8:00:00	0	11/29/2016	9:00:00	0
5/3/2016	9:00:00	0.00001	11/29/2016	10:00:00	0
5/3/2016	10:00:00	0.00001	11/29/2016	11:00:00	0
5/3/2016	11:00:00	0	11/29/2016	12:00:00	0
5/3/2016	12:00:00	0	11/29/2016	13:00:00	0
5/3/2016	13:00:00	0	11/29/2016	14:00:00	0.000005
Day's Total (m/day)		0.00285	Day's Total (m/day)		0.000039
Day's Maximum value		0.0007	Day's Maximum value		0.00003
Day's Minimum value		0.0001	Day's Minimum value		0.000004
Day's Mean (m/day)		0.00012	Day's Mean (m/day)		0.000002

Source: Field Measurements Using Sedimeter SM3A (2015/2016 and 2016/2017 rainy seasons)

It was observed that sediment depth was increasing steadily between 2014 and 2017 rising from 2.29 m in 2014/2015 to about 2.32 m by the end of of 2016/2017 warm-wet season (Figure 25a-b). Estimated ratios of sediment depth and water depth in the reservoir were computed by comparing the first and last maximum sediment depths (2.29 m and 2.31 m) with first and last maximum water depths (1.87 m and 1.78 m), respectively. As shown in Figure 25b, the sediment-water depth ratio at the begining of measurements in 2014/2016 was 1.21 m to 1 m, but at the end of the measurement in 2017, it was 1.26 m to 1 m. The graphs below illustrate how sediment depth changed per day and over the entire period of measurement. The idea behind this was to estimate depth of sediment and eventually use it for computation of real time sedimentation in volumetric and gravimetric terms assuming that sediment of same size settled at the same time within the bottom set of the reservoir and using formula shown under Table 14. The reservoir shape was also assumed to be trapezoidal and that sedimentation was taking place in the main reservoir not on the throwback.

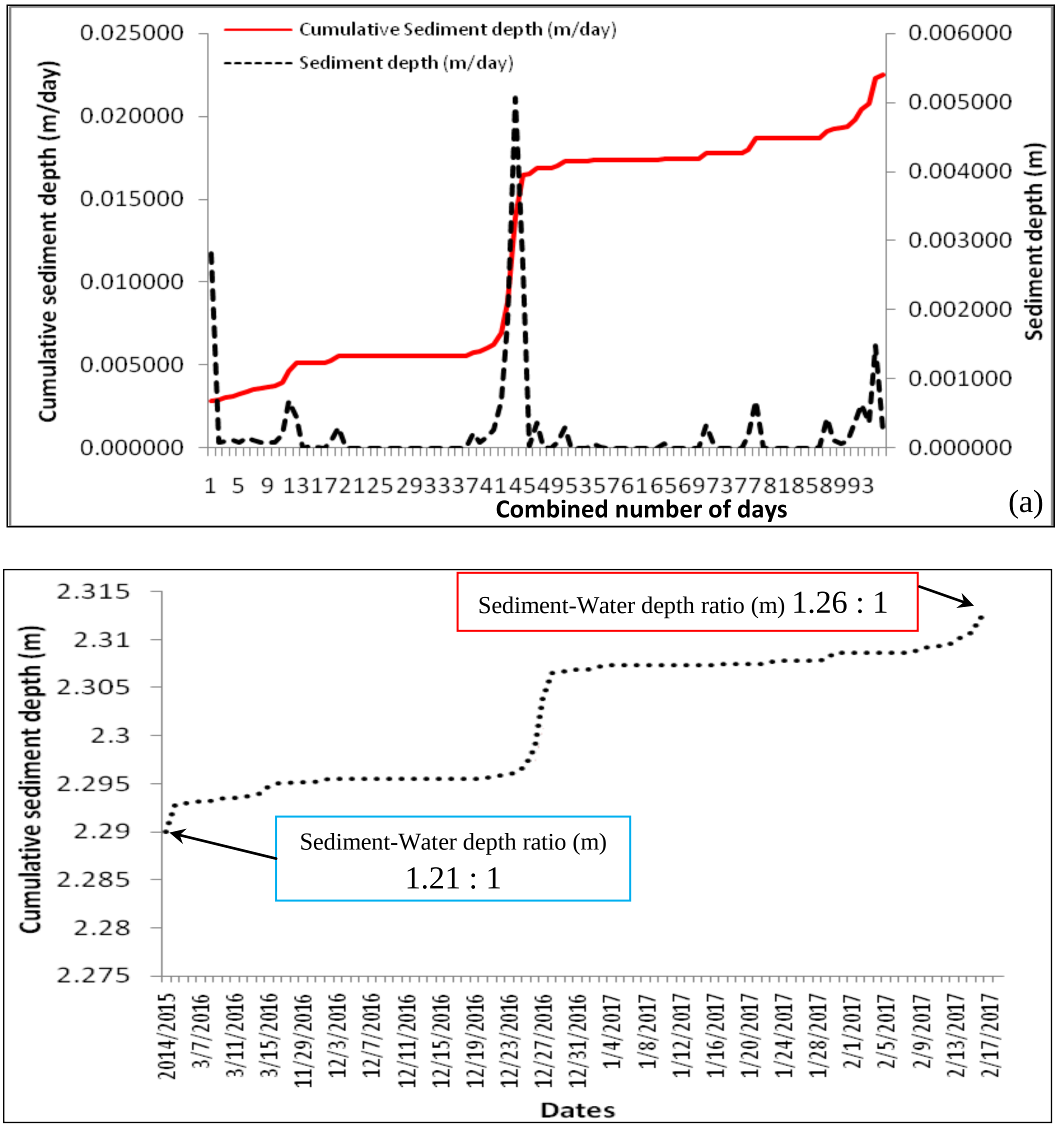


Figure 25: (a) Real time sedimentation for Makoye reservoir during the 2015/2016 and 2016/2017 periods and (b) Sediment depth changes and ratio in relation to water depth.

The relationship between real time mean daily sedimentation (in metres) and daily rainfall were established. After editing out some outliers, the result showed that there was a very strong relationship (r^2 = 0.93) between daily rainfall and mean sediment depth in real time (Figure 26a-b). The volumetric and gravimetric quantities of sediment are respectively shown in Figure 27a-b. These values were plotted based on data presented in Appendix J. A very strong relationship (r^2 = 0.99) between real-time sediment depth and volume as well as, daily rainfall and load of sediment was noted (Figure 27c-d). Major sediment depositions happened during peak rainfall events.

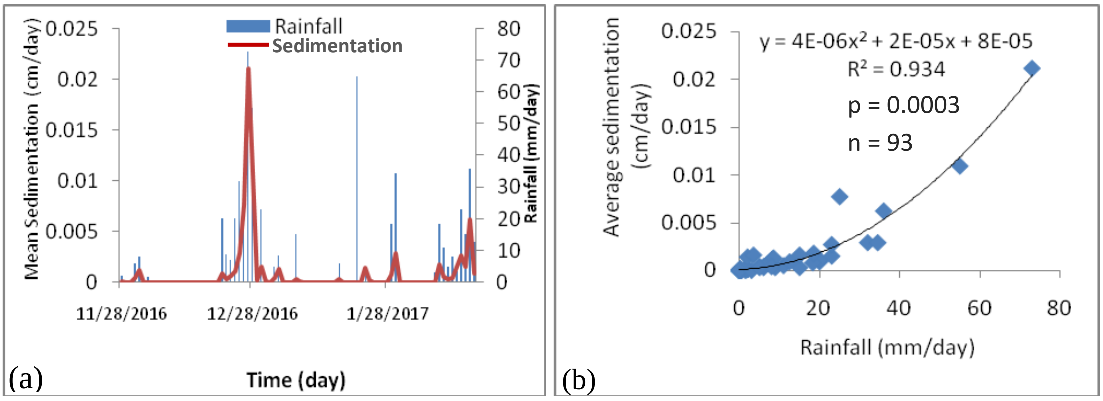


Figure 26: (a) Real time mean sedimentation trends in relation to changes in daily rainfall and (b) relationship between daily rainfall and real time mean sediment depth in the Makoye Reservoir during the 2015/2016 and 2016/2017 rainy seasons.

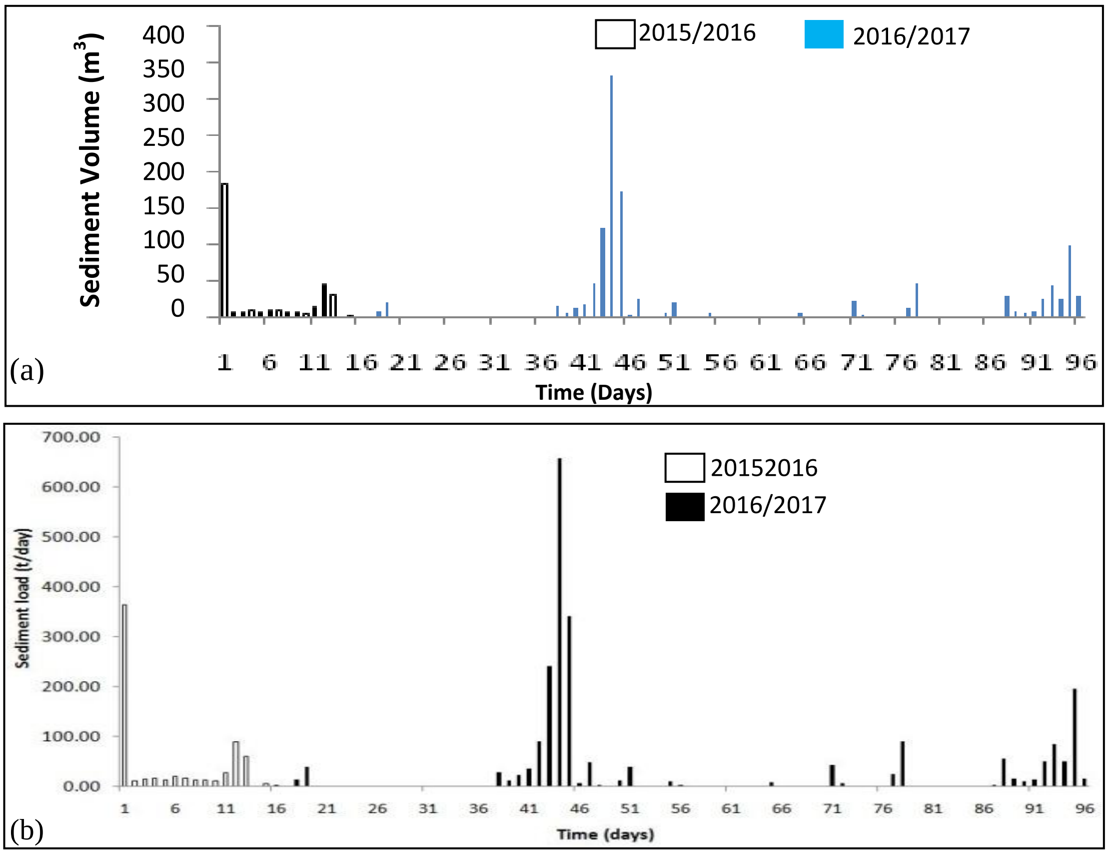
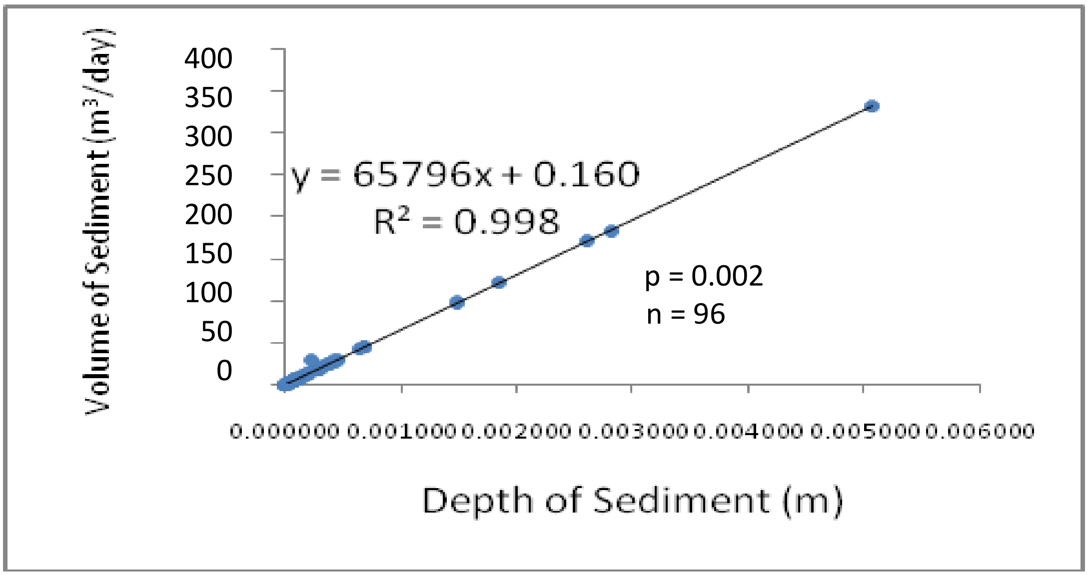


Figure 27: Computed real time daily (a) sediment volume (b) sediment load for Makoye Reservoir



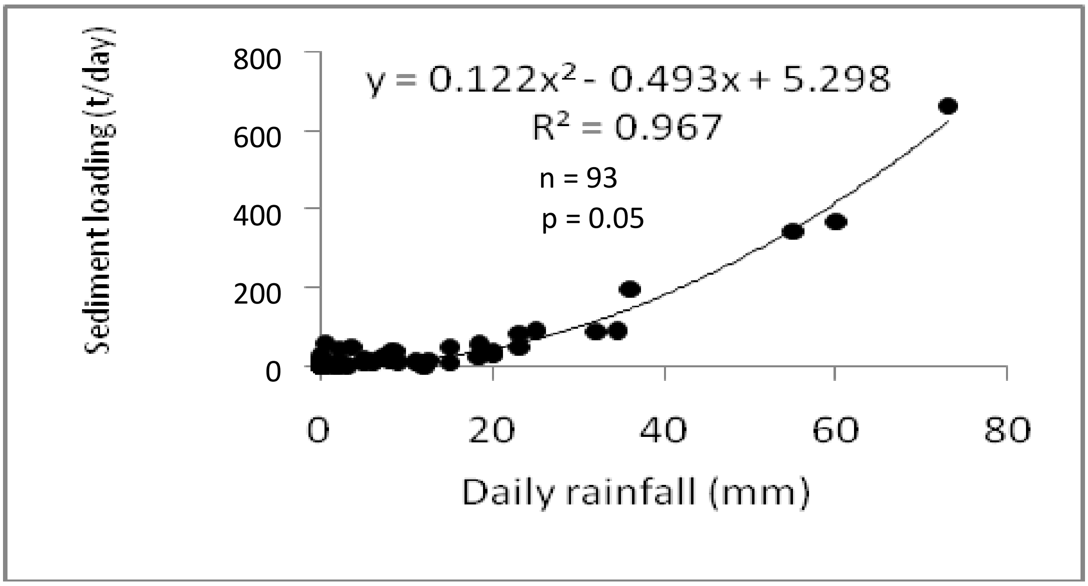


Figure 27: (c) Relationship between daily rainfall and real time daily sediment volume; (d) relationship between daily rainfall and daily sediment load for Makoye Reservoir during the 2015/2016/2017 warm-wet season.

In real time, inter-seasonal loadings of sediment for 2015/2016 and 2016/2017 were 685.57 tonnes and 2,362.90 tonnes, respectively (Table 15).

Table 15: Summary of computed sedimentation rates based on real time measurements at Makoye Reservoir, Monze District, Zambia.

Parameter	2015/2016 seasonal total	2016/2017 rainy season				2016/17 Seasonal total	Total for two seasons
	March	**Nov**	**Dec**	**Jan**	**Feb**		
Sediment Vol. (m^3)	**332.80**	2.94	773.91	117.19	253.00	**1,147.04**	**1,479.85**
Sediment Load (t)	**685.57**	6.06	1,594.26	241.41	521.18	**2362.90**	**3048.49**

During the 2014/2015 warm-wet season, sediment volume was 83,456.26 m^3 (172,104.2 tonnes), but by the end of 2016/2017 warm-wet season, it rose to 84,936.11 m^3 (175,026.17 tonnes). The sharp rise in Figure 28 coincided with heavy rainfall days. Hence, the best time for real time measurement of sediment is at the peak of rainfall because that is the time when much of transportation and deposition of sediment take place. Sediment-water volume ratios were 1.10 to 1 in 2014-2016 and 1.14 to 1 in 2017 (Figure 28). These were estimated using the same method, which was used to estimate depths ratios.

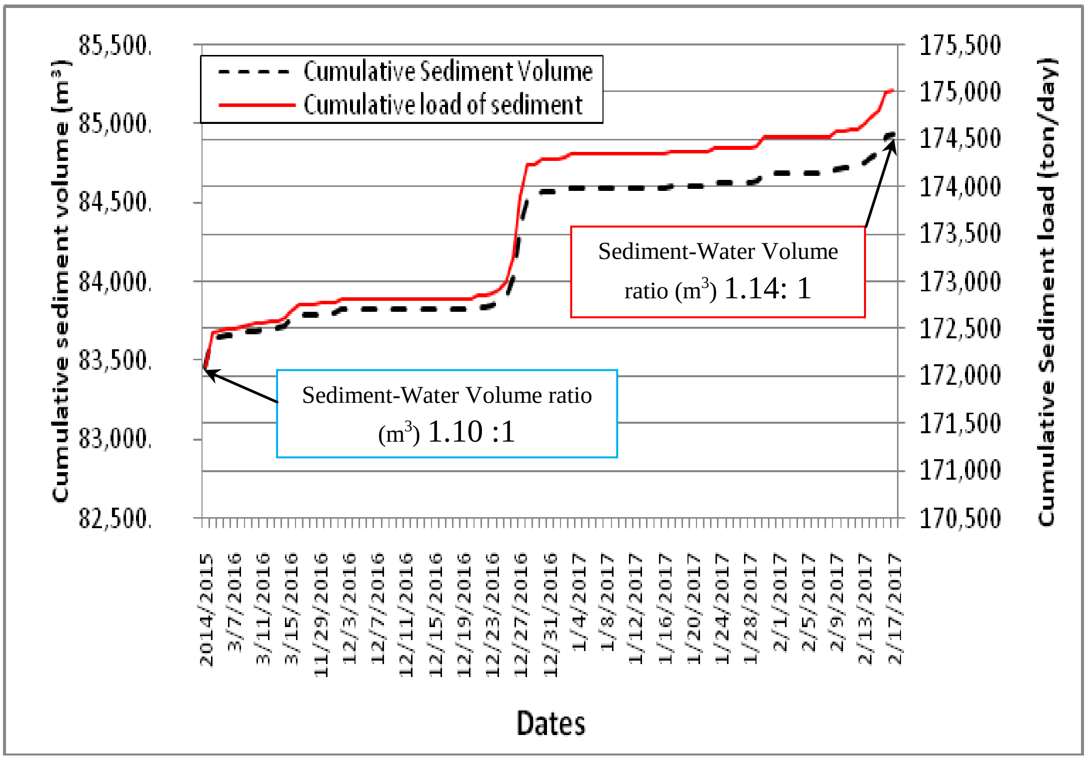


Figure 28: Relationship between cumulative sediment volume and cumulative sediment load for the Makoye reservoir for the period 2014 to 2017.

6.4 Discussion of results

The proceeding subsections discuss the above results in details, focussing on sediment volume, bulk density, loading as well as how such related to long-term sedimentation, reservoir capacity and useful life, respectively.

6.4.1 Hydro-geomorphometry, volume, bulk density and gravity of sediment

By the end of field measurements in 2017, Makoye Reservoir was 77 years old from the initial time of construction in 1940. However, going by the time when it was first renovated in 1988, is said that, by 2017, the reservoir was 30 years old. The reservoir is fed by a expressional channel with a second level stream order (Strahler, 2013).

Thornbury (1965) and Leopold *et al.* (1995) argue that low stream order such as first and second are usually associated with low sediment delivery especially if the stream density and frequency are also low as was the case for the Makoye Subbasin. Moreover, the stream distance in the subbasin was found to be only 3.22 km, which validates low stream frequency recorded. The type of drainage pattern is open dendritic (Strahler, 1964) with unsteady flow (Leopold *et al*., 1995) domiciled in an elongated subbasin whose size was 66.8 km^2.

There was no spatial homogeneity in terms of sediment depths distribution and by the time of measurement in 2014, the depth of sediment in Makoye Reservoir varied from 0.1 m to 2.29 m, averaging to about 0.72 m. The long term average depth of sediment based on 26 year period (1988-2014) was 2.8 cm or 0.028 m. Based on the GIS 3DSAT techniques, the quantity of sediment across the reservoir surface area was 87,163.14 m^3. Alternative computational algorithm (ECM) showed that 79,749.38 m^3 of sediment was sunken in the reservoir during the 26 year period. Since the latter value was within acceptable magnitude (CV = six percent) when compared to the former one, the final long term average volume of sediment was 83,456.26 m^3. As also observed in earlier studies (Brunner, 2011; Mavima *et al.*, 2011; Kamtukule and Kaseke, 2012; Sichingabula, 2018), sediment volumes that fall within such magnitude for small reservoirs (such as Makoye) are likely to reduce their optimum function due to reduced useful life and capacity. Hence the need to put up sediment control measures to preserve the current capacity (about 70,000 m^3) for the next decades. Dry bulk density (2.06 tonnes/m^3) indicated that, settled sediment on the reservoir bed was highly compacted gravimetrically translating its volume into 172.104×10^3 tonnes.

Hypsometric graphical analysis of sediment depth and volume relationship showed very strong positive non-linear relationship. Sediment volume deposited in the reservoir was very strongly dependent on the depth as illustrated by very strong r^2 values of about 0.95 and *p*-value of 0.0000003. Sediment surface area was also increasing with increase in sediment depth, a very strong relationship was determined with r^2 and *p* values of 0.98 and 0.001, respectively. As earlier observed in Chapter Five, this quantity of sediment affected the bathymetric stability of the reservoir and intrinsically points to high sedimentation rate as discussed in the following section.

6.4.2 Sedimentation rate

Based on computed long term quantity of sediment, the long term rate of sedimentation in the Makoye Reservoir for the period 1988 to 2017 was estimated at 3,209.86 m^3/year or 5834.12 tonnes/year. This was higher than the rates of sedimentation of some reservoirs earlier studied by Chomba and Sichingabula (2015) in Lusaka East, Zambia and by Kamtukule and Kaseke (2012) at Chamakala reservoir in Malawi. Tamene *et al.* (2011) and Haregeweny *et al.* (2006) also studied reservoirs whose rates of sedimentation were within magnitudes as those of Makoye Reservoir. The rapid rate of sedimentation in the Makoye Reservoir could partly be attributed to its small surface area (76,437.11 m^2), bank collapses, gully erosion as well as anthropogenic activities such as animal watering adjacent to the reservoir, crop agriculture, animal grazing, brick moulding, among others (Plate 6a-f).

Landcover change should have also indirectly catalysed generation, transportation and deposition of sediment in the reservoir, actually some earlier works (Tamene *et al.*, 2011; Haregeweny *et al.* 2006; Leopold *et al*. 1995) have perspicuously documented the influence of landuse change on sedimentation rates. In his earlier study of sediment transport in the Luangwa Catchment, Sichingabula (2000) noted that Luangwa River transported a total of 457 million tonnes of sediment with an annual mean of 15 million tonnes of clastic sediment deposited into the Zambezi River. This is noted in the current study, as huge sediment flux was partly attributed to anthropogenic activities. McCully (2001:1) further adds that, "the rate of reservoir sedimentation depends mainly on the size of a reservoir relative to the amount of sediment flowing into it. Small reservoirs such as Makoye on an extremely muddy river or stream lose capacity faster than large reservoirs. At such a rate of sedimentation as noted in this study, reservoir capacity is most likely to be compromised and consequently, its useful life reduced.

Plate 6: Selected causes and sources of rapid sedimentation in the Makoye Reservoir; (a) bank erosion of the stream feeding into the reservoir; (b) part of the stream blocked by the gardeners to intercept water for garden watering; (c) open cultivated and grazing fields on the banks; (d) biological loosening of soils/sediment as cattle drink from the reservoir; (e) wells sunken on the throwback of the reservoir with excavated debris dumped in water; and (f) brick moulding on the banks of the reservoir. (2016/2017)

6.4.3 Reservoir capacity and useful life

The long-term quantity of sediment loaded in the Makoye Reservoir (by 2014) reduced its original reservoir capacity (160,689.67 m^3) by over 50 percent since 1988 when the reservoir was renovated. This means that only less than 50 percent of reservoir storage capacity was available as of 2014. So when the reservoir gets full, about 70,000 m^3 of water is wasted over the spill way, with possible risks of causing crop and household flooding downstream. This reservoir capacity loss was found to be within closer range with those earlier observed in other spatial contexts by Rooseboom and Lotriet (1992) at Welbeck reservoir in South Africa (66 percent), Haregeweny *et al.* (2006) at several reservoirs in Ethiopia (50 percent), Onwuegbunam *et al.* (2009) at Afaka reservoir in Nigeria (35 percent), Chihombori *et al.,* 2013 at Marah reservoir in Zimbabwe (50 percent), Majumdar (2015) at Khodiyar Reservoir in Gujarat, India (36.12 percent) and Rahmani *et al.* (2018) at selected reservoirs in central USA (17 percent on average).

By 2014, the useful life of Makoye Reservoir stood at 23.6 years, but given the dynamics that characterise rates of sedimentation, the life span may possibly be less or more than the projected duration. This means that by the year 2040 or before that time, the reservoir may possibly not be functional if sedimentation is not addressed. A recent study by Sichingabula (2018) also indicates that by the year 2040, several small reservoirs in southern Zambia may be filled with sediment in the near future. As earlier shown under discussion of bathymetric results in Chapter Five, the total load of clastic sediment trapped in the Makoye Reservoir absorbed an estimated 1,229.32 m^3 of water by the time of measurement (October, 2014). Had the water not been trapped in sediment, it would have been useful for livestock during that water stressful period. Using Equation 27 devised in this study, about 56,400 m^3 of water was required to saturate about 83,456.26 m^3 of dry sediment in Makoye Reservoir before water could start accumulating for livestock and domestic purposes.

Where:

$$V_{wss} = V_{tsr}\left(\frac{V_{dss}}{V_{scs}}\right) \quad (27)$$

V_{WSS}	Estimated volume of water required to saturate total volume of sediment in a reservoir (m^3);
V_{tsr}	Total measured volume of sediment in the reservoir (m^3);
V_{dss}	Volume of water required to saturate dry sediment core sample (m^3); and
V_{scs}	Volume of sediment core sample (m^3).

The above scenario confirms that sedimentation is a main challenge that hydro-geomorphologists and water resource managers have to struggle with as compared to other physical processes earlier discussed. The short term measurement of moving sediment deposition indicated that more water would actually be required as the reservoir continues silting up.

6.5 Real time total daily depth of sediment and sedimentation rates

The maximum daily real time sedimentation rates during 2015/2016 and 2016/2017 warm-wet seasons were 0.003 m/ day and 0.005 m/day, respectively. During the respective periods, minimum records for both seasons were 0.00001 m/day and 0.000001 m/day. Due to very scanty rainfall during the 2015/16 rainy season, measurements could only be done in March during which 332.80 m^3 of sediment was deposited in the reservoir. During the 2016/17 rainy season, sediment depositions were spread across four months, the highest (773.91 m^3) total sediment deposition was recorded in December at the peak of rainfall. The total volume of sediment deposited in the reservoir for both seasons was 1,479.85 m^3. The total depth of sediment that settled on the Makoye Reservoir bed for the 2015/2016 warm-wet season was 0.00688 m and the average settling rate for the entire period was 0.0004 m/day. In the 2016/2017 warm-wet season, the total depth of sediment deposited on the Makoye Reservoir bed in real time was 0.0156 m, with average settling rate at 0.0002 m/day. During this season, sedimentation readings in volumetric and gravimetric terms were fairly spread across the entire period of measurement as compared to the 2015/2016 warm-wet season and this could be linked to a good distribution of rainfall across various days during the 2016/2017 warm-wet season than during the 2015/2016 one.

Cumulatively, sediment depth (Figure 25 above) showed a positive increase over the two periods of measurements and a total of 0.02248 m of sediment had approximately accumulated on the reservoir bed during the two seasons. This was fairly closer (CV = 16 percent) to the long term (1988-2014) average depth (0.028m) of sediment determined through sediment coring. Real time sediment depth cumulatively led to an increase in the depth of sediment and eventually the load or volume by the end of 2016/2017 warm-wet season.

6.6 Real time relationship between rainfall and daily sediment depth

During the 2015/16 warm-wet season, low accumulation of sediment was caused by scanty rainfall punctuated by El-Nino (ZMD, 2016), hence, results cannot be generalized to the whole warm-wet season as they were only restricted to individual rainfall events. Figure 20a-b above showed a strong positive relationship (r^2 = 0.93) between daily rainfall and mean sediment depth in real time. This means that 93 percent of the sediment quantity that transported and deposited into the reservoir bed could be explained by the amount of rainfall received. The strong relationship between rainfall and sedimentation has already been noted in earlier studies by Langbein and Schumm (1958); Sichingabula (1997); Rajtantra (2013), among others. This therefore shows that, the best timing for measuring sedimentation especially in real time is during peak rainfall periods.

6.7 Real time sediment depth-volume-load relationships

Similar to the coring method results earlier discussed, real time sediment depth very strongly (r^2 = 0.99) influenced sediment volume. The relationship between daily rainfall and daily sediment load (in tonnes) was also found to be very strong as indicated by r^2 value of 0.97. This means that sediment depth strongly and positively influenced the volume of sediment. During the 2015/16 rainfall events, 332.80 m^3 of sediment was deposited in the reservoir. This gravimetrically translated into 657.12 tonnes of sediment loaded into the reservoir. In the 2016/2017 warm-wet season, sediment depositions were volumetrically spread across four months, the highest (773.91 m^3) was recorded in December, 2016 at the intensification of rainfall. The second highest record (253 m^3) was noted in February 2017, followed by January, 2017 during which 117.19 m^3 was recorded. The least record (2.94 m^3) was captured in November, 2017 at the onset of the rainy season. Gravimetrically, the total volume of sediment deposited in the reservoir during the 2016/2017 was 2264.85 tonnes. Therefore, for both seasons, the total deposition was 1,479.85 m^3 translating into 2,921.97 tonnes during the two periods of measurements in real time. The average between the long-term and real time sediment loading in the Makoye Reservoir was still found to be high at over 4,000 tonnes/year, intrinsically pointing to a poorly managed catchment (Kamtukule, 2008). The real time sediment loadings provided physically measured data (Appendix G) for the calibration and validation of the SWAT Model of sedimentation for the Makoye reservoir.

6.8 Cumulative sediment depth and cumulative sediment loads

The increase in sediment depth from 2.29 m in 2014 to 2.3125 m at the end of 2016/2017 warm-wet season respectively led to increase in sediment volume from about 83,456.26 m^3 (172,104.2 tonnes in 2014) to about 84,936.11 m^3 (175,026.17 tonnes in 2017). This represents a two percent increment from the initial quantity of sediment measured in 2014. Since the storage loss was computed at 54 per cent in 2014, it can be said that, by the end of 2016/2017 warm-wet, the storage loss had increased to 56 percent, which means that even the useful life further reduced from 23.6 years in 2014 to about 23.1 years in 2017. Most of the small reservoirs surveyed by Sichingabula (2018) were also found to have a life span of less than three decades if sediment remained untamed.

6.9 Chapter Summary

The study concluded that, sedimentation is a major problem in the Makoye Reservoir and its catchment. With average annual siltation rate above 5,000 tonnes/years, the reservoir was highly silted with sediment (>172,000 tonnes) whose magnitude was high as compared to other selected reservoirs with similar problem. This burden of sediment already compromised the storage capacity by over 50 percent and reduced water holding capacity thereby punctuating water stressful period in the catchment. Although the average sediment settling rate in real time was mild (0.0003 m/day), the findings pointed to a pending rise in sedimentation rates, reduction in reservoir depth and storage capacity in the near future. Based on the real time measurements, the study revealed that, about 2% of the reservoir's storage capacity was lost during the period of measurement raising Makoye Reservoir's storage capacity loss from 54% in 2014 to about 56% by the end of 2016/2017 warm-wet season. It was noted that, rainfall is critical in determining real time sediment settling rates as there was a strong link between the two variables.

Sustainability of water supply for animals is possibly under threat because the reservoir's useful life was found to have been reduced to only about 23.1 years by 2017. This implies that, by 2040 or in less than three decades, there is a possibility that the reservoir may not be functional if sedimentation rates remain unchecked. It should also be noted that deposition is a non-linear phenomenon (Sichingabula, 2000), as such, there is also a likelihood that the reservoir may last longer than the estimated useful life depending on the anthropogenic activities and physical processes on the upstream of catchment.

Sedimentation was generally found to be a major threat to pastoral economy of the residents in the catchments given that, it had compromised Makoye Reservoir's water storage capacity. There is therefore a need for sustainable catchment management strategies which may include community engagement through relevant authority on reduction of sediment generation from the upstream crop and grazing fields, planting trees within radius of 50 metres around the reservoir catchment and controlling animal passages around the reservoir.

CHAPTER SEVEN: COMPOSITION OF SOILS, SEDIMENT AND WATER QUALITY FOR LIVESTOCK PURPOSES

This chapter focuses on presentation and discussion of results based on Objective 4 and it is divided into four sections. The first subsection presents results on the composition of soils and moving sediment as well as settled sediment, respectively. Although these were not reflected in the objective, they have a strong link with regard to the study of water quality. The second part presents results of water quality from spatio-temporal context. The third part focuses on the links between the chemical characteristics of sediment and hydrochemistry of the reservoir. The last part provides a discussion of these results. All the analytical results and discussions were based on raw data in Appendix M, Appendix N and Appendix O.

7.1 Composition of soils on the catchment upstream, and moving and settled sediment in the Makoye reservoir

This section discusses the composition of soils on the catchment upstream as well as moving and settled sediment in the Makoye Reservoir.

7. 1.1 Soils and moving sediment

The composition of soils across Makoye Reservoir basin showed similarities and also variations. In absolute terms, the most notable one was sodium (17.07 cmol/kg) whose main source was from range/grassland soils. The range/grassland soil also accounted for the highest content of Sulphur (165.29 mg/kg) when compared to other sampling points (Figure 29).

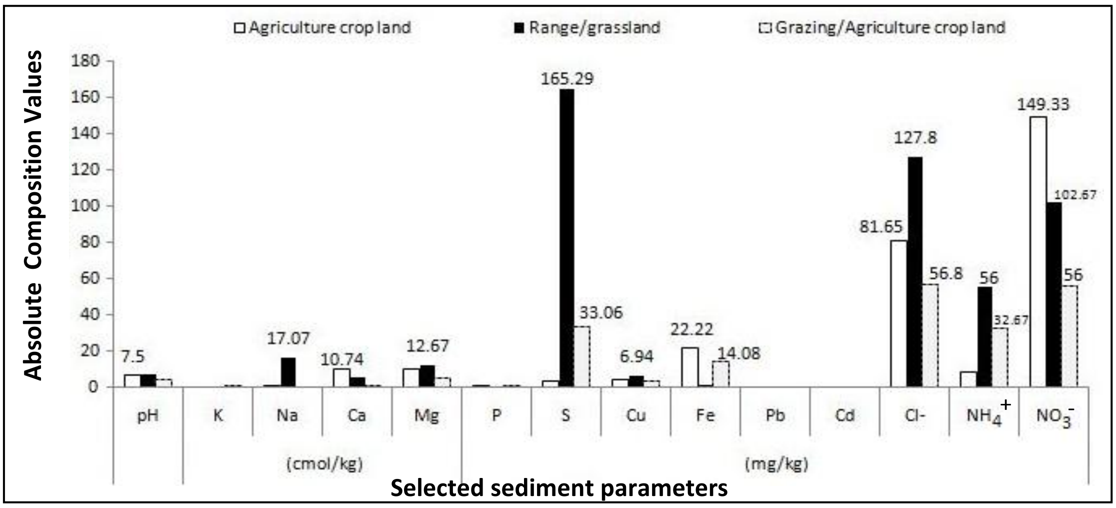


Figure 29: Average composition of soils (50 cm depth) within the Makoye Reservoir subbasin. Based on field soil sampling (2016/2017)

The composition of sediment from the traps is presented in Table 16, for easy reporting, absolute values were converted to percentages by adding values from the two traps and thereafter compute proportions in percentage terms. Sediment from Crop/grazing land North-East of the reservoir supplied more phosphorus (74 percent) and iron (68 percent) to the reservoir than the sediment from purely crop fields South-East of the reservoir (Trap B, refer to Figure 7). However, on average, the latter also supplied a fairly high quantity of nitrate as compared to the former part of the subbasin.

Table 16: Composition of moving sediment and soils from the upstream of the Makoye reservoir

PARAMETERS (MG/KG)	SEDIMENT TRAP A	SEDIMENT TRAP B	TOTAL	MEAN	A (%)	B (%)	STANDARD DEVIATION BETWEEN A AND B	COEFFICIENT OF VARIATION BETWEEN A AND B	MEAN COMPOSITION FOR SOILS	MEAN COMPOSITION FOR SOIL AND SEDIMENT	DEVIATION BETWEEN SOILS AND SEDIMENT MEANS	CV BETWEEN SOILS AND SEDIMENT MEANS
pH	6.64	6.85	13.49	6.74	49	51	0.15	*2.20*	6.58	6.66	0.12	***0.02***
P	1.47	0.53	2	1	**74**	27	0.66	**66.47**	0.81	0.90	0.14	0.15
S	33.76	32.37	66.13	33.07	51	49	0.98	*2.97*	67.52	50.30	24.36	0.48
Cu	1.76	3.26	5.02	2.51	35	**65**	1.06	42.26	4.92	3.72	1.70	0.46
Fe	18.68	8.98	27.66	13.83	**68**	32	6.86	49.59	12.77	13.30	0.75	***0.06***
Pb	0.44	0.16	0.6	0.3	**73**	27	0.20	**66.00**	0.47	0.39	0.12	0.31
Cd	0	0	0	0	0	0	0.00	*0.00*	0.00	0.00	0.00	***0.00***
Cl-	74.55	81.65	156.2	78.1	48	52	5.02	6.43	88.75	83.43	7.53	***0.09***
NH_4	32.67	32.67	65.34	32.67	50	50	0.00	*0.00*	32.67	32.67	0.00	***0.00***
NO_3	70	116.6	186.7	93.34	37	**63**	33	35.36	102.6	98.00	6.59	***0.07***

A: Composition of sediment from Crop/grazing land North-East of the reservoir
B: Composition of sediment from Crop land South-East of the reservoir.

7.2.2 Settled sediment on the Makoye Reservoir bed

Particle analysis of entire settled sediment core sample (0.5 m long) showed that all particles were less than one milimetre at different levels. The pH levels were narrowly variable from one layer of the bed sediment to the other, only layer four (L4) moderately varied (CV=24%) from the others in terms of pH levels (Figure 30).

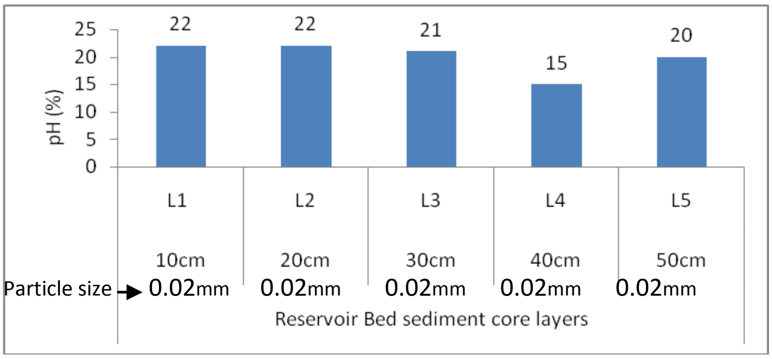


Figure 30: pH values and particle size of sediment core layers from the Makoye Reservoir bed (October, 2015)

Intra and inter-layer analysis of the composition of sediment from the reservoir bed also showed that the concentration levels of some parameters were variable at different depths. Potasium was high in topmost layer one (L1), but in the succeeding layers, it drastically reduced and maintained almost the same level of concentration (Figure 31a-j). All statistics are percentages of total mineral composition shown in Appendix M.

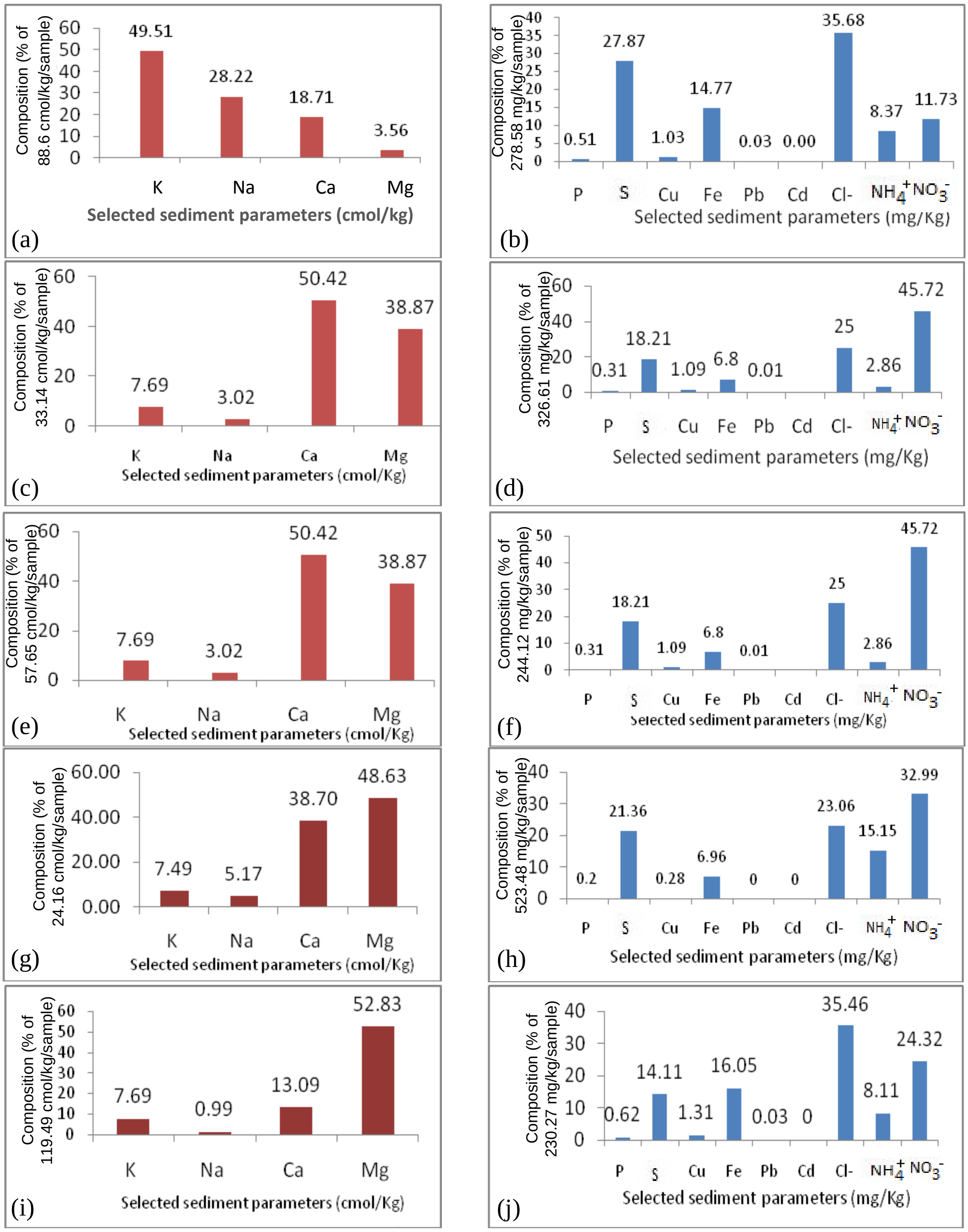


Figure 31: Mineralogical composition of Settled sediment at different depths, 10 cm (a-b); 20 cm (c-d); 30 cm (e-f), 40 cm (g-h); and 50 cm (i-j) of the Makoye Reservoir bed. (October, 2015)

Out of the total potassium and sodium in the bed sediment, the highest concentrations (35.14 percent and 87.11 percent, respectively) were in layer one. Whilst calcium was almost uniformly distributed across the entire sediment sample, magnesium was highly variable as it was only highly concentrated (67.12 percent) in layer five as compared to other layers of the sediment core (Figure 32a, Appendix M).

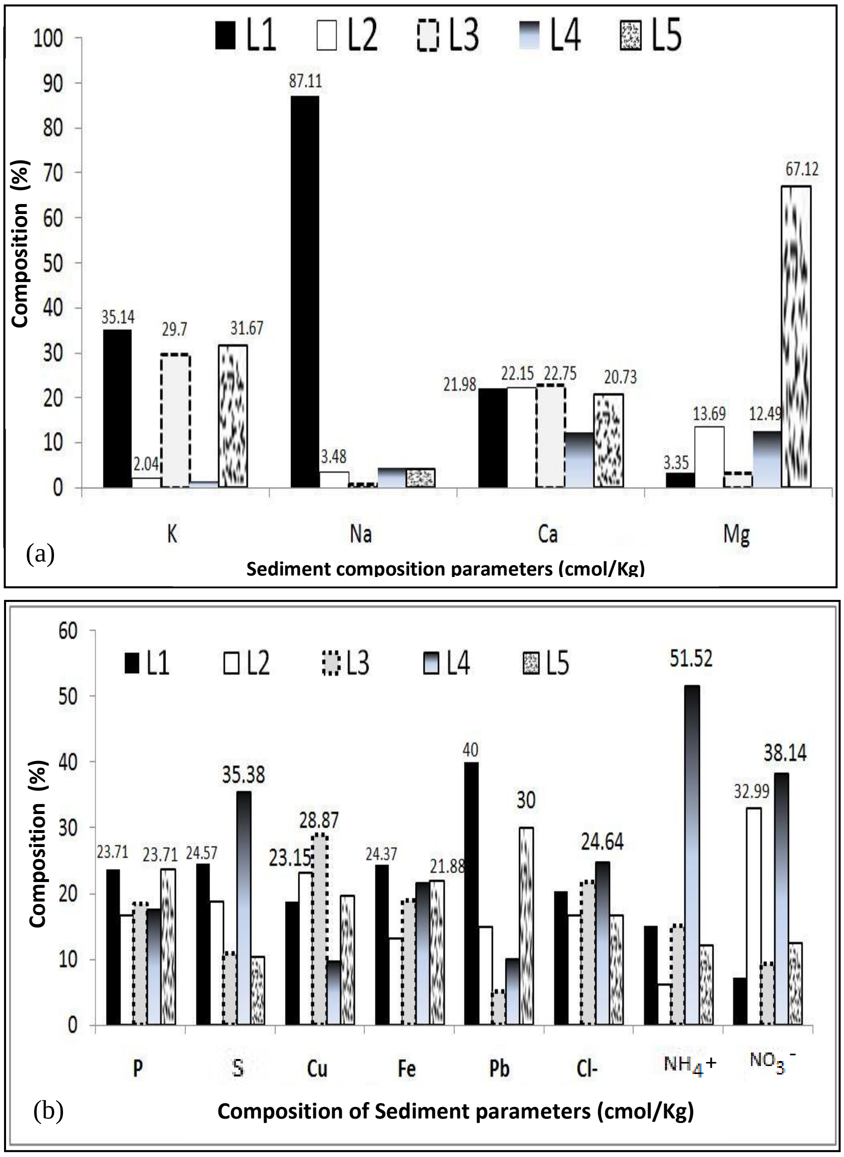


Figure 32: (a) Inter-sediment layer comparison of concentration of metals and extractable ions and heavy metals (b) in the Makoye Reservoir bed sediment (2015).

Phosphorus was most prominent in layers one (L1) and five (L5) (23.71 percent each). The highest concentration of sulphur was found in layer four (35.38 percent), seconded by layer one (25.57 percent) (Figure 32(b)) above. The composition of sediment and soil on the upstream of the reservoir was found to be closer to the composition on the reservoir's bed and this could be confirmed by low to moderate coefficients of variation (CV) between them (Table 17).

Table 17: Coefficient of variation between the composition of sediment and soils on the upstream and sediment on the Makoye Reservoir bed, 2016-2017

Selected parameters	composition of soils and sediment	Mean composition of sediment on the reservoir bed	CV (%)
pH	6.66	5.58	12.48
Phosphorus (mg/kg)	0.9	1.2	20.2
Sulphur (mg/kg)	50.3	63.21	16.08
Copper (mg/kg)	3.72	3.08	13.31
Iron (mg/kg)	13.3	33.78	61.52
Lead (mg/kg)	0.3	0.04	115.11
Cadmium (mg/kg)	0	0	0
Chloride (mg/kg)	83.43	97.98	11.34
Amonium (mg/kg)	32.67	30.8	4.17
Nitrate/Nitrite (mg/kg)	98	90.53	5.6

7.3 Spatial analysis of the composition of water in the Makoye Reservoir

This section presents results on the composition of water in the reservoir whose data analysis was based on raw data in Appendix N.

7.3.1 Physical parameters

The concentration levels of Total Dissolved Solids (TDS), Total Suspended Sediment (TSS) and turbidity across the reservoir during the warm-wet and cool-dry seasons are shown in Table 18. The three parameters demonstrated stable equilibrium in terms of their concentration across the reservoir.

Based on FAO (2013) standards, the average concentration of TDS across the reservoir were within very acceptable limits for livestock across the reservoir at all seasons, but the levels of concentration for TSS and turbidity were above the prescribed standards during warm-wet seasons (Table 18).

Table 18: Concentration levels of TDS, TSS and Turbidity in the Makoye Reservoir, 2015-2017

Sampling points	X	Y	TDS (mg/l)		TSS (mg/l)		Turbidity (NTU)	
			3/3/16	**17/07/17**	**3/3/16**	**17/07/17**	**3/3/16**	**17/07/17**
1	574803.07	8203961.3	44	194	3850	2.2	2252	2.24
2	574855.45	8203855.4	56	205	2240	1	1868	1.73
3	574736.68	8203846.7	42	186	1800	4	1174	2.37
6	574591.94	8203949.4	42	190	2040	1	1265	0.72
7	574695.22	8204061.5	42	182	3050	1	1807	3.74
8	574641.14	8203921.7	40	187	2950	2.4	1927	5.12
9	574750.68	8204137.6	41	186	3100	3.9	2130	10.7
10	574880.2	8204081.8	68	187	2100	1	1794	4.69
11	574823.71	8204131.2	43	182	4120	2.6	2254	3.11
12	574723.08	8203972.9	90	182	2800	1	673	1.02
Average levels			**50.8**	**188.1**	**2805**	**2.01**	**1714.4**	**3.54**
FAO standards (MPL)			**1000**		**1000**		**1000**	
Coefficient of Variation between average concentration and the FAO standard (%)			**128**	**97**	**67**	**141**	**37**	**140**

The visual impression of spatial variation of concentration of Turbidity, TDS and TSS is illustrated in Figure 33. Both turbidity and TDS were spatially less stable during warm-wet season than during the cool-dry season. During the two seasons, turbidity was highly variable from one sampling point to the other as compared to TDS (Table 19 for specific CVs).

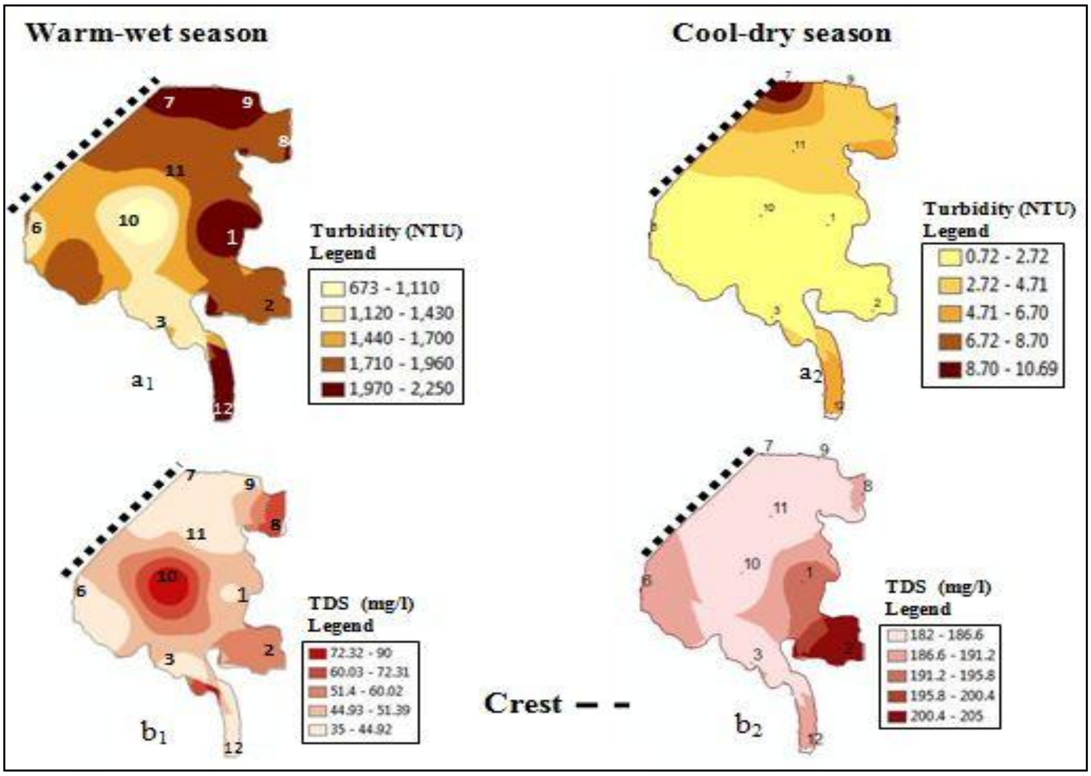


Figure 33: Spatial distribution of Turbidity (a_1) in warm-wet season (3/3/2016); (a_2) cool-dry season (17/7/2017); TDS distribution (b_1) in warm-wet season (3/3/2016); (b_2) cool-dry season (17/7/2017).

Table 19: Coefficients of variation (%) for Turbidity during (a_1) warm-wet season (a_2) cool-dry season; TDS (b_1) warm-wet season (b_2) cool dry season, 2015 to 2017

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	13.18	44.5	39.69	15.5	11	3.94	16.01	0.06	76.34
S2		0	32.26	27.22	2.35	2.2	9.27	2.86	13.24	66.51
S3			0	5.28	30.03	34.34	40.92	29.54	44.56	38.36
S6				0	24.95	29.33	36.03	24.46	39.75	43.2
S7					0	4.54	11.6	0.51	15.57	64.67
S8						0	7.08	5.05	11.06	68.21
S9							0	12.11	4	73.51
S10								0	16.07	64.26
S11									0	76.39
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	18.17	3.99	72.62	35.47	55.34	92.46	50	23	52.92
S2		0	22.08	58.3	51.97	69.99	102.06	65.2	40.32	36.51
S3			0	75.52	31.71	51.92	90.13	46.47	19.1	56.32
S6				0	95.76	106.55	123.59	103.78	88.25	24.38
S7					0	22.03	68.16	15.94	13.01	80.81
S8						0	49.88	6.2	34.54	94.43
S9							0	55.23	77.73	116.81
S10								0	28.65	90.9
S11									0	71.57
S12										0

b_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	17	3.29	3.29	3.29	6.73	4.99	30.30	1.63	48.55
S2		0	20	20	20	24	22	14	19	33
S3			0	0	0	3	2	33	2	51
S6				0	0	3	2	33	2	51
S7					0	3	2	33	2	51
S8						0	2	37	5	54
S9							0	35	3	53
S10								0	32	20
S11									0	50
S12										0

b_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	3.9	2.98	1.47	4.51	2.6	2.98	2.6	4.51	4.51
S2		0	6.87	5.37	8.4	6.49	6.87	6.49	8.4	8.4
S3			0	1.5	1.54	0.38	0	0.38	1.54	1.54
S6				0	3.04	1.13	1.5	1.13	3.04	3.04
S7					0	1.92	1.54	1.92	0	0
S8						0	0.38	0	1.92	1.92
S9							0	0.38	1.54	1.54
S10								0	1.92	1.92
S11									0	0
S12										0

S1, S2....S12: Sampling points

Figure 34c_{1-2} show the distribution of TSS across the reservoir during the warm-wet season and cool-dry season. Concentration levels were found to be spatially unstable during the warm-wet season (Table 19c_1) than during the cool-dry season (Table 19c_2).

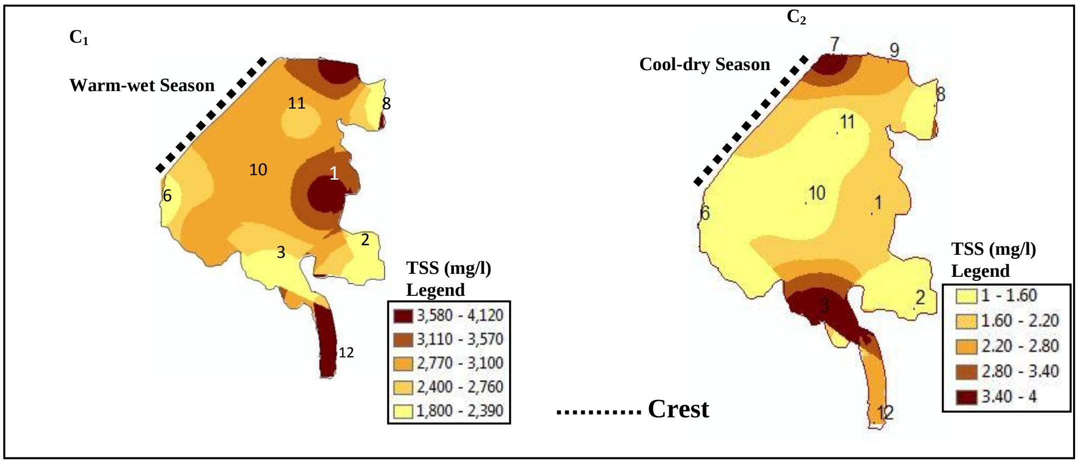


Figure 34: Spatial distribution of TSS during (c_1) warm-wet season (3/3/2016); (c_2) cool-dry season (17/7/2017) across the Makoye Reservoir.

Table 19: Coefficients of variation for TSS during (c_1) warm-wet season (3/3/2016); (c_2) cool-dry season (17/7/2017) across the Makoye Reservoir.

	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	37.39	51.31	43.46	16.4	18.72	15.26	41.59	4.79	22.33
S2		0	15.4	6.61	21.65	19.35	22.78	4.56	41.8	15.71
S3			0	8.84	36.45	34.24	37.52	10.88	55.42	30.74
S6				0	28.06	25.79	29.16	2.05	47.75	22.21
S7					0	2.36	1.15	26.09	21.1	6.04
S8						0	3.51	23.8	23.4	3.69
S9							0	27.2	19.98	7.19
S10								0	45.93	20.2
S11									0	26.98
S12										0

c_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	53.03	41.06	53.03	53.03	6.15	39.41	53.03	11.79	53.03
S2		0	84.85	0	0	58.23	83.7	0	62.85	0
S3			0	84.85	84.85	35.36	1.79	84.85	30	84.85
S6				0	0	58.23	83.7	0	62.85	0
S7					0	58.23	83.7	0	62.85	0
S8						0	33.67	58.23	5.66	58.23
S9							0	83.7	28.28	83.7
S10								0	62.85	0
S11									0	62.85
S12										0

7.3.1.1 Real time turbidity

A comparison of real time turbidity rates in the middle water column and near the reservoir bed is presented in Figure 35a. It is evident that mean daily turbidity rates were higher near the water surface than near the bottom. This implied that there was large quantity of suspended sediment in the middle water column than near the reservoir bed. The total mean daily turbidity rates in the reservoir's subsurface water were generally found to be high (Figure 35b).

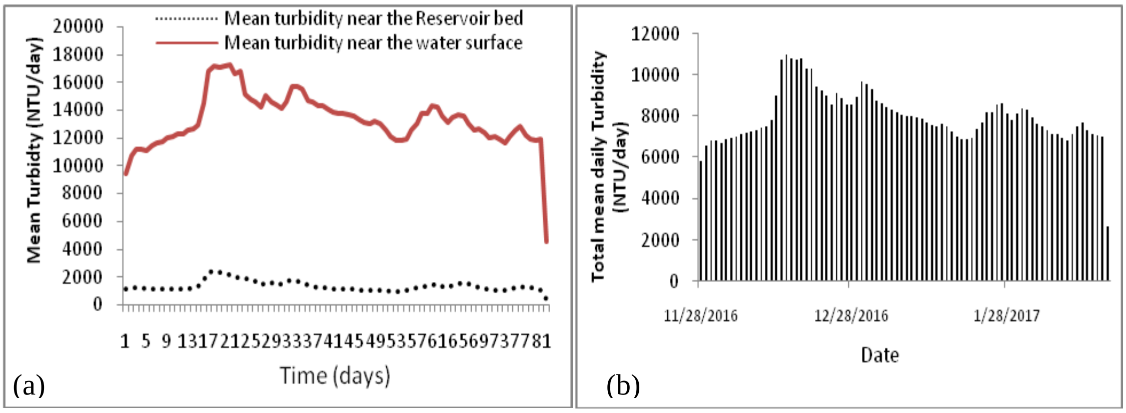


Figure 35: Real-time mean daily Turbidity rates near the water surface and reservoir bed (a) and Real-time total mean daily turbidity in the reservoir's subsurface water (b).\ based on field measurements (2016/2017 warm-wet season).

Figure 36a-b present relationship between turbidity and Total Suspended Solids (TSS) levels on a daily basis. It is very clear from the graphs that turbidity levels were almost perfectly (r^2=0.99) related to suspended sediment. A positive real time relationship between daily rainfall and Total daily Suspended Sediment loading was observed (Figure 36c). Although the relationship was initially weak, it improved after editing out about 20 outliers (Figure 36d). The criteria used to remove outliers was their extreme distance from the desired line of best fit.

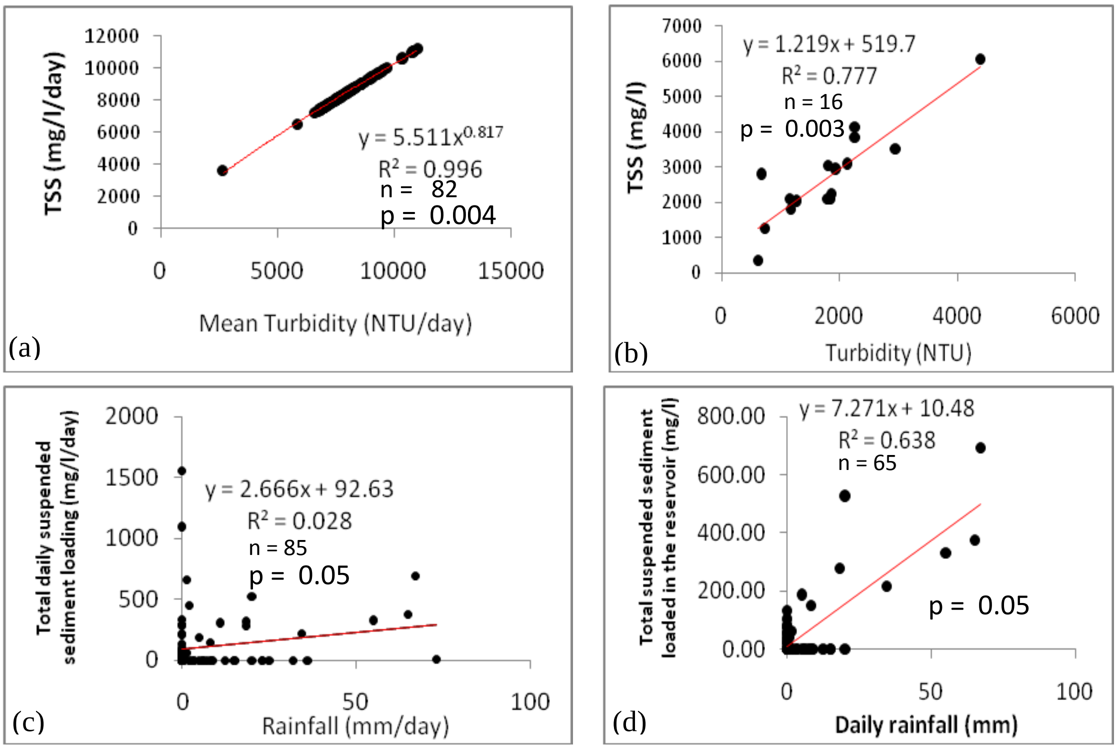


Figure 36: (a) Real time relationship between the levels of Turbidity and Total Suspended Solids (TSS) in the water subsurface; (b) relationship between Turbidity and TSS near the water surface on selected dates; (c) relationship between daily rainfall and real time loading of suspended sediment with outliers and; (d) relationship between daily rainfall and real time loading of TSS without outliers in the Makoye Reservoir based on Field data (2016/2017 warm-wet season).

7.3.2 Chemical parameters

The concentration levels of most selected chemical parameters were within prescribed Maximum Permissible Limits (MPLs) for livestock at all times across the reservoir and they narrowly varied from one sampling space to the other, except total phospahtes during warm-wet season (Table 20).

Table 20: Levels of concentration of selected chemical parameter in water across the Makoye Reservoir, Monze District, Zambia 2016-2017

Sampling points	Sulphates (mg/l)		Nitrates (mg/l)		Chloride (mg/l)		Phosphorus (mg/l)		Ammonia (mg/l))		Total phosphates (mg/l)	
	3/3/16	17/7/17	3/3/16	17/7/17	3/3/16	17/7/17	3/3/16	17/7/17	3/3/16	17/7/17	3/3/16	17/7/17
1	9.77	23.99	5.87	0.01	29	14.0	0.05	0.01	0.18	0.01	0.12	0.01
2	5.35	25.22	4.52	0.01	15	15.2	0.42	0.01	0.14	0.01	0.97	0.01
3	11.35	23.74	3.04	0.01	22	12.0	0.06	0.01	0.04	0.01	0.12	0.01
6	11.13	27.74	1.52	2.44	15	14.0	0.07	0.01	0.18	0.01	0.16	0.01
7	29.28	24.6	12.76	1.34	20	12.0	0.2	0.01	0.38	0.01	0.47	0.01
8	48.8	23.67	1.7	0.01	23	14.0	0.01	0.01	0.32	0.01	0.01	0.01
9	77.87	23.08	2.81	1.36	21	11.0	0.85	0.01	0.19	0.01	1.95	0.01
10	76.41	22.87	2.74	2.42	19	14.0	0.09	0.01	0.22	0.01	0.22	0.01
11	65.49	22.52	5.97	0.01	22	9.0	0.72	0.01	0.17	0.01	1.64	0.01
12	9.94	22.77	3.74	0.01	23	11.0	0.01	0.01	0.09	0.01	0.01	0.01
Average	**34.54**	**24.02**	**4.47**	**0.26**	**20.9**	**12.6**	**0.25**	**0.01**	**0.19**	**0.01**	**0.57**	**0.01**
FAO Standards	**1000**		**100**		**1000**		**1**		**0.5**		**0.1**	
CV (%)	**132**	**135**	**129.3**	**139**	**136**	**138.0**	**85**	**139**	**64**	**136**	**99.2**	**116**

Source: Field measurements (2016-2017)

Figure 37a_{1-2} show how sulphate was spatially distributed across the Makoye Reservoir during the warm-wet and cool-dry seasons.

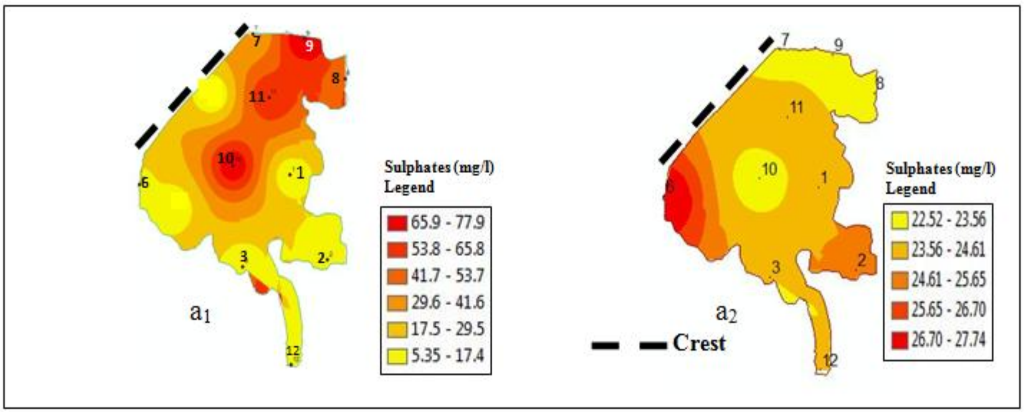


Figure 37: Concentration of sulphates across the Makoye Reservoir during (a_1) warm-wet season and (a_2) cool-dry season (2016-2017)

The concetrations levels of sulphate were highly variable among selected points, for example in Table 21a_1, S6 varied from S7 by 111.31 percent during warm-wet season, but during cool-dry season, the variation was just 8.48 percent between the same points (Table 21a_2).

Table 21: Coefficients of variation (%) between water sampling points for sulphate across the Makoye Reservoir during (a) warm-wet season and (b) cool-dry season.

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	18.4	44.9	83.3	52.3	77.9	49.9	51.41	1.19	31.35
S2		0	27.7	70.2	67.44	64.12	33	34.67	19.55	13.35
S3			0	47.1	87	39.98	5.56	7.34	45.99	14.6
S6				0	111.31	7.91	42.1	40.5	84	59.69
S7					0	108.2	90.4	91.42	51.27	77.31
S8						0	34.8	33.13	78.73	53.03
S9							0	1.78	50.9	20.08
S10								0	52.44	21.82
S11									0	32.48
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	3.53	0.74	10	1.78	0.95	2.7	3.38	4.47	3.69
S2		0	4.27	7	1.76	4.48	6.3	6.9	8	7.22
S3			0	11	2.52	0.21	2	2.64	3.73	2.95
S6				0	8.48	11.2	13	13.6	14.7	13.9
S7					0	2.72	4.5	5.15	6.24	5.46
S8						0	1.8	2.43	3.52	2.74
S9							0	0.65	1.74	0.96
S10								0	1.09	0.31
S11									0	0.78
S12										0

The visual impression of the concentration of nitrate across the reservoir during the warm-wet and cool-dry seasons was as shown in Figure 38a_{1-2}. Its variation at different sampling points was as shown in Table 22a_{1-2} demonstrating that although the variations were minimal among some points, in others instances they were high.

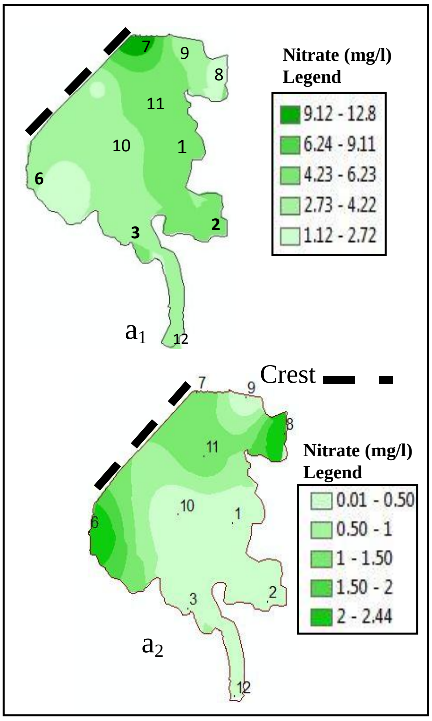


Figure 38: Concentration changes of nitrate across the Makoye Reservoir during (a_1) warm-wet season and (a_2) cool-dry season

Table 22: Coefficients of variations (%) between water sampling points for Nitrates across the Makoye Reservoir during (a_1) warm-wet season and (a_2) cool-dry season, Field measurements (2016-2017).

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	41	10.6	9.2	70.7	94.2	109.9	109	105	1.22
S2		0	50.81	50	97.72	113.5	123.24	122.9	120.1	42.45
S3			0	1.4	62.4	88.1	105.4	105	99.6	9.37
S6				0	63.52	88.89	106.05	105.5	100.3	7.99
S7					0	35.36	64.13	63.06	54.03	69.74
S8						0	32.46	31.18	20.65	93.56
S9							0	1.34	12.21	109.4
S10								0	10.88	108.86
S11									0	104.15
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	0	0	140.27	139.33	0	139.36	140.26	0	0
S2		0	0	140.27	139.33	0	139.36	140.26	0	0
S3			0	140.27	139.33	0	139.36	140.26	0	0
S6				0	41.15	140.27	40.19	0.58	140.27	140.27
S7					0	139.33	1.05	40.62	139.33	139.33
S8						0	139.36	140.26	0	0
S9							0	39.66	139.36	139.36
S10								0	140.26	140.26
S11									0	0
S12										0

The visual impression of how the concentration of chloride was distributed across the reservoir during the hot-wet and cool-dry seasons is respectively depicted in Figure 39a$_{1-2}$. Variations were minimal among several sampling points, but in others instances, wide variations were noted (Table 23).

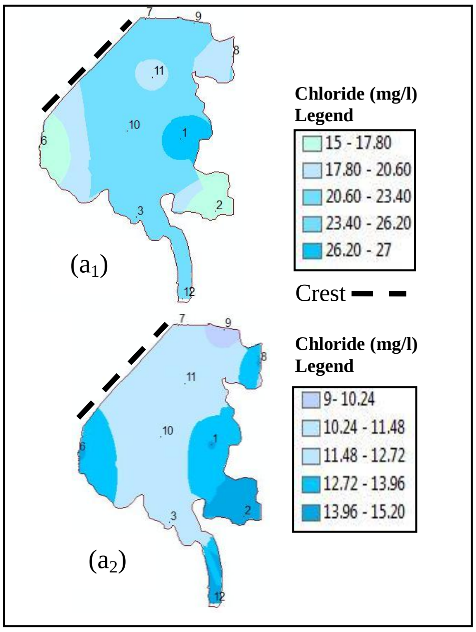


Figure 39: Spatial concentration of chloride at different sampling points across the Makoye Reservoir during (a_1) warm-wet and (a_2)

Table 23: Coefficients of variations between water sampling points for Chloride across the Makoye Reservoir during (a_1) warm-wet season and (a_2) cool-dry season, 2016 to 2017

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	45	19.4	45	26	16.3	22.6	29.5	19.41	16.3
S2		0	26.8	0	20.2	29.8	23.6	17	26.8	29.8
S3			0	26.8	6.73	3.14	3.29	10.4	0	3.14
S6				0	20.2	29.8	23.6	16.6	26.76	29.8
S7					0	9.87	3.45	3.63	6.73	9.87
S8						0	6.43	13.5	3.14	0
S9							0	7.07	3.29	6.43
S10								0	10.35	13.5
S11									0	3.14
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	5.8	10.88	0	11	0	17	0	30.74	16.97
S2		0	16.6	5.81	17	6	22.7	5.8	36.2	22.7
S3			0	10.88	0	11	6.15	10.9	20.2	6.15
S6				0	11	0	17	0	30.74	16.97
S7					0	11	6.15	10.9	20.2	6.15
S8						0	17	0	30.74	16.97
S9							0	17	14.14	0
S10								0	30.74	16.97
S11									0	14.14
S12										0

During the hot-wet and cool dry season, the pH and alkalinity levels across the Makoye Reservoir were both within the FAO prescribed MPLs for livestock. For example, average alkalinity varied below its MPL by 111 percent during the hot wet-season and by 80 percent during the cool-dry season. Spatially, both pH and alkalinity levels narrowly varied from one sampling point to the other, implying negligible changes from one sampling point to the other (Table 24).

Table 24: Levels of Acidity in water across the Makoye Reservoir based on measurements on 3/3/2016 and 17/07/2017

Sampling points	PH		Alkalinity	
	warm-wet season	**Cool-dry season**	**Warm-wet season**	**Cool-dry season**
1	7.02	7.49	102	134
2	7.22	7.64	86	158
3	7	7.67	48	148
6	7.23	6.93	52	138
7	7	7.61	53	128
8	7.24	7.66	74	130
9	7.41	7.58	44	134
10	7.45	7.44	74	132
11	7.38	7.66	42	142
12	7.08	7.77	34	140
Average concentration	**7.2**	**7.55**	**60.9**	**138.4**
FAO Standards	**9**		**500**	
CV (%)	**16**	**12**	**111**	**80**

7.3.3 Metals

On average, all the metal constituents in water across the reservoir were within very normal ranges when compared to the MPLs (Table 25). Only iron (5.26 mg/l on average for the warm wet season), was alarming, about 19 times higher than its MPL (0.3mg/l).

Table 25 : Concentration levels of metals in the Makoye Reservoir in the warm-wet season (3/3/2016) and cool-dry season (17/7/2017)

Sampling point	Iron (mg/l)		Magnesium mg/l)		Calcium (mg/l)		Sodium (mg/l)		Fluoride (mg/l)		Copper (mg/l)	Lead (mg/l)	Cadmium (mg/l)
	WWS	**CDS**	**WWS**	**CDS**	**WWS**	**CDS**	**WWS**	**CDS**	**WWS**	**CDS**	**WWS/ CDS**	**WWS /CDS**	**WWS/CDS**
1	5.57	0.82	8.64	8.16	27.2	40.0	9.9	9.33	0.08	0.13	0.003	0.01	0.002
2	7.41	0.01	11.04	15.36	16.8	37.6	14.52	9.34	0.12	0.15	0.003	0.01	0.002
3	6.76	2.07	6.72	18.72	8	28.0	9.9	7.82	0.07	0.12	0.003	0.01	0.002
6	3.88	0.01	3.84	17.28	15.2	27.2	13.86	7.92	0.07	0.14	0.003	0.01	0.002
7	5.81	0.01	5.52	18.92	12.58	30.4	12.54	9.42	0.07	0.13	0.003	0.01	0.002
8	4.97	0.45	9.36	14.40	14.8	29.6	14.52	7.26	0.14	0.14	0.003	0.01	0.002
9	4.7	0.93	5.76	14.40	8.8	29.6	15.18	9.24	0.12	0.03	0.003	0.01	0.002
10	5.17	0.01	9.36	17.76	13.2	27.2	15.84	5.82	0.14	0.01	0.003	0.01	0.002
11	3.19	0.31	4.56	17.28	10	28.0	15.14	7.19	0.06	0.14	0.003	0.01	0.002
12	5.16	0.35	7	15.36	13.7	30.4	13.6	7.30	0.09	0.14	0.003	0.01	0.002
Average	**5.26**	**0.5**	**7.18**	**15.76**	**14.03**	**30.8**	**13.5**	**8.06**	**0.09**	**0.11**	**0.003**	**0.01**	**0.002**
FAO	**0.3**		**80**		**200**		**100**		**2**		**0.5**	**0.1**	**0.05**
CV (%)	**126**	**34**	**118**	**95**	**123**	**104**	**108**	**120**	**128**	**126**	**140**	**116**	**131**

Analysis of iron and sodium distribution showed that, there was no spatial homogeneity in their concentration across the reservoir. Iron was highly variable from one point to the other during the cool-dry season than during the warm-wet season (Figure 40a_{1-2} and Table 26 a_{1-2}). For sodium, the variability of concentration ranged from negligibly to moderately across the reservoir for both seasons (Figure 40b_{1-2} and Table 26 b_{1-2}).

Table 26: Coefficients of variation between sampling points for iron during (a_1) warm-wet season, (a_2) cool-dry seson; sodium during (b_1) warm-wet season and (b_2) cool-dry season

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	20.05	13.65	25.29	2.98	8.05	11.98	5.27	38.42	5.4
S2		0	6.49	44.22	17.12	27.87	31.65	25.18	56.3	25.31
S3			0	38.28	10.69	21.58	25.42	18.85	50.74	18.98
S6				0	28.17	17.42	13.52	20.16	13.8	20.02
S7					0	11.02	14.94	8.24	41.17	8.38
S8						0	3.95	2.79	30.85	2.65
S9							0	6.73	27.07	6.6
S10								0	33.49	0.14
S11									0	33.37
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	138.01	61.17	138.01	138.01	41.2	8.89	138.01	63.83	56.81
S2		0	140.06	0	0	135.27	138.41	0	132.58	133.56
S3			0	140.06	140.06	90.91	53.74	140.06	104.58	100.51
S6				0	0	135.27	138.41	0	132.58	133.56
S7					0	135.27	138.41	0	132.58	133.56
S8						0	49.19	135.27	26.05	17.68
S9							0	138.41	70.71	64.08
S10								0	132.58	133.56
S11									0	8.57
S12										0

b_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	26.76	0	23.57	16.64	26.76	29.77	32.64	29.59	22.27
S2		0	26.76	3.29	10.35	0	3.14	6.15	2.96	4.63
S3			0	23.57	16.64	26.76	29.77	32.64	29.59	22.27
S6				0	7.07	3.29	6.43	9.43	6.24	1.34
S7					0	10.35	13.47	16.44	13.28	5.73
S8						0	3.14	6.15	2.96	4.63
S9							0	3.01	0.19	7.76
S10								0	3.2	10.76
S11									0	7.58
S12										0

b_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	0.08	12.45	11.56	0.68	17.65	0.69	32.76	18.32	17.26
S2		0	12.53	11.63	0.6	17.72	0.76	32.84	18.39	17.34
S3			0	0.9	13.12	5.25	11.77	20.74	5.94	4.86
S6				0	12.23	6.15	10.88	21.61	6.83	5.76
S7					0	18.31	1.36	33.41	18.99	17.93
S8						0	16.97	15.57	0.69	0.39
S9							0	32.12	17.65	16.59
S10								0	14.89	15.95
S11									0	1.07
S12										0

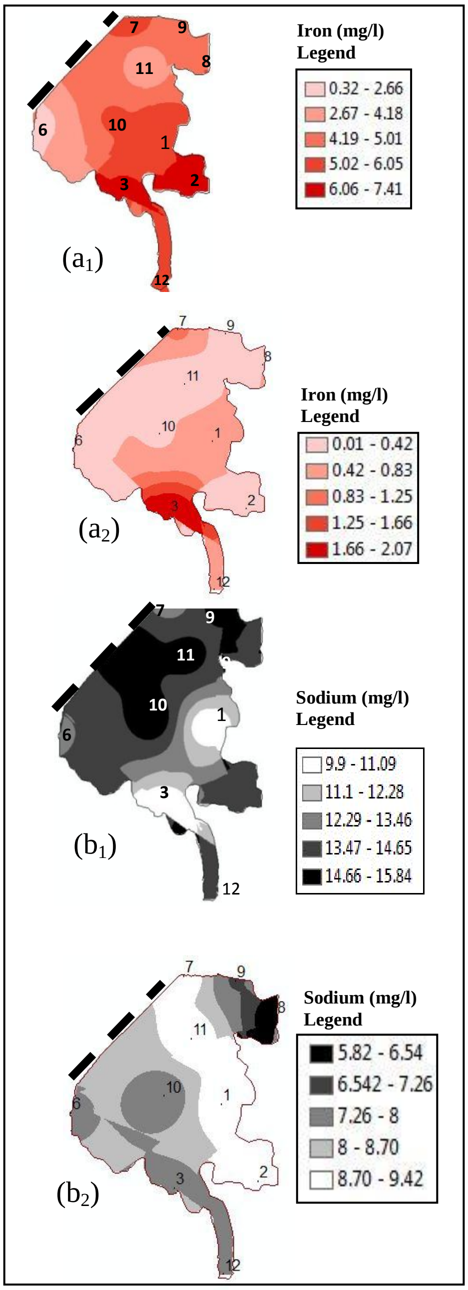


Figure 40: Spatial distribution of iron across the Makoye Reservoir during (a_1) warm-wet season; (a_2) cool-dry season; Sodium during; (b_1) warm-wet season and (b_2) cool-dry season

Calcium and magnesium varied from one sampling point to the other across the reservoir during the warm-wet and cool-dry seasons (Figure 41a_{1-2}-b_{1-2}), respectively. Both parameters varied negligibly to moderate across the reservoir (Table 27a_{1-2}-b_{1-2}).

Table 27: Coefficients of variation for calcium concentration during (a) warm-wet season, (b) cool-dry seson; magnesium during (c) warm-wet season and (d) cool-dry season, Makoye Reservoir 2016-2017

a_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	33.43	77.14	40.02	51.98	41.75	72.28	49.01	65.39	46.68
S2		0	50.18	7.07	20.31	8.95	44.19	16.97	35.88	14.37
S3			0	43.89	31.47	42.18	6.73	34.69	15.71	37.15
S6				0	13.34	1.89	37.71	9.96	29.18	7.34
S7					0	11.47	25	3.4	16.16	6.03
S8						0	35.95	8.08	27.37	5.46
S9							0	28.28	9.03	30.8
S10								0	19.51	2.63
S11									0	22.08
S12										0

a_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	4.37	24.96	26.94	19.28	21.13	21.13	26.94	24.96	19.28
S2		0	20.7	22.7	14.97	16.84	16.84	22.7	20.7	14.97
S3			0	2.05	5.81	3.93	3.93	2.05	0	5.81
S6				0	7.86	5.98	5.98	0	2.05	7.86
S7					0	1.89	1.89	7.86	5.81	0
S8						0	0	5.98	3.93	1.89
S9							0	5.98	3.93	1.89
S10								0	2.05	7.86
S11									0	5.81
S12										0

b_1	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	17.25	17.68	54.39	31.16	5.66	28.28	5.66	43.71	14.83
S2		0	17.68	54.39	31.16	5.66	28.28	5.66	43.71	14.83
S3			0	38.57	13.86	23.22	10.88	23.22	27.08	2.89
S6				0	25.38	59.14	28.28	59.14	12.12	41.23
S7					0	36.5	3.01	36.5	13.47	16.72
S8						0	33.67	0	48.77	20.4
S9							0	33.67	16.44	13.74
S10								0	48.77	20.4
S11									0	29.85
S12										0

b_2	S1	S2	S3	S6	S7	S8	S9	S10	S11	S12
S1	0	43.29	55.56	50.7	56.19	39.12	39.12	52.38	50.7	43.29
S2		0	13.94	8.32	14.69	4.56	4.56	10.25	8.32	0
S3			0	5.66	0.75	18.45	18.45	3.72	5.66	13.94
S6				0	6.41	12.86	12.86	1.94	0	8.32
S7					0	19.18	19.18	4.47	6.41	14.69
S8						0	0	14.78	12.86	4.56
S9							0	14.78	12.86	4.56
S10								0	1.94	10.5
S11									0	8.3
S12										0

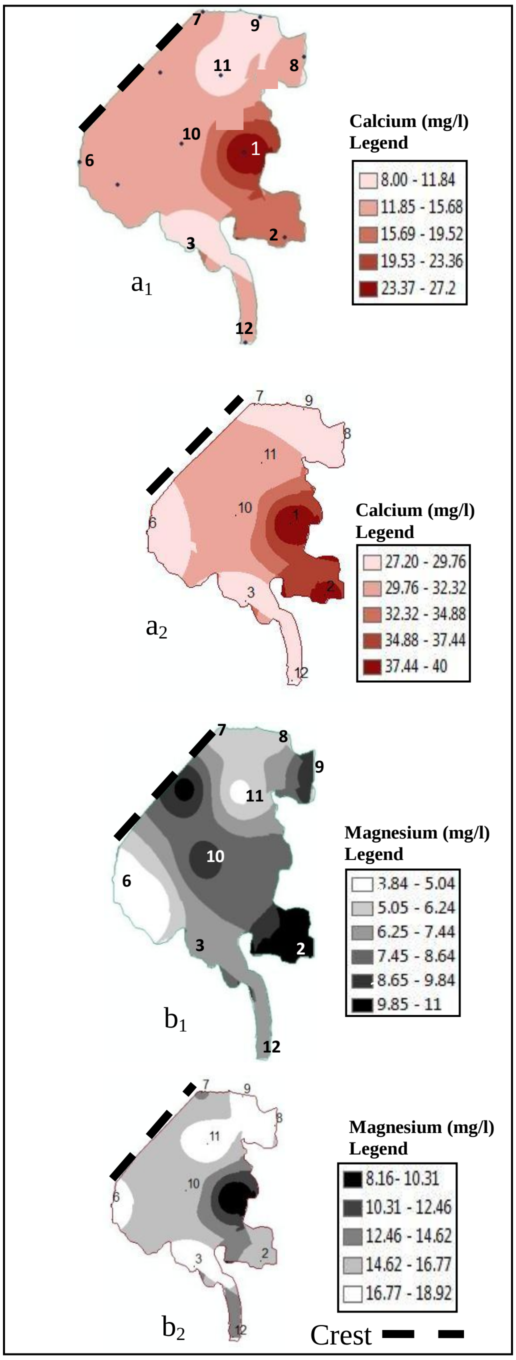


Figure 41: Concentration of calcium across the Makoye Reservoir during (a_1) warm-wet season; (a_2) cool-dry season and; Magnesium during (b_1) warm-wet season; and (b_2) cool-dry season.

A paired t-test of selected parameters at 0.01 level of significance showed that the average concentration levels of nitrate, TSS, turbidity, sodium, iron and chloride across the reservoir significantly differed between the wet-hot season and the cool-dry season. The rest of the parameters did not significantly differ (Table 28) and this was also verified by respective Coefficients of Variation.

Table 28: Paired t-test summary results for the warm-wet and the cool-dry seasons across the Makoye Reservoir based on Field data (2016-2017)

Parameter	N	3/3/2016	17/7/2017	Df	t-stats	*p*-value	Significance of difference between the means (at 0.01 Level of significance)	CV (%)
		Means						
PH	10	7.203	7.545	9	-3.42	0.004	not significant	3.28
Alkalinity	10	60.9	138.4	9	-10.40	0.000003	not significant	54.99
Ammonia	10	**0.19**	**0.01**	9	5.74	**0.0001**	**Significant**	**127**
Phosphorus	10	**0.25**	**0.01**	9	2.43	**0.01**	**Significant**	**130**
Nitrate	10	4.467	0.762	9	3.31	0.01	**Significant**	100.20
Sulphates	10	34.54	24.02	9	1.09	**0.15**	**not significant**	**25.40**
Total Phosphate	10	**0.567**	**0.01**	9	2.48	0.03	not significant	136.52
TDS	10	50.8	188.1	9	-23	0.000000001	not significant	81.28
TSS	10	2805	2.01	9	11.44	0.000001	**Significant**	141.22
Turbidity	10	1714.4	3.544	9	10.47	0.000001	**Significant**	140.84
Calcium	10	14.028	30.8	9	-16.27	0.0000001	not significant	52.91
Sodium	10	13.5	8.064	9	6.07	0.0002	**Significant**	35.65
Iron	10	**5.262**	**0.497**	9	12.27	**0.000001**	**Significant**	**117.01**
Magnesium	10	7.18	15.764	9	-5.93	0.0002	not significant	52.91
Fluoride	10	0.096	0.113	9	-0.76	0.23	not significant	11.50
Chloride	10	20.9	12.62	9	5.25	0.0003	**Significant**	34.93

7.3.4 Temporal analysis of composition of water in the Makoye Reservoir

Intra and inter-seasonal average concentrations of selected parameters in the reservoir as well as their CVs in connection to respective MPLs are presented in Table 29. Although 80 percent of parameters were extremely below their prescribed MPLs, 20 percent of them (ammonium, iron, phosphorus and total phosphates) were above the MPLs for livestock. Apart from affecting water quantity for livestock, sedimentation also affects quality of water to a large extent both spatially and temporally. It was therefore deemed relevant to assess the quality at different seasons so as establish how sediment effect on water quality varies inter-seasonally.

Inter-seasonally, some parameters (i.e. TDS, Ammonia) were very highly variable indicating wide margins in terms of seasonal average concentrations. Among all the parameters, pH was the least variable inter-seasonally (Table 30).

Table 29: Seasonal and long term averages of selected physico-chemical parameters and their variations from their respective MPLs at Makoye Reservoir, 2015-2017

Parameters (mg/l)	**AVERAGES**					**FAO MPLs**	**CVs BETWEEN MPLs AND SEASONAL AVERAGES (%)**			
	WWS15-16	**WWS16-17**	**CDS-17**	**WDS-17**	**Inter-Seasonal**		**WWS15-16**	**WWS16-17**	**CDS-17**	**WDS-17**
Alkalinity	51.3	48.2	137.5	193	107.5	500	115.1	116.6	80.4	62.7
Ammonia	***0.3***	***1.9***	***0***	***2.6***	***1.2***	***0.5***	35.4	***82.5***	***141.4***	***95.8***
Cadmium	0	0	0	0	0	0.05	141.4	141.4	141.4	141.4
Calcium	11.7	11.2	29.5	23.6	19	200	125.8	126.4	105.1	111.6
Chloride	21.8	12.6	12.6	30	19.2	1000	135.4	137.9	137.9	133.2
Conductivity *[1] (*um*/s)	118.7	109	372.8	663.5	316	1000	111.4	113.6	64.6	28.6
Copper	0	0	0	0	0	0.5	141.4	141.4	141.4	141.4
Fluorides	0.1	0.1	0.1	0.2	0.1	2	128.0	128.0	128.0	115.7
Iron	***5.5***	***5.2***	***0.4***	***2.4***	***3.4***	***0.3***	126.8	***126.0***	***20.2***	***110.0***
Lead	0	0	0	0	0	0.1	141.4	141.4	141.4	141.4
Magnesium	5.8	5	16.2	32.2	14.8	80	122.3	124.8	93.8	60.3
Nitrate	5.1	5.7	0.8	5	4.1	100	127.7	126.2	139.2	128.0
pH*[2]	7.1	6.7	7.6	7.6	7.3	9	16.7	20.7	11.9	11.9
Phosphorus	***0.1***	***4***	***0***	***6.4***	***2.6***	***1***	115.7	***84.9***	***141.4***	***103.2***
Sodium	14.6	7.6	8.2	20	12.6	100	105.4	121.4	120.0	94.3
Sulphates	7.8	45.1	24.2	41.4	29.6	1000	139.2	129.2	134.7	130.2
TDS	56.8	52.2	186.5	331.5	156.8	1000	126.2	127.4	97.0	71.0
Total phosphate	***0.3***	***5.4***	***0***	***8.5***	***3.5***	***0.1***	70.7	***136.3***	***141.4***	***138.1***
TSS	2832	346	1.8	50.5	807.6	1000	67.6	68.7	140.9	127.8
Turbidity*[3] (NTU)	1824	879	3.1	542	812	1000	41.3	9.1	140.6	42.0
Sample sizes	***n = 24***	***n = 36***	***n = 13***	***n = 2***						
Dates sampled	30/11/16-6/3/16	28/11/16-17/2/17	17/7/17	30/10/17						

Key: WWS15-16: Warm-Wet Season 2015/16, WWS16-17: Warm-Wet season 2016/17; CDS: Cool-dry Season 2017; WDS17: Warm-dry season 2017 *mg/l doesn't apply

Table 30: Inter-seasonal Coefficients of Variation (%) for selected parameters in the Makoye Reservoir during Warm-Wet Season, Cool-Dry Season and Warm-Dry Season, 2015-2017

Parameter		2016WWS	2017WWS	2017CDS	2017WDS
a. Alkalinity (as mg CaCO3/l)	2016WWS	0	9	60	78
	2017WWS		0	67	84
	2017CDS			0	24
	2017WDS				0
b. Ammonia (as NH4-Mmg/l)	2016WWS	0	104	132	114
	2017WWS		0	141	24
	2017CDS			0	140
	2017WDS				0
c. Calcium (mg/l)	2016WWS	0	9	55	41
	2017WWS		0	63	49
	2017CDS			0	16
	2017WDS				0
d. Chloride (mg/l)	2016WWS	0	38	36	24
	2017WWS		0	1	59
	2017CDS			0	58
	2017WDS				0
e. Conductivity (us/cm)	2016WWS	0	0	77	101
	2017WWS		0	77	101
	2017CDS			0	40
	2017WDS				0
f. Fluorides (mg/1)	2016WWS	0	16	13	39
	2017WWS		0	28	53
	2017CDS			0	26
	2017WDS				0
g. Iron (mg/l)	2016WWS	0	0	121	51
	2017WWS		0	121	51
	2017CDS			0	100
	2017WDS				0
h. Magnesium (mg/l)	2016WWS	0	14	63	95
	2017WWS		0	74	103
	2017CDS			0	47
	2017WDS				0

Parameter		2016WWS	2017WWS	2017CDS	2017WDS
j. Sodium (mg/l)	2016WWS	0	44	38	24
	2017WWS		0	6	64
	2017CDS			0	59
	2017WDS				0
k. Sulphates (mg/l)	2016WWS	0	95	66	92
	2017WWS		0	43	7
	2017CDS			0	37
	2017WDS				0
l. Total Dissolved Solids(mg/l)	2016WWS	0	1	77	101
	2017WWS		0	78	102
	2017CDS			0	40
	2017WDS				0
m. Total phosphates (mg/l)	2016WWS	0	116	136	125
	2017WWS		0	141	32
	2017CDS			0	141
	2017WDS				0
n. Total Suspended Solids (mg/l)	2016WWS	0	108	141	136
	2017WWS		0	140	106
	2017CDS			0	132
	2017WDS				0
o. Turbidity (NTU)	2016WWS	0	50	141	74
	2017WWS		0	140	30
	2017CDS			0	140
	2017WDS				0
p. Nitrates (as NO3-N mg/l)	2016WWS	0	73	130	80
	2017WWS		0	108	10
	2017CDS			0	104
	2017WDS				0
q. pH	2016WWS	0	4	4	4
	2017WWS		0	8	8
	2017CDS			0	0
	2017WDS				0
r. Phosphorus (mg/l)	2016WWS	0	126	130	132
	2017WWS		0	141	33
	2017CDS			0	141
	2017WDS				0

7.4 Hydro-chemical regimes of water in the Makoye Reservoir

The hydro-geochemistry of water in Makoye Reservoir on selected dates during the 2015/2016 and 2016/2017 warm-wet seasons are respectively presented in Figure 42 and Figure 43 using piper diagrams. The percentage level of hydrochemical mixings were calculated based on the number of dot symbols in each category divided by the total number of dots in each quadrant (cation triangle, anion triangle and the rhombus) then multiplied by hundred percent.

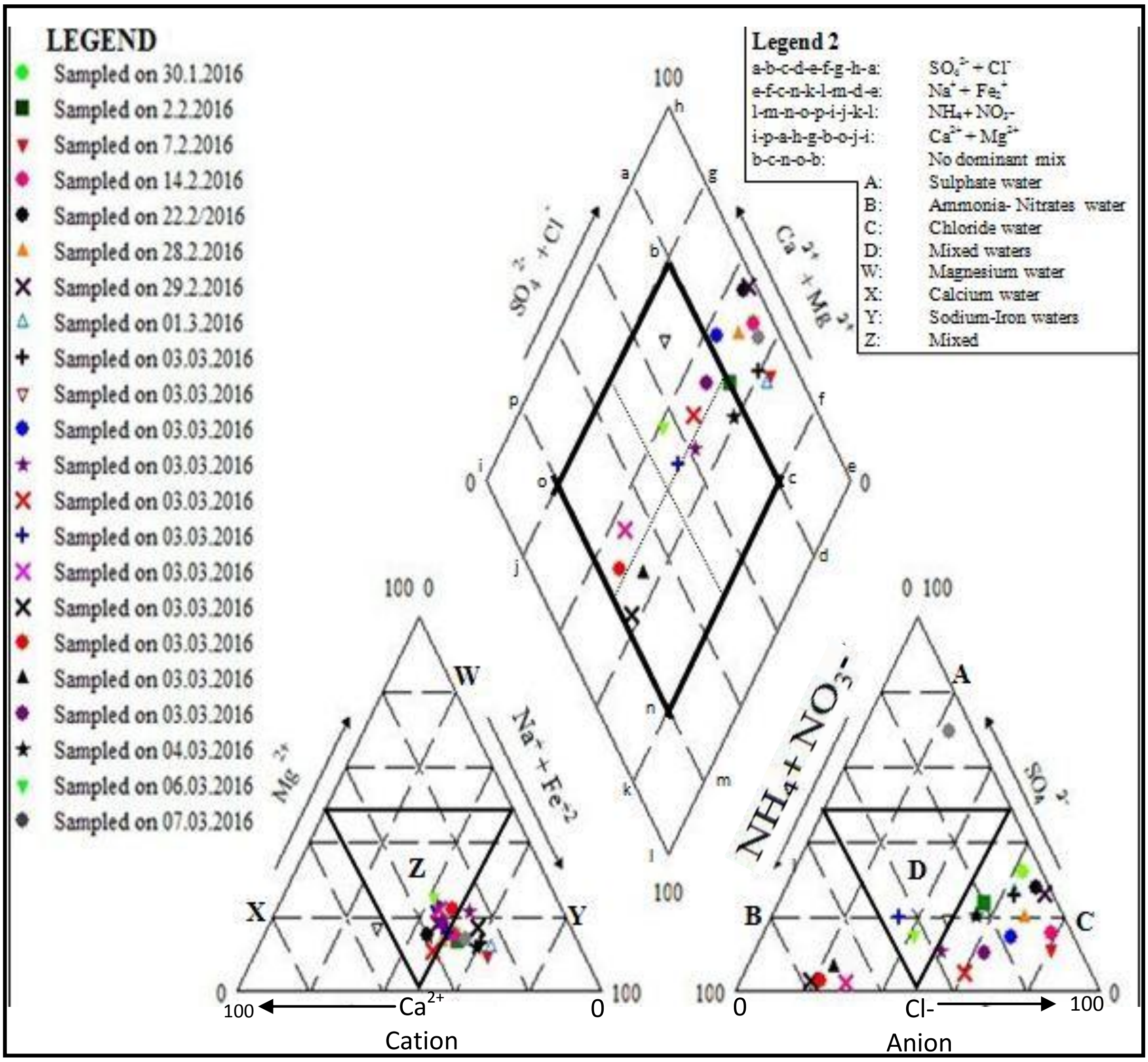


Figure 42: Intra-seasonal hydrochemical regimes of water in the Makoye Reservoir based on field measurements (2015/2016 warm-wet season), Monze District, Zambia.

In anion terms, the most dominant type of water during the 2015-2016 warm-wet season was chloride water (63 percent) (Figure 42 above). However, the scenario was different during the 2016-2017 warm-wet season because 100 percent of water was sulphate in anion terms. In cation terms (Figure 43), the most dominant type of water was mixed accounting for 50 percent and 53 percent in 2015-2016 and 2016-2017, respectively.

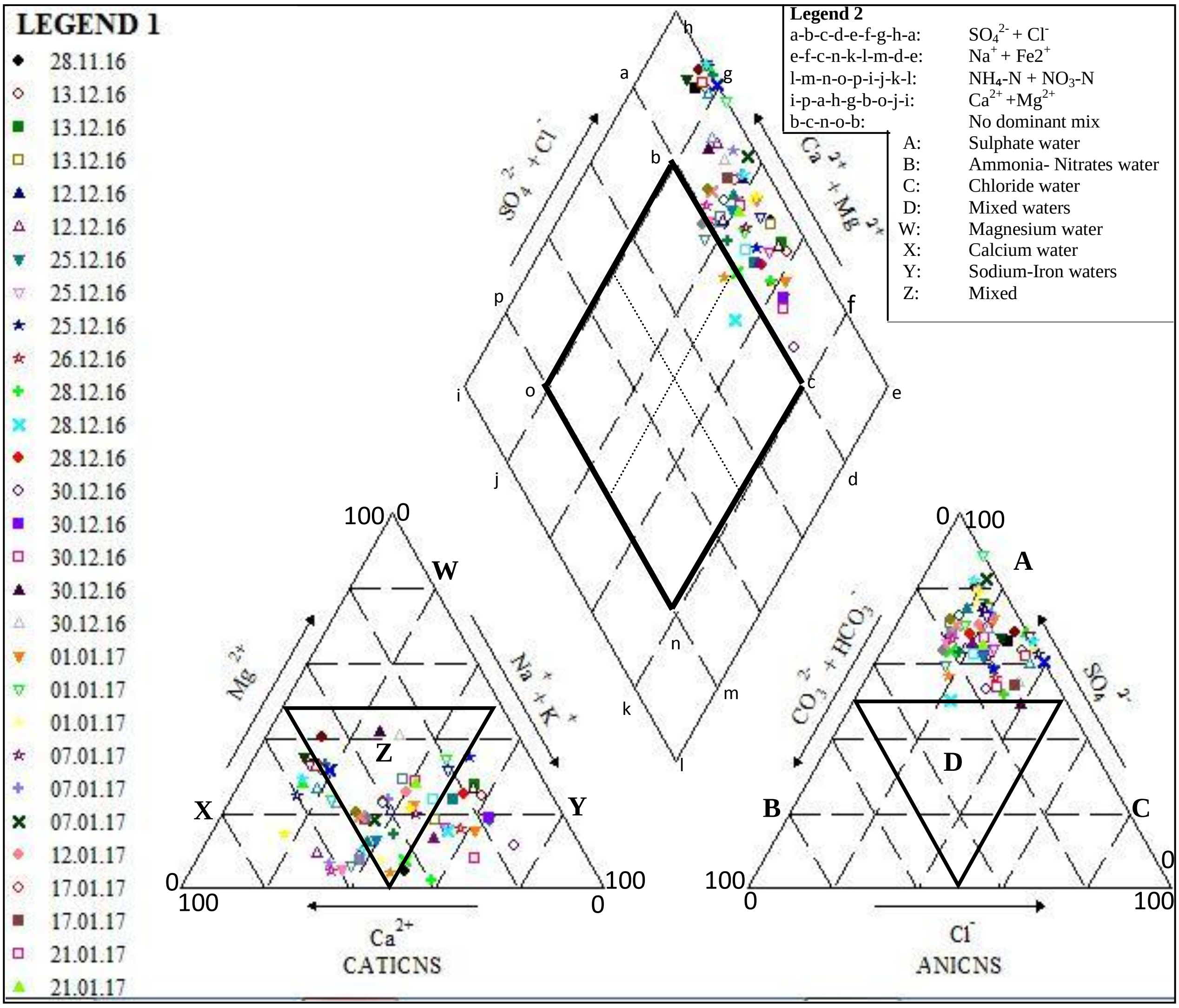


Figure 43: Intra-seasonal hydrochemical regimes of water entering the Makoye Reservoir, Monze District based on field measurements (2016/2017 rainy season)

During the 2015-2016 warm-wet season, waters were mixed in seven different ways and the most notable (45 percent) hydro-chemical mix was sulphate-chloride followed by a mix of sulphate-chloride-calcium-magnesium (22 percent). In 2016-2017, a similar scenario was noted where 95 percent of the hydrochemical mixing was sulphate-chloride. This could be attributed to the geochemistry of the earth's surface and agricultural practices on the upstream (Advanced Purification Engineering Corp [APEC], 2017). For example, sulphur from earth roads and chloride from fertilised agricultural fields were relatively high in the soils and sediment samples on the upstream, this could have influenced the type of water in the reservoir. Other mixings in cation and anion terms are shown in Figure 44a-b. Diversity of mixing was observed in the 2015/2016 warm-wet season than in the 2016/2017 (Figure 44c). This could be attributed to large scale delivery of sediment with various mineralogical compositions from upstream.

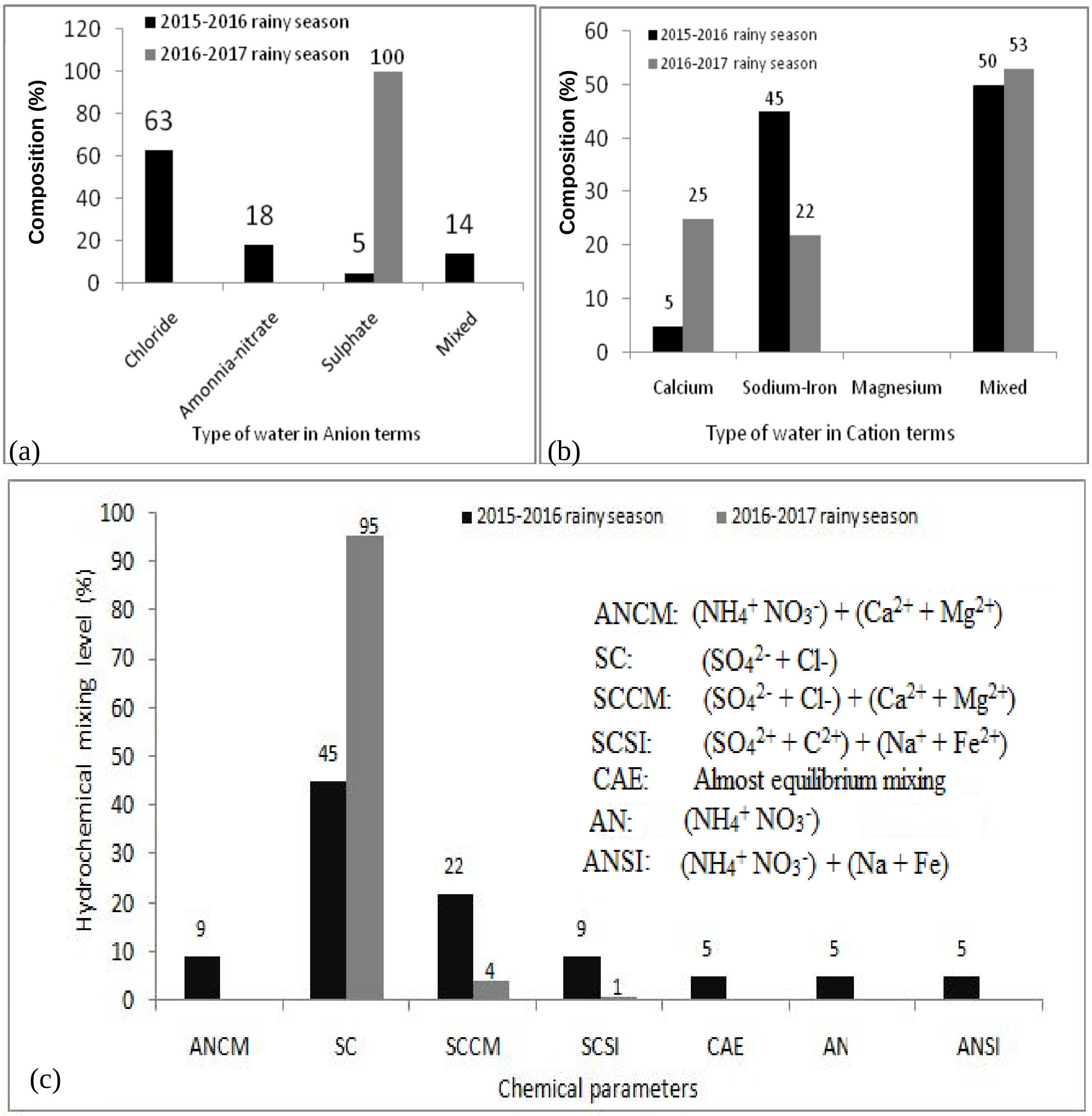


Figure 44: Types of water in Anion terms(a); Cation terms (b) and; Inter-seasonal hydrochemical regimes of water (c) in the Makoye Reservoir based on field measurements (2015-2017).

7.4.1 Relationship between the geochemistry of soils/sediment and the reservoir's hydrochemistry

A combination of the geochemistry of soils and sediment positively and significantly influenced the hydrochemistry of reservoir's water at 0.05 level of signficance. This is demonstrated by high r^2 value of 0.77 and a fairly small p value of 0.03. At individual source level, it was noted that sediment on trap B (stationed between the reservoir and agriculture crop land on the upstream) geochemically and signficantly resembled the hyrochemistry of reservoir's water (Table 31 below).

Table 31: Multiple regression summary output of the relationship between soil/sediment chemistry and the Makoye Reservoir water chemistry based on field Measurements (2016-2017)

Regression Statistics			
Multiple R	0.88		
R Square	**0.77**		
Significance	**0.03**	**Coefficients**	***P*-value**
Agriculture crop land		0.17	0.43
Range/ grassland		0.11	0.14
Mixed (Grazing/Agriculture crop land)		-0.77	0.12
Sediment Trap A		-0.20	0.62
Sediment Trap B		**0.66**	**0.05**

7.5 Discussion of results on composition of soils, sediment and water quality in the Makoye subbasin and reservoir

Surface water quality is affected by diverse factors, but the most obvious and dominant according to McCool and Renard (1990) as well as Issaka and Ashraf (2017) are soils and clastic suspended sediment from the catchment upstream. Sediment chemistry and reservoir sedimentation affects water quality in many ways (Zereg *et al.*, 2018). It is therefore inappropriate to study water quality without first understanding the composition of soils and sediment in the catchment. Makoye Reservoir subbasin constitutes two main types of soils namely chromic luvisols and orthic ferralsols, the sediment was clastic in nature. This section discusses results on the composition of soils as well as moving sediment from the upstream of the subbasin and settled sediment from the reservoir bed. Afterwards, water quality results will be discussed.

7.5.1 Sources and composition of soils and moving sediment in the Makoye reservoir basin

Sedimentation problem is not only associated with reducing reservoir capacities and water supply, buts also water quality for livestock use (Ashraf, 2017). About 60 percent of soil erosion and sediment yields in the Makoye reservoir basin were occurring in the crop fields and grazing areas, these constituted the main sources of sediment that was entering the reservoir. All the soil samples from the three sampling areas were closer to neutral in terms of pH, which shows that acidity levels were near equilibrium. The cation composition (K, Na, Ca, Mg) was within the range of 0 to 18 cmol/kg with sodium as the most dominant. In terms of extracted minerals the range/grassland soils constituted the highest quantity of sulphur (165.29 mg/kg), which was coming from the earth roads where vehicles pass and chlorides (127.8 mg/kg) from fertilised fields; followed by soils from the range/agricultural crop land. Generally, all the sampling points contained a moderate to higher supply of chloride, ammonium and nitrite (32.67-149.33 mg/kg). This can be attributed to landuse practices such as cattle grazing which eventually leave a lot of excreta rich in nitrate and salts, which when introduced in water bodies through runoff, influence the water chemistry (Glowacz and Niznikowski, 2017). For obvious reason of fertiliser application to agriculture fields (Kandler *et al.*, 2017; Song *et al.*, 2017) and animal grazing (Glowacz and Niznikowski, 2017), soils from agriculture crop land constituted the highest content of nitrate followed by those from range/grassland and grazing/agriculture crop land respectively.

Iron content was cumulatively high (36.28 mg/kg) in agriculture crop land and grazing/agriculture crop land soils, but scarcely found in range/grassland soil samples. These sampling points were found to be underlained by orthic ferralsols which are naturally rich in iron (FAO, 2007), this partly explains why iron was high from such fields. Whilst copper concentration was cumulatively around 6 mg/kg for all soil samples, lead and cadmium were extremely low (<0.005 mg/kg). The presence of heavy metals such as lead could be attributed to motor vehicle earth roads that pass through the grazing and crop fields. As motor vehicles frequently pass through such roads, they drop some fuel which contains such traces of heavy metals (Appleton and Cave, 2018). On its way to the reservoir, total moving sediment from the grazing/crop land north-eastern side of the reservoir, contained more phosphorus (74 percent), iron (68 percent) and lead (73 percent) than the sediment from the crop fields, south-eastern side of the reservoir basin. On the other hand the latter trap also captured moving sediment with fairly high nitrite (63 percent) and copper (65 percent) as compared to the former trap. The concentration levels for other parameters were almost within same range as indicated by very small standard deviations and coefficients of variations. On average, concentration of chemicals in the soils did not widely vary from those of trapped moving sediment, which imply that soils from the cropland grazing land and a blend of the two were a source of the sediment entering the reservoir. This can be confirmed by the minimal coefficient of variations or zero for some parameters such as ammonia. The most highly variable parameters were sulphur, copper and lead whose CVs were moderately high at 48 percent, 46 percent and 31 percent, respectively. When moving sediment reaches the reservoir or water body, it starts settling down and when fully settled and compacted on the bed, it becomes settled sediment except in circumstances where it is scoured and re-suspended into water again where it becomes scoured sediment. Such findings are not just unique to current study area, but were similarly observed by Anyekulu *et al.* (2013) in Ethiopia, and Betrie *et al.* (2011) in Egypt.

7.5.2 Mode of transport and composition of settled sediment on the reservoir bed

Particle analysis in the sediment core sample showed that, sediment in the main reservoir was transported there through suspension because all particle sizes were below one milimetre. Rubey (1933), (Kime (1979), Leopold *et al.* (1995); Walling *et al.* (2002) have initially documented how particle sizes influence mode of sediment transport. Ferrari and Collins (2006) earlier noted that, the bottom set, which is typically the main reservoir, traps the finest sediment particles as compared to the top and medium sets.

Based on intra-layer analysis of sediment composition, it was found that calcium was the least variable followed by magnesium. Chloride and nitrite were the least variable in all the sediment stata. Inter-layer comparison showed that sediment that settled on the bed had diverse composition at different layers. For example, sodium was highest on the second and first layers, respectively, but it was the least in the fifth layer. Generally, the variations in terms of composition of sediment at different depths point to different historical landuse and erosion patterns on the upstream (USGS, 2018; Leopold *et al*., 1995; Walling *et al*., 1988). Had the landuse and erosion intensities not been diverse at different historical times, the concentration levels would have been the same at different depths of the samples.

Sediment and soils composition on the upstream of the reservoir did not widely vary from the composition on the bed of the reservoir. This also instrinsically show that the upstream part of the reservoir especially crop field were the main sources of the sediment on the bed. The only exceptions were iron and lead which indicated wide variations due to the fact that, if the former was scoured right at the point of deposition (reservoir), which was underlained by orthic ferralsol rich in iron whereas, the latter could be attributed to bioaccumulation through the clay that settled on the bed over time (Asthana and Asthana, 2001). Unlike recent studies by Ekett *et al.* (2018); Nazneen *et al.* (2019), which found high concentration of heavy metals in sediment cores, the current study found them to be the least notable (copper 1.31 percent, lead 0.03 percent and cadmium 0 percent) of the total concentration of metals in the sample). As much as heavy metals could be in smaller quantities, they may bioaccumulate over the years and may pose a risk to aquatic ecosystem and livestock especially during water stressful periods when bed sediment may be scoured back (through animal trampling) into the available waters (Bervoets *et al.,* 2016;). However, another case study by Stephansen *et al.* (2016) in Denmark indicated that accumulation of heavy metals in sediment and water may not necessarily affect biodiversity and community structure in an aquatic ecosystem. Such contra-positions create opportunities for continuous and more focused studies on the influence of heavy metal accumulation in sediment on micro invertebrates and livestock. As far as the current study is concerned and based on evidence discussed above, once settled sediment resuspends from the bed through scouring process, it may be more risky because it constitutes accumulated chemicals and metals that may harm livestock. Other scholars (Selvaraj *et al.*, 2010 in Taiwan; Fosu-Mensah *et al.*, 2017 in Ghana) have especially expressed concern over the threat that arise from the heavy metals when they accumulate over time. The composition of both soils and sediment from the study area showed similarities and variations in diverse ways, but they all pointed to a common source of influence, thus, the human activities on the upper catchment.

7.5.3 Spatio-temporal analysis of physico-chemical parameters in the reservoir

During the 2015/2016 warm-wet season, the average turbidity (1,714.4 NTU) was above the standard (1,000 NTU) prescribed by FAO (2013) for livestock. The coefficient of variation above the limit was 37 percent. On the contrary, during the cool-dry season, the average turbidity was extremely minimal (3.54 NTU) with coefficient of variation at 140 percent below the prescribed turbidity limit for livestock. The turbidity levels were almost twice higher than than the MPL for livestock consumption during warm-wet season, but during the cool-dry season turbidity levels plummated far below MPL, the cool-dry season could therefore, be the best timing for animal watering, but this is also dependent on water availability. Even though the reservoir was a closed hydrological system, there was no spatial homogeneity in terms of turbidity concentration from one point of the reservoir to the other. Concentration levels varied from one point to the other, but it was noted that not all sampling points across the Makoye Reservoir varied widely. Turbidity levels were in unstable equilibrium (Chorley and Kennedy, 1971) from one sampling point to the other in the warm-wet season than in the cool-dry season during which the spatial distribution was almost pointing to stable equilibrium (Table 19 a_{1-2} above).

Apart from the surface water's turbidity, subsurface water (mid-way of the vertical water column and near the reservoir bed) turbidity was also determined in real time. The mean daily turbidity levels were found to be higher (13,465.25 NTU) midway (≥47 cm) from the reservoir bed than near the bed (≤36cm) (1,344.77 NTU). Evidence in Figure 31a-b above showed that, the average turbidity levels were more unstable in the subsurface water column ≥47 cm above the reservoir bed than near the bed. The overall mean turbidity level for the two subsurface water columns was 7,995.84 NTU. This high turbidity level (as also noted by Kamtukule (2008)), points to a poorly managed catchment. Based on evidence in Table 28 above, paired t-test statistics indicated that, the average turbidity level across the reservoir was significantly higher in the warm-wet season than in the cool-dry season at 0.01 level of significance because during the former season, the reservoir was still receiving eroded sediment and soils through surface runoff. In the past, an idea was held that t-test can only be run on at least, 30 samples, but recent study by de Winter (2013) showed that t-test can be run on sample size as small as 10 depending on the intended purpose and the phenomenon being tested. In the case of small reservoirs like Makoye, 10 water samples were very representative as the water chemistry does not change abruptly from one point to the other.

From a temporal perspective, the study noted seasonal average turbidity to be above the prescribed standard during the 2015/2016 warm-wet season with a coefficient of variation above the MPL of 41.3 percent. On a good note, the average turbidity levels (879 NTU, 3.1 NTU and 524 NTU, respectively) for the 2016/2017 warm-wet season and 2017 cool-dry and warm-dry seasons were all below turbidity MPL for livestock. The grand long term average for all periods of measurements was 812 NTU, which means that from a long term context, turbidity level was within normal range with cool dry season being the safest (CV 140.6 percent below the MPL) period in as far as turbidity levels were concerned. Warm-wet and hot-dry seasons showed possibilities of rise in turbidity levels due to continuous inflow of sediment laden runoff and reduction in volume of water, respectively.

As opposed to the current study which recorded high turbidity levels in warm-wet season, Chomba and Sichingabula (2015) and Brunner (2011) found that, during the similar season, turbidity levels (< 1 NTU) measuring way suitable for human and livestock among selected reservoirs in eastern Lusaka. This points to a good landuse management in the latter study area than in the Makoye Basin. Inter-seasonal comparison of variations of turbidity levels showed that there was no stable equilibrium of turbidity in the reservoir as indicated in the coefficient of variations (CVs 0-141 percent).

The average concentration of TDS across 10 points on the reservoir during warm-wet season was 50.8 mg/l, but during the cool-dry season, it increased to 188.1 mg/l, which represents about 73 percent rise from the previous average. This could be attributed to different water levels during the two periods. It was found that in both instances of spatial analysis of the concentration of TDS, the levels were safely below FAO (2013) standards for animal watering as can be comfirmed by wide coefficients of variation (128 percent for warm-wet season and 97 percent for cool-dry season). So, when compared to prescribed standard (1,000 NTU), it can be said that the TDS levels were about 20 times safer for animal watering during warm-wet season and five times safer during cool-dry season. On average, the TDS levels were spatially likely to be much safer in the warm-wet season due to a high volume of water than during subsequent seasons.

The study noted that the levels of concentration of TDS were not necessarily the same from one point of the reservoir to the other and this entails that, even if a reservoir is a closed hydrological system, it is innacurate to simply sample water at one point and make conclusions based on one point as noted in most reviewed studies (Kamtukule, 2008; Chomba and Sichingabula, 2015; and Ougang, 2005). Although differences over space were noted, a paired t-test statistics showed that, there was no significant difference in the average concentration levels of TDS across the reservoir during the warm-wet season and the cool-dry season, at 0.01 level of significance. At intra-seasonal scale, average TDS level was highest (33.1 mg/l) during the warm-dry season followed by cool-dry (186.5 mg/l) and 2015/16/17 warm-wet seasons, respectively. The long term average TDS levels for the four seasons was 156.8 mg/l with 2016/17 warm-wet season being the safest period in terms of TDS levels. Generally, at all times, TDS levels were within very normal ranges (CVs ranging from 71 to 127.4 percent below MPL for livestock).

TSS was higly concentrated (between 1,800 mg/l and 3,580 mg/l) across the reservoir during the 2015/16 warm-wet season than during the 2017 cool-dry season when its concentration across the reservoir only ranged between one and four milligram per litre. The average concetrations across the entire hydrological space were 2,805 mg/l and 2.01 mg/l for both the former and latter seasons, respectively. Whilst the warm-dry season average concentration of TSS was above prescribed standard (1,000 mg/l) (CV=67 percent), its cool-dry season average concentration was 99.80 percent below the prescribed standard with the coeficient of variation at 141 percent. In other words, average TSS concentration was spatially above the MPL by almost three times (2.8) during the 2015/16 warm-wet and almost 500 times below the MPL during the 2017 cool-dry season. Although the TSS levels among the 10 sampling points across the reservoir were high in the warm-wet season, they were not as highly variable (CV=0-55.42 percent) from one another as was the case in the cool-dry season during which the differences between sampling points varied between 0 and 84.85 percent.

Turbidity levels in water were inextricably influenced by concentration of TSS as shown by very high r^2 values (0.99 and 0.78, respectively). A positive relationship between rainfall and daily TSS loaded in the reservoir was noted, but it was very weak as illustrated by a very low r^2 (0.03). Nevertheless, the r^2 value was drastically improved from 0.03 to 0.64 after eliminating outliers. Such relationships between rainfall and TSS are not are not only unique the current study area, but they simply confirm earlier works by other scholars as (Erlingsson, 2018; Sichingabula, 1996; Leopold *et al*., 1995; Langbein and Schumm, 1958). A daily average of 113.47 mg/l of total suspended sediment was being added to the reservoir during the entire period of real time measurement. During this period of measurement, the maximum record of suspended sediment load was 1,552 mg/l and the minimum record was seven milligram per litre.

At intra-seasonal scale, the 2015/2016 warm-wet season recorded the highest seasonal average level of TSS (2,832 mg/l), above the MPL (CV 67.6 percent). During the other seasons, TSS levels were safely below MPL (CVs ranging 68.7-140.9 percent) and its average safest level (1.8 mg/l) was in the 2017 cool-dry season, which implies that most if not all suspended sediment from the 2016/17 warm-wet season had already settled on the bed by 17/7/2017. The long term average for TSS was 807.6 mg/l, so it is said that, on long-term, TSS level was within safe range. TSS levels were inter-seasonally highly variable and thus, in unstable equilibrium as already shown in Table 29.

According to FAO (2013), surface water (such as Makoye Reservoir's) whose turbidity and TSS levels go beyond 1000 NTU 1,000 mg/l, respectively, is susceptible to chlorine-resistant pathogens such as *Cryptosporidium*, which cause animal diseases such as diarrhoea. The MLF (2016) stated that cattle in Makoye Reservoir catchment suffered from reduced immune system and diarrhoea partly due to poor quality of water they drunk, leading to death and reduction in population of cattle between 2015 and 2016. This study recommends a separate study on how TSS and Turbidity can influence animal health and mortality. Worth noting was the reality that, although the reservoir is specifically meant for livestock, there are still people, especially children who swim in the waters and may unintentionally drink this water with possibility of contracting water-borne diseases such as bilharzia and typhoid (Plate 7).

Plate 7: Children Swimming in the Makoye Reservoir, Monze District, Zambia, (2017).

The study generally noted that turbidity, TSS and TDS were within normal ranges in the cool-dry season, but in the warm-wet season, turbidity and TSS were extremely beyond the MPL, making water unsuitable for animal consumption during that period. The average TSS level across the reservoir was significantly higher in the warm-wet season than in the cool-dry season at 0.01 level of significance. Aside other factors such as particle size and particle solubility (Rubey, 1933) that may have affected TSS loading, rainfall was confirmed to have had a positive influence on the amount of suspended sediment loaded in the reservoir. Such findings reconfirm earlier classic works by Langbein and Schumm (1958).

Chemical analysis of water quality revealed that, on average, sulphate concentration was not spatially homogenous, the CVs (0-111.1 percent in warm-wet season; 0-14.7 percent in cool-dry season) demonstrated that intra-spatial variations were high and less stable in the warm-wet season than in the cool-dry season. There was no signficant difference in the average spatial concentration of sulphate between the hot-wet and cool-dry seasons. From a general perspective, all the levels of sulphates including the long term average were below the MPL, with 2015/2016 warm-wet season recording the lowest level. Compared to the FAO (2013) standards, the average nitrate concentration levels across the reservoir were 22 times safer in the warm-wet season and 400 times safer in the cool-dry season. The CVs (129.3 percent in warm-wet season and 139 percent in cool-dry season) confirmed how highly variable the measured concentration levels were from the respective MPL. The variations between sampling points across the reservoir ranged from 0 to 123 percent and from 0 to 140.27 percent during the warm-wet and cool-dry seasons, respectively. This means that during the latter season, the concentration levels among the 10 points were more widely different from each other than during the former period. It was further noted that, during the latter season, some points shared same levels of nitrate concentration as indicated by zero percent CVs (Table 22 earlier presented), which points to a fairly more stable equilibrium of nitrate during this period than in the former period. The study found that spatially, the average concetrations of nitrate during the warm-wet season was signficantly higher than in the cool-dry season. From a temporal perspective, nitrate was on average, within safer ranges (CV 126-139 percent below MPL). Premised on CVs in Table 29, nitrate's average concentration levels were inter-seasonally variable.

In comparison to the prescribed MPL, chloride levels were 48 and 79 times safer during the hot-wet and cool-dry seasons, respectively. Just like other parameters, chloride concentration was found to be inconsistent at different sampling points across the reservoir. The variability was found to be less pronounced (0-30.74 percent) in the cool-dry season than in the warm-wet season (0-45 percent). Nonetheless, chloride concentration was spatially and on average, significantly higher during the warm-wet season than cool-dry season at 0.01 level of significance (Table 28 above). This could be attributed to high deposition through surface runoff during the warm-wet season, a scenario also earlier documented by Korkanc *et al*., 2017 and Kamtukule, 2008). It was found that during the 2016/17 warm-wet season and 2017 cool-dry season, chloride concentration levels were equal. This could be attributed to reservoir inability to dilute chloride over time. Compared to their respective MPL, chloride levels, including the long term average were all within very safe ranges as also demonstrated by their CVs below MPL at different temporal scales (133-138 percent). In their earlier study Cui and Chui (2018) also noted that, surface runoff is one of the main sources of chloride and other chemical sediment, which vary from season to the other.

The average concetrations of phosphorus and ammonia were higher across the reservoir during the warm-wet season than during the cool-dry season, however, this was not the case for total phosphate whose means for both seasons were significantly different. From a temporal perspective (intra and inter-seasonal average analysis), the three elements were found to be above the prescribed MPLs. Their inter-seasonal variations ranged from 1-59 percent. According to Crouse *et al.* (1981), phosphorus is a challenging element once introduced in reservoirs because it encourages growth of algae, which when dead, is a food for high oxygen-demanding organisms. So if it remains unchecked, it is a silent problematic process that comes with suspended sediment to change oxygen balance in water and eventually make water unsuitable for animals and even other aquatic organisms.

Spatially, water acidity was as closer to nuetral as possible given that all pH readings were around 7 and that all of them were within permissible limits for animal consumption during both warm-wet and cool-dry seasons. Paired t-test statistics further confirmed that, spatially, there was no signficant difference between the average levels of pH during the hot-wet and cool-dry seasons at 0.01 level of signficance. The pH was found to be the most stable parameter both spatially and temporally, but earlier study (Korkanc *et al.*, 2017) in Turkey found it to be the most unstable temporally. Closely associated with pH was alkalinity whose minimum and maximum levels in the warm-wet and cool-dry seasons ranged from 34-102 mg of $CaCO_3$/l as well as 130-158 mg of CaCO3/l, respectively. Whilst the alklinity levels were spatially high during cool-dry season, they indicated a stable equilibrium across the reservoir than during the former, because most of the values at different sampling points oscillated around 130-158 mg of $CaCO_3$/l with spatial average of 138.4 mg of $CaCO_3$/l. In the warm-wet-season, alkalinity was spatially averaging at 60.9 mg of CaCO3/l as individual values at different points ranged between 34 and 102, implying unstable equilibrium in the spatial distribution of alkalinity. Nyambe *et al.* (2018) also noted a similar trend of unstable spatial distribution of parameters they studied in their water quality study in Western Zambia.

From the context of pH and alkalinity, the water in the reservoir was safer for animal consumption as both spatial average concentrations of pH and alkalinity were far below MPLs as also indicated in the high CVs (111 percent for pH; 80 percent for alkalinity below respective MPLs). Based on paired t-stastics in Table 28 above, there was no signficant difference between the average levels of alkalinity across the reservoir during the warm-wet and cool-dry seasons at 0.01 level of significance. The average interseasonal variation of alkalinity ranged from 9-84 percent which means that some levels of concentration were low whilst other were high (Table 29 above). The study generally observed that all the chemical paramaters were within acceptable limits for livestock consumption.

7.5.4 Spatio-temporal concentration of selected metals

The average spatial concentration of iron across the reservoir was 5.26 mg/l and 0.5 mg/l in the warm-wet and cool-dry dry seasons, respectively. Spatially, the reservoir was almost 11 times highly concentrated with iron in the warm-wet season than in the cool-dry season. Although the average spatial concentration of iron drastically reduced during the cool-dry season (0.5 mg/l) compared to warm-wet season (5.26 mg/l), it was still above the MPL (0.3 mg/l) for livestock. In the warm-wet season, the average level of iron varied above the MPL by 126 percent, but in the cool-dry season, it was not highly variable (34 percent) as compared to the former season.

Using a paired t-test, the study noted that the average level of iron across the reservoir was significantly higher in the warm-wet season than in the cool-dry season, at 0.01 level of significance. Iron was not only unstable spatially, but also temporally and it was the only metal that was above the MPL in all instances. This could be attributed to the incoming sediment, but more especially to the pedospheric system (orthic ferralsols) on which the reservoir is constructed, which allows various agents of denudation such as surface runoff, wind and animal movements (Leopold, *et al.*, 1995) to easily transport iron-rich sediment into the reservoir.

According to Linn (2013), iron affects smell and taste of water. Since cattle are sensitive to both odour and taste, high levels of iron as noted in Makoye Reservoir would repel them from drinking water. In general, cattle can, to some extent, withstand water containing up to 4 mg/l of iron beyond which they reduce water intake and may develop water related complications especially if they are lactating (Braul and Kirychuk, 2001). Based on earlier observations by Braul and Kirychuk, (2001), it is said that, iron levels were safer for animals during the cool-dry season than during the warm-wet season. However, if viewed from the context of FAO (2013) standard, the average iron levels were unsafe for livestock during both seasons. Since animals were observed drinking the very water deemed highly loaded with iron, the proposed standard by Braul and Kirychuk (2001) is more realistic for African context than the FAO standard.

Sodium, calcium and magnesium concentrations were heterogeneously distributed across the reservoir. Sodium's concentration was below the MPL by seven times (CV 108 percent) during the warm-wet and by 12 times (CV 120 percent) during cool-dry seasons. Its presence was in safer ranges for livestock. Spatial variations in concentration of sodium were almost within same magnitude ranges in the warm-wet season (0-32.64 percent) and cool-dry season (0-32.84 percent). Compared to sodium, calcium was found to be more variable (0-77.14 percent) across the reservoir during the warm-wet season than during the coo-dry season (0-26.94 percent). On average, calcium and magnesium showed increase during the cool-dry season (by >100 percent).

The CVs for magnesium among specific sampling points oscillated around 0-29.77 percent in warm-wet season and 0-33.41 percent in cool-dry season, which means that the stability of magnesium concentration across the reservoir was not highly variable during both seasons. Fluoride was not a matter of concern in as far as suitability of water for animal consumption was concerned. However, on average, it also showed a positive increase during the cool-dry season. The current study findings resonate with earlier study by Ougang, 2005) which also noted that concentration of most parameters varied from one season to the other. This qualifies earlier observations by Kapungwe (2007); Al-Mutairi *et al.* (2014); Dalu *et al.* (2017); Wijesiri *et al.* (2018); and Cui *et al.* (2018) that, assessment of seasonal changes in quality of surface water is imperative for evaluating temporal variations of water quality due to changes in inputs from anthro-biophysical processes. This implies that in all studies on water quality, researchers need to carefully consider human activities in the catchment as these influence composition of sediment entering water bodies at different temporal scales.

The current study found that, all hazardous heavy metals such as copper, lead and cadmium were far below respective MPLs as they respectively measured below 0.003 mg/l, 0.01 mg/l and 0.002 mg/l in the reservoir water samples. The CVs (>100 percent in all cases) between them and their respective MPLs demonstrated how extremely negligible they were to cause any threat to livestock. Nevertheless, studies by Song *et.al* (2017); Kandler *et al*., (2017; Dai *et al.* (2018); Lu and Yu (2018) observed high, but negatively trending heavy metals in water. This challenges water scientists to be alert to both inter and intra spatial variations in terms of how different parameters like heavy metals can affect water quality, it is not always that they are at detrimental levels of concentration, time and place should be considered.

7.5.5 Hydro-chemical typology of water in the Makoye Reservoir in warm-wet seasons

Both anion and cation waters entered the Makoye Reservoir during the two warm-wet seasons. During the 2015/2016 warm-wet season, Makoye Reservoir received diverse types of water in anion terms, but during the 2016/17 season, there was only one anion type of water received, pointing to a mixed landuse on the upstream where sediment was coming from. During 2015/2016 warm-wet season, the most predominant (63 percent) was chloride water, followed by ammonium-nitrate water

(18 percent) and sulphate water (five percent). It was further noted that, 14 percent of water was a mixed type as it constituted all types of anions. Based on these types of water in anion terms, it is said that, the sediment which was ridden by these waters was coming from agricultural fields and grazing areas because they were all found to contain high chloride levels as also noted through trapped sediment samples. During the 2016/17 warm-wet season, it was noted that sulphate water was 100 percent dominating. This could be due to poor mixing of anions or that other chemical parameters were diffused off in water thereby making their visibility negligible.

In cation terms, the study noted that, the mixed type of water was the most predominant (50 percent in 2015/16 and 53 percent in 2016/17) during the two warm-wet seasons. This shows a very high mixing efficiency of cation in water. Sodium-iron water was the second most dominant water (45 percent) especially during the 2015/16 warm-wet season as compared to the 2016/17 warm-wet season (22 percent). In another study by Umsan *et.al* (2014) in Nigeria, the latter (mixed type) was found to be the most predominant in the Obajana Catchment, which shows that, such a mixing of the water is not only unique to the current study area, but also in other spatial contexts. Calcium water was higher (25 percent) than sodium-iron water during the latter season, but was the least prominent (five percent) during the 2015/16 warm-wet season. All these types of waters implicitly pointed to the sources of sediment earlier mentioned and catchment geology because they shared similar chemical characteristics.

The predominant types of water from both anion and cation groups influenced the type of water at the final mixing phase (Figure 39c above). During the 2015/16 warm-wet season, water in the reservoir was highly heterogeneous as it mixed in seven different ways, but during the 2016/17 warm-wet season, it only mixed in three ways. In the former warm-wet season, the most (45 percent) notable type of water was sulphate-chloride, which was also the most dominant (95 percent) during the latter season. Baumle *et al.* (2007) found almost similar type of water (sodium-sulphate) in their analysis of water using Piper diagram among selected hot springs in the Zambezi Catchment (parent catchment for the study area).

The second most dominant mix of water in both the former (22 percent) and latter (four percent) seasons constituted a blend of sulphate-chloride-calcium-magnesium, inherently showing how influential sulphate and chloride were in suspended and dissolved sediment. For the 2015/16 season, the third most prominent types of water (nine percent each) were ammonium-nitrate and calcium-magnesium as well as, sulphate-chloride and sodium-iron. Ammonium-nitrate and calcium-magnesium type of water were also observed during the 2016/17, but only accounted for one percent of all types of water mix during the said period. Aside the types of water mixes already mentioned for the 2015/16 warm-wet season, ammonium-nitrate and a blend of ammonium-nitrate-sodium-iron were also found each scoring five percent of all observed hydrochemical mixing of water. Last but not the least, five percent of water mix constituted all the parameters, which were almost in equilibrium such that there was no one dominant element.

Synoptically, the reservoir was more diversely mixed chemically and eventually, had diverse types of water in the 2015/16 warm-wet season than during the 2016/17 warm-wet season. This also inherently points to diverse landuse that were taking place at diverse temporal scales on the upstream of the reservoir. A comparison of the current study finding (on the hydro-chemical faces of water) to other studies (Talabi *et al.*, 2013 in Nigeria; Dano, 2001 in USA) show that water bodies had diverse mixing capabilities and that, the chemical mixing provided a geochemical signature of their catchment. Therefore, piper technique can also be used to identify sources of sediment in the catchment by comparing the chemistry of water to the chemistry of sediment and soils on the upstream. Generally, during the two warm-wet seasons (2015/16/17), Makoye Reservoir was found to be highly laden with sulphate-chloride water. This could be linked to rampant agricultural activities on the upstream as also noted by APEC (2017).

7.5.6 Relationship between the geochemistry of soils/sediment and the reservoir's hydrochemistry

Sediment naturally or anthropogenically enters reservoirs from diverse sources (Anyekulu *et al*., 2013). Based on multiple regression results, the study concluded that a combination of the geochemistry of soils and sediment were positively and signficantly responsible for the hydrochemistry of reservoir's water. This was confirmed by a high r^2 value of 0.77 and a fairly small p value of 0.03, which means that 77 percent of what was chemically happening in the reservoir could be explained or attributed to the chemistry of soils and sediment eroded from the agricultural fields and deposited in the reservoir. The most influential source of sediment and soils, which affected the reservoir water's chemistry was agriculture-range/grassland on the upstream. This was the most signficant (*p*-value 0.05) source of sediment as indirectly reflected in the geochemistry of sediment that passed by Trap B (placed between reservoir and agriculture crop land-range/grassland on the upstream) to the reservoir. Other studies (Kandler *et al*., 2018 in Germany; Nyambe *et al.*, 2018 in Western Zambia) also noted that, the composition of soils/sediment on the upstreams of the catchment greatly influence the water chemistry down stream. This presents a challenge to water managers to explore strategies for sustainable landuse in the catchment and to always factor in soil/sediment composition analysis whenever water quality studies are undertaken. It is inconclusive to study water quality without an understanding of the soil or sediment or geological composition on the upstream of the catchment.

7.6 Chapter Summary

The study observed that the concentration levels of 80 percent of parameters were below their respective MPLs for livestock, with exception of iron, total phosphate, phosphorus and ammonia, which on average were above their respective MPLs for livestock. It was also noted that although sediment might be detrimental to reservoir water, it could also be a benefit to pastoralist communities because it supplies natural minerals many of which could be accessed by animals through the water they drink from the reservoir. This implies that, over 10,000 cattle would have access to supplementary source of natural minerals such as calcium that support bone development and blood production (FAO, 2013). On the other hand those parameters such as iron that were above permissible limits throughout the four seasons of measurement may reduce water intake by animals leading to loss of weight and even premature death thereby leading to socio-economic challenges among 474 pastoral farming-dependent households. Continuous assessment of the status of concentration of parameters in the reservoir and their possible implications on livestock would be useful to find new ways of increasing benefits from chemical sediment in the reservoir, whilst reducing any possible detrimental effects. The chemical and physical characteristics across reservoir was also a perfect scanning tool to determine the nature of landuse across the whole catchment, therefore, determination of concentration levels and distribution of selected physical and chemical parameters across the Makoye Reservoir was an eye opener for implementation of sustainable landuse practices around the catchment. The study further challenges the idea of attempting to understand the concentration levels of chemical and physical parameters of water in reservoir using a single point of sampling and one off measurement, because, it was established that concentration levels of most parameters temporally and spatially vary across the reservoir. Therefore, a temporally and spatially distributed approach in analysis of water quality would yield the best averages on which conclusions could be drawn.

CHAPTER EIGHT: MODELLING SEDIMENTATION USING SWAT IN THE UNGAUGED MAKOYE RESERVOIR SUBBASIN AND ITS 3D CONCEPTUAL MODEL

This chapter presents and discusses results based on objectives 5 and 6 whose focus was on modelling sedimentation in using SWAT 2010 and designing a 3 dimension conceptual model for the Makoye Reservoir. The purpose of this modelling was to test the efficiency of the tool in simulating sedimentation in ungauged reservoir subbasin by comparing physically measured sediment to simulated one so as to provide framework, which future studies may adapt and, which is useful for communities water resource management and decision making. Firstly, the chapter presents processed DEM, landuse, slope, soils, HRU excerpt report and maps. The second subsection will show specific simulation results. Just before discussion of results, conceptual synthesis models for improved understanding of sedimentation and simulation processes in ungauged reservoirs and basins will be presented.

8.1 Processed DEM, landuse and soils maps and delineated catchment and HRUs

SWAT processing based on the SRTM-DEM showed that much of the Makoye Reservoir catchment is characterized by a gentle slope with Mean Altitude Above Sea Level (MASL) between 1070 m and 1140 m (Figure 45).

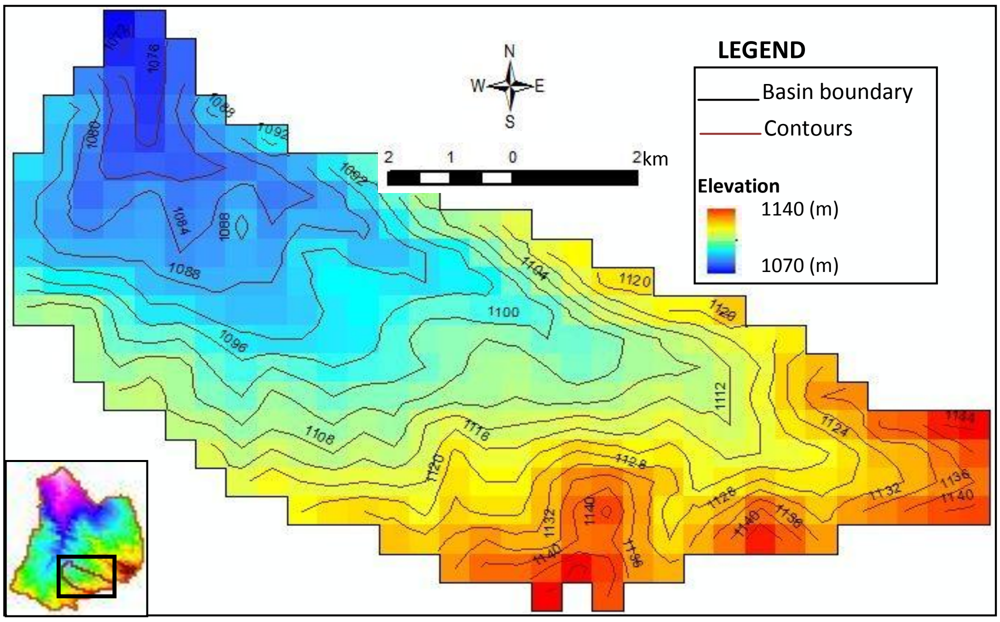


Figure 45: DEM Figure clipped from SRTM and contours showing elevation dynamics in the Makoye Catchment, Monze District based on SWAT DEM Processing

Makoye catchment had four main types of landuse, the most prominent one were agriculture/crop land and grazing grassland which cumulatively accounted for 83% of the total landuse (Figure 46a-b).

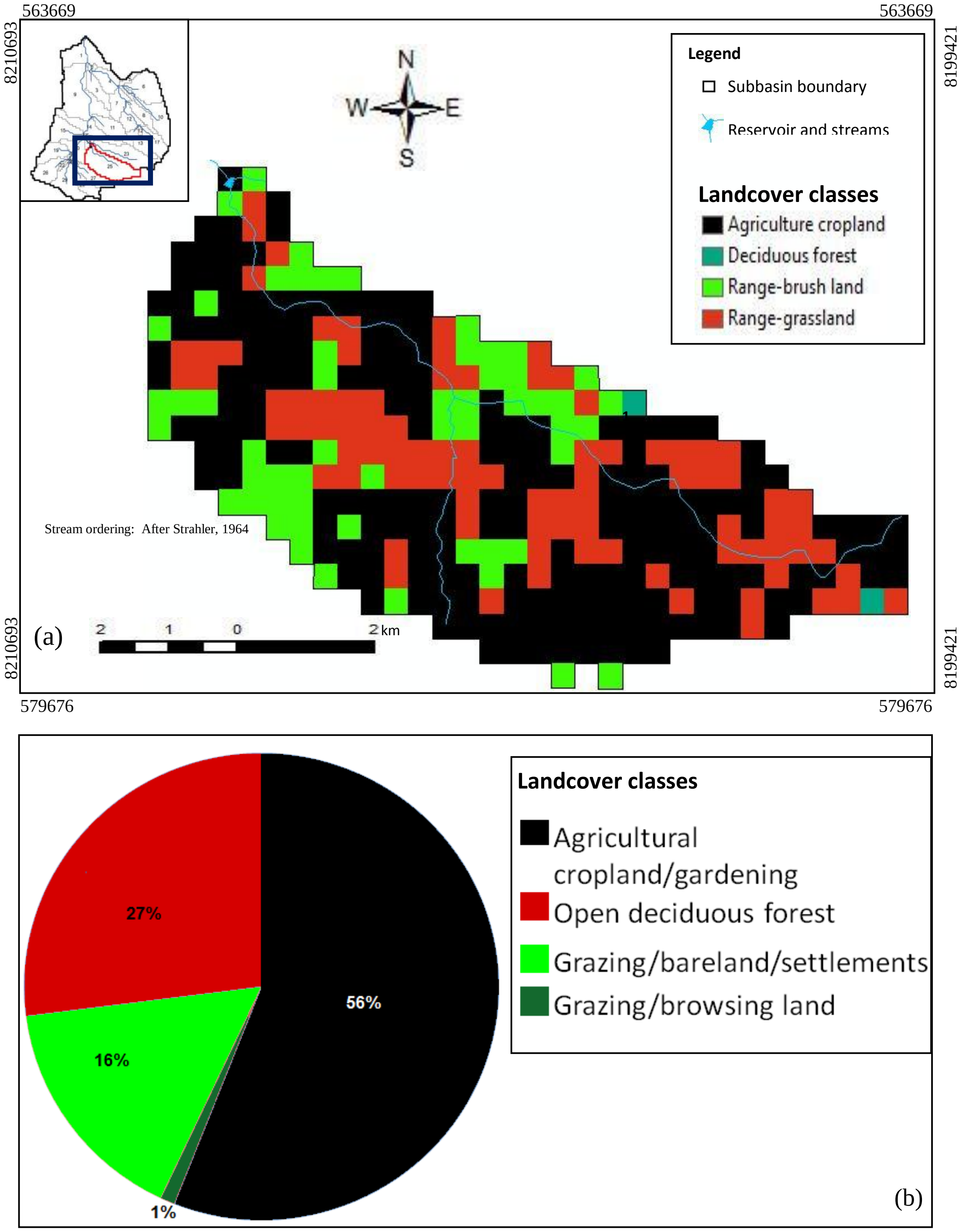
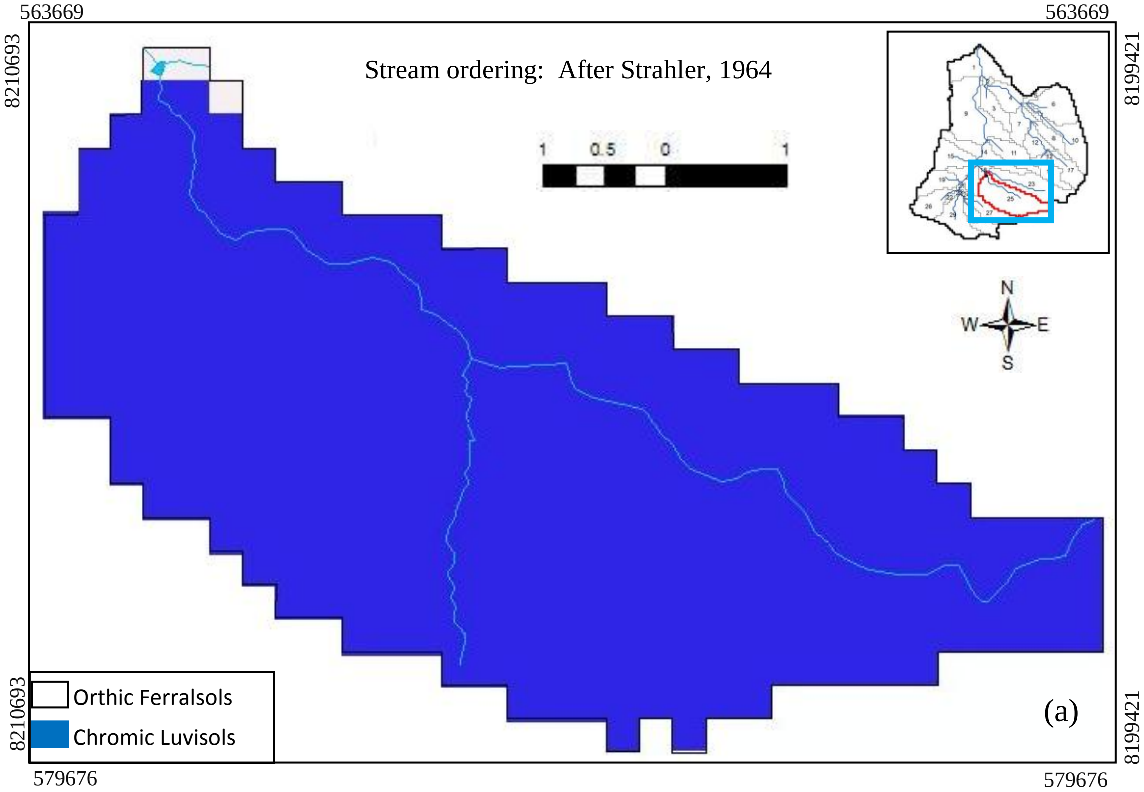


Figure 46: Makoye Basin's (a) spatial distribution of landuse and (b) spatial distribution of landuse based on SWAT reprocessing of Globecover Map v2.3.tif-2009 and field observations, 2015-2017.

Chromic luvisol is the most spatially distributed type of soil covering 99 percent of the sub-basin, orthic ferralsol only covered one percent of the total area, but it is the one that mainly predominates the immediate biophysical environment of the reservoir (Figure 47a-b).



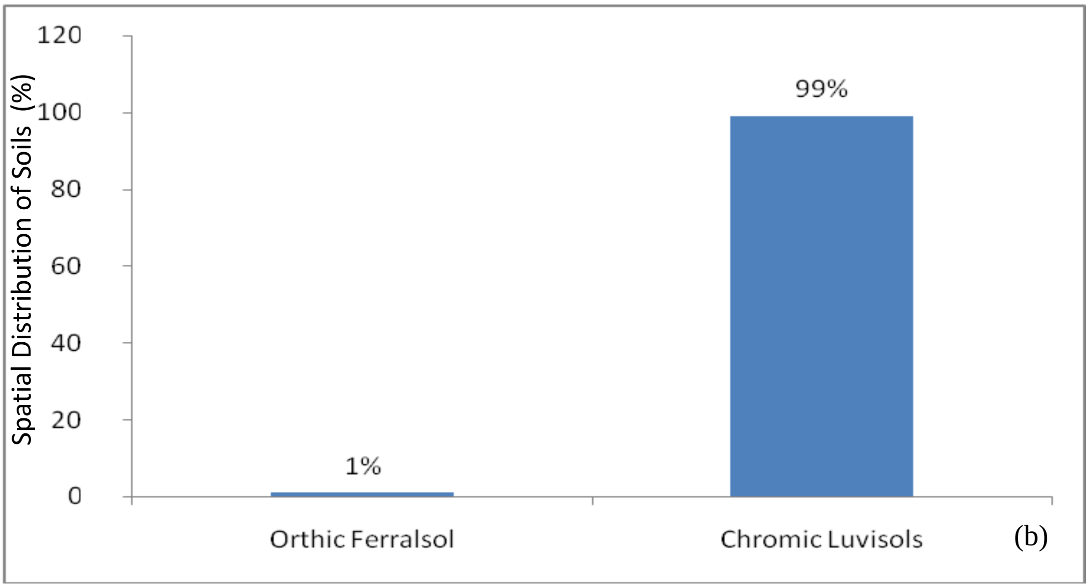


Figure 47: Makoye basin's (a) spatial distribution of soils and (b) areal extent of soils based on Soils Map of Africa by FAO (2007)

Based on the combination of DEM, landuse and soils map, the slope and hydrological maps were created (Figure 48a-d).

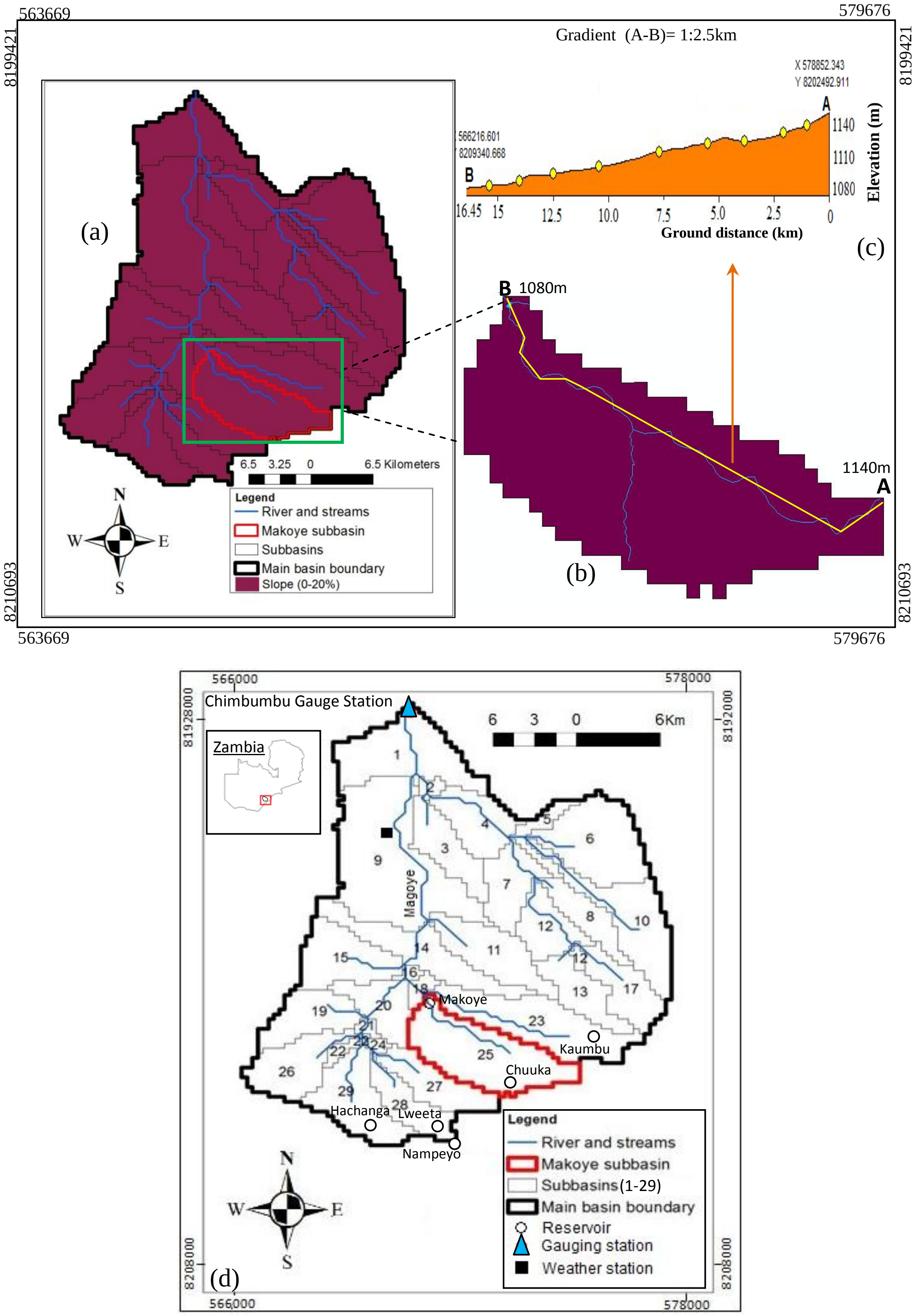


Figure 48: Slope map for (a) Upper Magoye watershed; (b) Makoye subbasin (c) 2D view of Makoye subbasin's longitudinal profile and (d) Location of Makoye Reservoir catchment

SWAT processing based on the STRM-DEM generated the watershed whose delineated subbasins (29), stream network, main outlet and boundaries are as shown in Figure 48d above. The spatial extent of the delineated watershed for Magoye was 903.96 Km^2. The specific subbasin area (study area) of the Makoye Reservoir was 66.82 km^2. The total number of HRUs generated by the SWAT model was 148 (Table 32 and Appendix K for a complete raw HRU report). Out of the total HRUs generated, four percent (six) were from the Makoye Subbasin. In a SWAT output map of the HRUs for Makoye subbasin (Figure 49), four of the six HRUs were underlained by chromic luvisols (Table 33).

Table 32: Direct excerpt of the final HRU reports generated by SWAT in-txt file format for all HRUs in the Magoye Subbasin.

SWAT model simulation Date:12/21/2017 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 0 / 0 / 0 [%]
Number of HRUs: 148
Number of Subbasins: 29

		Area [ha]	Area[acres]	%Wat.Area
Watershed		90396.0000	223373.0358	
LANDUSE:				
	Agricultural Land-Row Crops --> AGRR	30273.7500	74807.9499	33.49
	Forest-Deciduous --> FRSD	13608.0000	33626.0484	15.05
	Forest-Mixed --> FRST	607.5000	1501.1629	0.67
	Range-Brush --> RNGB	29382.7500	72606.2444	32.50
	Range-Grasses --> RNGE	16524.0000	40831.6302	18.28
SOILS:				
	Chromic Luvisols-Lc54	66825.0000	165127.9163	73.92
	Orthic Ferralsols-Fo77	23571.0000	58245.1196	26.08
SLOPE:				
	0-20	90396.0000	223373.0358	100.00

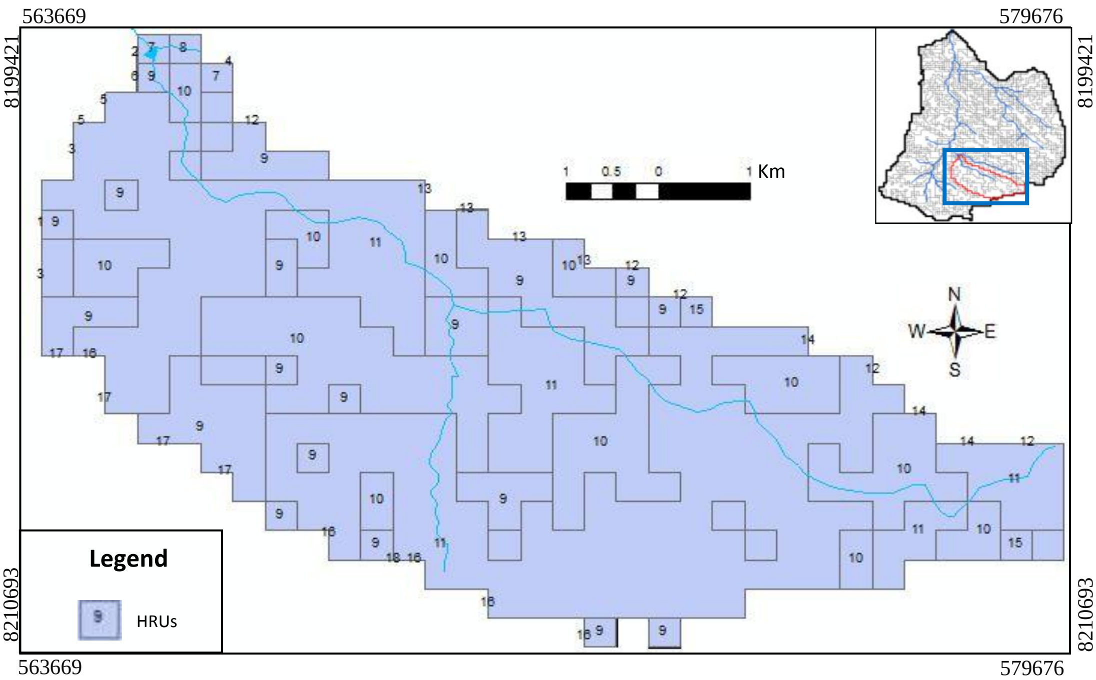


Figure 49: HRU map of the Makoye Subbasin, Monze District based on SWAT model Processing outputs.

Table 33: Selected characteristics of the HRUs in the Makoye Reservoir Subbasin, Monze District based on SWAT model HRU final report

HRU ID	SUBBASIN	LU_NUM	LU_CODE	SOIL_NUM	SOIL_CODE	SLOPE_NUM	SLOPE_CODE	MEAN_SLOPE	UNIQUECOMB	Shape Area (Km^2)
7	25	30	AGRR	538	Orthic Ferralsols-Fo77	1	0-20	0.56	25_AGRR_Orthic Ferralsols-Fo77_0-20	0.4
8	25	130	RNGB	538	Orthic Ferralsols-Fo77	1	0-20	0.6	25_RNGB_Orthic Ferralsols-Fo77_0-20	0.2
9	25	130	RNGB	715	Chromic Luvisols-Lc54	1	0-20	1.01	25_RNGB_Chromic Luvisols-Lc54_0-20	10.9
10	25	140	RNGE	715	Chromic Luvisols-Lc54	1	0-20	1	25_RNGE_Chromic Luvisols-Lc54_0-20	17.82
11	25	30	AGRR	715	Chromic Luvisols-Lc54	1	0-20	1.02	25_AGRR_Chromic Luvisols-Lc54_0-20	31.04
15	25	50	FRSD	715	Chromic Luvisols-Lc54	1	0-20	0.77	25_FRSD_Chromic Luvisols-Lc54_0-20	0.4

8.2 SWAT simulation outputs

This section presents results on simulation of sedimentation in the Makoye Reservoir catchment. The first subsection presents 30-year simulated discharge at the subbasin 1, which had a gauging station at Chimbumbu Farm, but regionalised to the entire watershed. Afterwards, calibrated and validated discharge results for the period 2016 and 2017 are presented. It should be noted that these discharge results were for the sake of having an idea of what would be the possible hydrological processes in the other 28 ungauged subbasins such as the current study's site (subbasin 25) (Figure 48d). After presenting reflective discharge results for subbasin 1 (with spatially similar hydro-biophysical characteristics as the other 28 subbasins), sediment simulation results (at the ungauged study site) are presented in terms of general sediment erosion (1988 to 2017), calibrated sedimentation results (2016) and validated ones (2017), respectively. After presenting main sediment simulation results, sensitivity and uncertainty analysis of the calibrated sediment model are presented.

8.2.1 Regionalised calibration of the hydrological component of the SWAT model

In order to understand historical hydrological scenario of the Makoye Reservoir Catchment, simulation was done from the period 1988 to 2017. It was noted that, between 1988 and 2017, simulated discharge at the watershed outlet was low and this could be attributed to too many reservoirs on the upstream of the catchment. During this period of simulation, the long term mean discharge was 0.43 m^3/s, the maximum and minimum discharges were 2.6 m^3/s and 0.001 m^3/s, respectively (Figure 50a). The maximum and minimum values of discharge remained the same for the period of calibration (2016) and validation (2017) of discharge. Figure 50b presents long term water discharge-depth rating curve for selected periods between 1988 and 2014. Figure 50c shows short-term rating curve generated for the period of discharge calibration and validation.

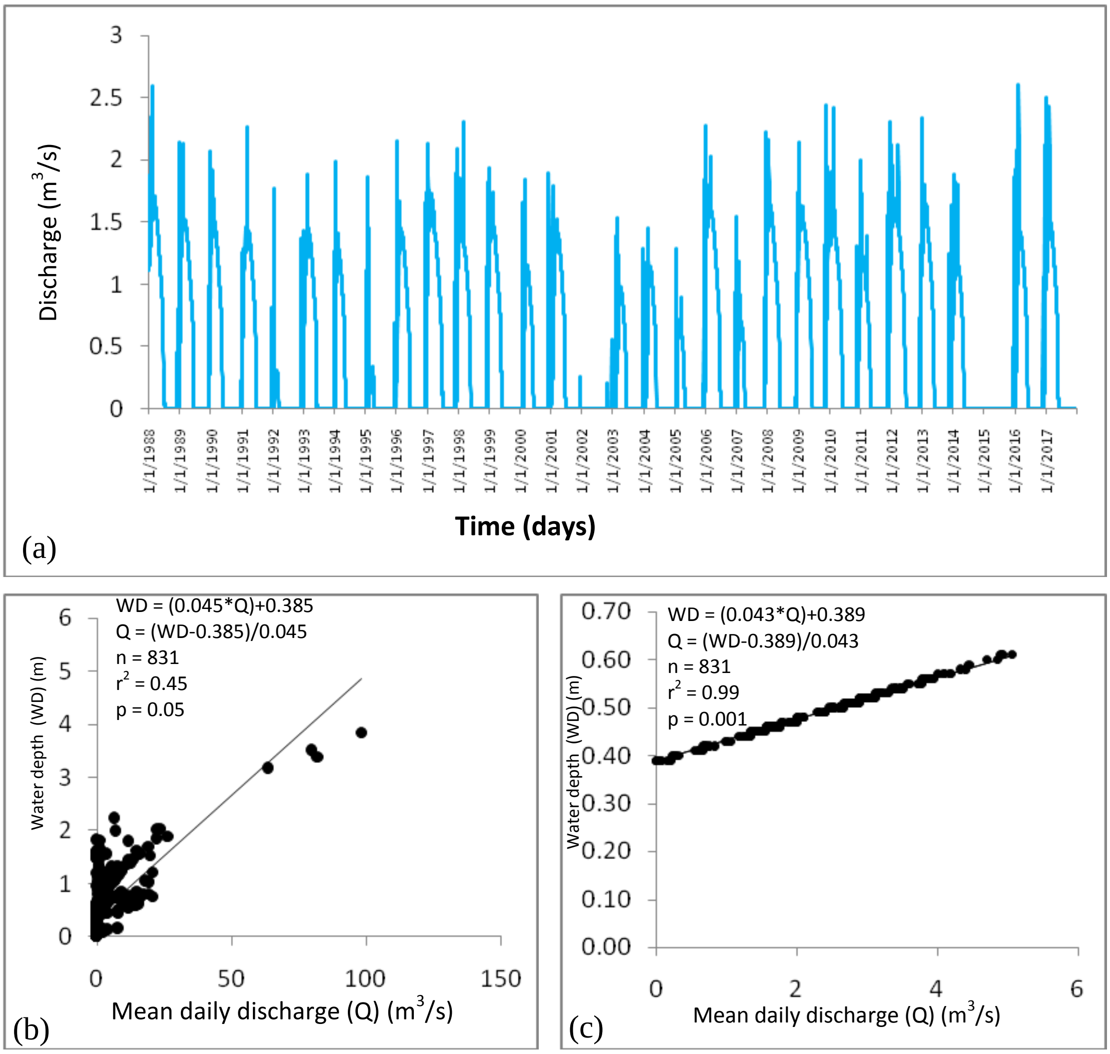
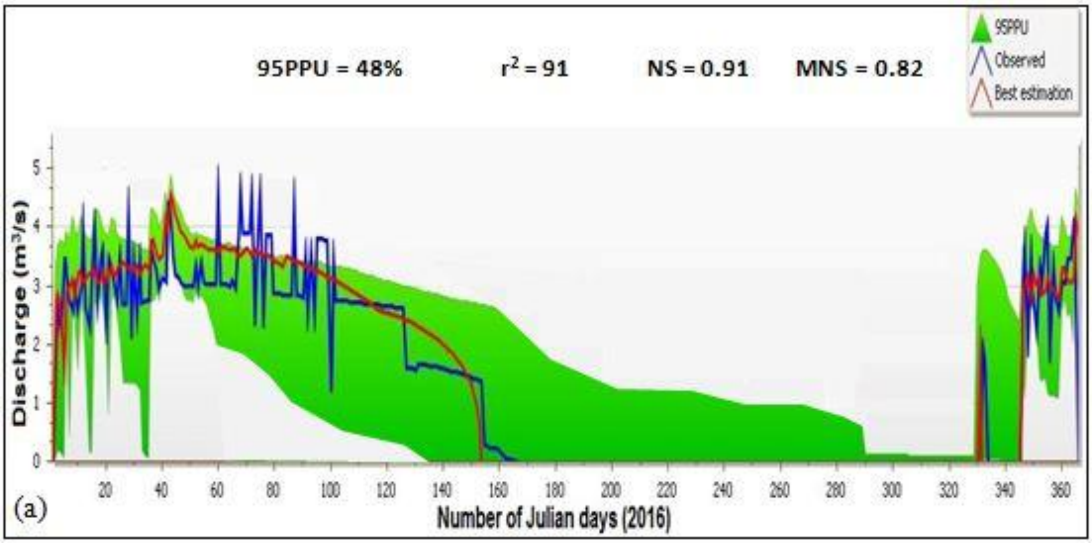


Figure 50: (a) General long term (1988-2017) simulated discharge hydrograph at Chimbumbu Gauging Station (b) long term (1988-2017) discharge-water depth rating curve at Chimbumbu Gauging Station (c) short term (2016-2017) discharge-water depth rating curve at Chimbumbu Gauging Station based on (a) SWAT InOuttxt; (b) DWA's selected data sets, 1979-2017; (c) Field measurement (2016-2017).

There was a positive relationship between the long term water discharge and depth (Figure 50b), although this relationship was not strong (r^2 = 0.45). On the other hand Figure 50c (2016-2017) demonstrates a very strong positive relationship between discharge and water depth as indicated by r^2 value of 0.99. Simulated against observed discharge during the calibration period is shown in Figure 51a-b.

The reflective calibrated hydrological model was generally very good given the high NS value of 0.91 and coefficient of determination (r^2) value of 0.91. During calibration period, the model had very strong predictive power. However, it did not satisfactorily account for a wider range of uncertainties in the hydrological system (48 percent).



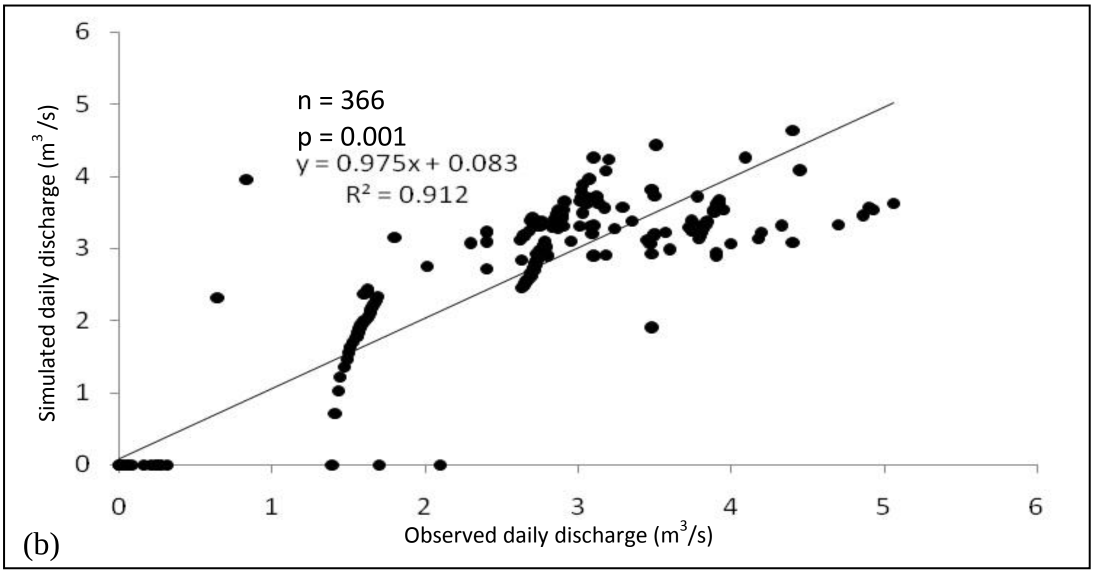


Figure 51: (a) Calibrated hydrological model for Chimbumbu gauging station (2016) (b) relationship between observed and simulated dicharge for the calibration period (2016) based on SWATCUP SUFI-2 calibration outputs

8.2.2 Reflective validation of hydrological model

Validation of the hydrological model was done for one year in 2017. Results are presented in Figure 52a-b. Evidence shows that the model performed poorly in the period outside the calibration period as demonstrated by a low NS value (0.41) and r^2 value of 0.47 due to inability of the SWAT model to simulate the flows during the first twenty days of validation.

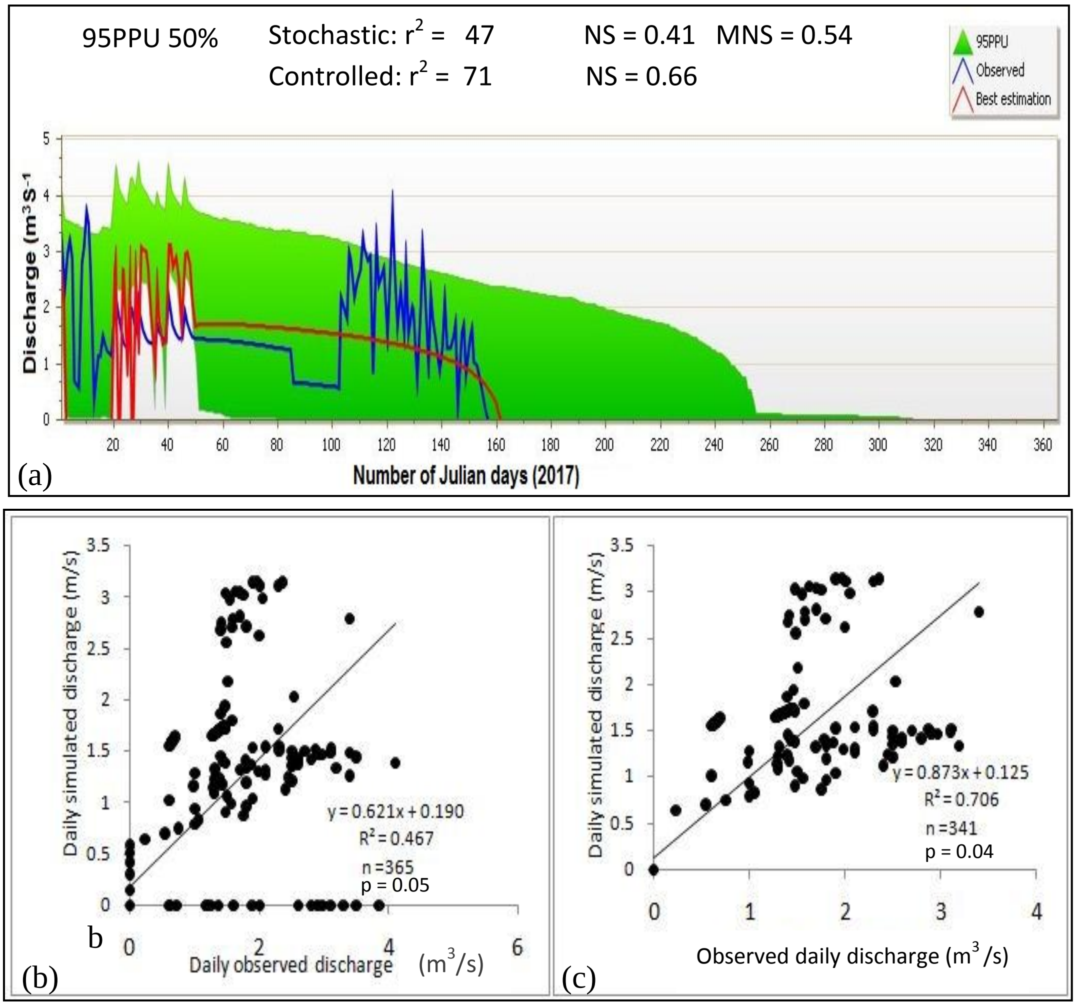


Figure 52: (a) Validated hydrological model for Chimbumbu Gauging Station (2017); (b) Stochastic relationship between measured and simulated discharge.(c) Controlled relationship between measured and simulated discharge based on SWATCUP SUFI-2 calibration outputs.

After editing out 24 data sets of outliers during the validation period, the predictive power drastically improved from being weak to very strong (r^2 = 0.71). The NS value also improved from 0.41 to 0.66 after controlling outliers. The SUFI-2 default parameters used to calibrate discharge are presented in Table 34. These flow routing parameters were deemed to have a bearing on the magnitude of discharge other than the weather, landuse, DEM and soils data sets used to run the initial model in ArcSWAT.

Table 34: Default and fitted parameter ranges used for regionalized discharge calibration at Chimbumbu Gauging Station, Monze District using SUFI-2 in SWATCUP

Parameter codes	Description	Default ranges of parameters		Fitted ranges of parameters	
		min	max	Min	Max
r__CN2.mgt	Curve number	-0.2	0.2	0.04	0.17
v__ALPHA_BF.gw	Base flow alpha factor	0	1	0.25	0.53
v__GW_DELAY.gw	Ground water delay	0	500	322.99	510.44
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).	0	2	1.67	2.42
v__GW_REVAP.gw	Groundwater "revap" coefficient.	0	0.2	0.04	0.12
v__ESCO.hru	Soil evaporation compensation factor	0	1	0.88	1.03
v__CH_N2.rte	Manning's "n" value for the main channel	-0.01	0.3	0.13	0.20
v__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium.	-0.01	500	63.80	115.52
v__ALPHA_BNK.rte	Base flow alpha factor for bank storage.	0	1	0.52	0.96
r__SOL_AWC(1).sol	Available water capacity of the soil layer	0	1	0.24	0.41
r__SOL_K(1).sol	Saturated hydraulic conductivity	-0.8	0.8	-1.29	-0.37
r__SOL_BD(1).sol	Moist bulk density	-0.5	0.6	0.35	0.69
r__CH_COV1.rte	Channel erodibility factor	-0.05	0.6	0.33	0.47
r__CH_COV2.rte	Channel cover factor	-0.001	1	-0.97	-0.19
r__SURLAG.bsn	Surface Lag	0.05	24	4.49	15.77
r__SLSUBBSN.hru	Average slope length.	10	150	-9.52	71.61
r__HRU_SLP.hru	Average slope steepness	0	1	2.80	4.59
r__OV_N.hru	Manning's "n" value for overland flow	0.01	30	9.80	24.68
r__GWHT.gw	Initial groundwater height (m)	0	50	31.10	44.48
r__CH_S2.rte	Average slope of main channel.	-0.001	10	6.70	9.86
v__EPCO.hru	Plant uptake compensation factor.	0	1	0.88	1.38
r__CH_SIDE.rte	Change in horizontal distance per unit vertical distance	0	5	-1.12	0.63
r__DIVMAX.mgt	Maximum daily irrigation diversion from the reach	0	150	76.27	149.04
v__POT_FR.hru	Fraction of HRU area that drains into the pothole.	0	1	0.60	0.93
r__POT_VOLX.hru	Initial volume of water stored in the pothole.	0	100	5.96	53.23
r__DIS_STREAM.hru	Average distance to stream (m)	0	100000	42162.21	85042.20
r__CH_N1.sub	Manning's "n" value for the tributary channels.	0.01	30	-0.93	11.72
r__CH_S1.sub	Average slope of tributary channels.	0.0001	10	-0.20	5.20
r__CH_W1.sub	Average width of tributary channels (m).	1	1000	513.14	754.35
r__CH_W2.rte	Average width of main channel.	0	1000	721.76	990.88
v__FLOWMIN.mgt	Minimum in-stream flow for irrigation diversions	0	100	46.84	110.69
v__PCPD().wgn	Average number of days of precipitation in month.	0	31	-4.30	11.40
v__PCPMM.wgn	Average amount of precipitation falling in month. [mm/d]	0.2	600	506.35	706.23
r__PLAPS.sub	Precipitation lapse rate.	-1000	1000	-197.37	444.49
r__SOL_CRK.sol	Crack volume potential of soil.	0	1	0.63	0.95
v__SOLARAV.wgn	Average daily solar radiation in month.	0	750	104.19	431.78
r__SUB_KM.sub	Area of subbasin (km^2)	0.1	5000	4.22	3060.88

8.2.3 Sensitivity analysis of the hydrological component of the model

The levels of sensitivity of parameters to discharge are in Figure 53 and Table 35. Evidence shows that ALPHA_BNK (Base flow alpha factor), CN2 (Curve Number), HRU_SLP (Average Slope and SOL_AWC (Figure 53 and Table 35) were the most sensitive parameters because they recorded higher t-statistics values, but with very low p-values (≤0.05). Figure 53 generally show the default parameters which were significantly sensitive to flow routing at Chimbumbu Gauging Station in the entire watershed

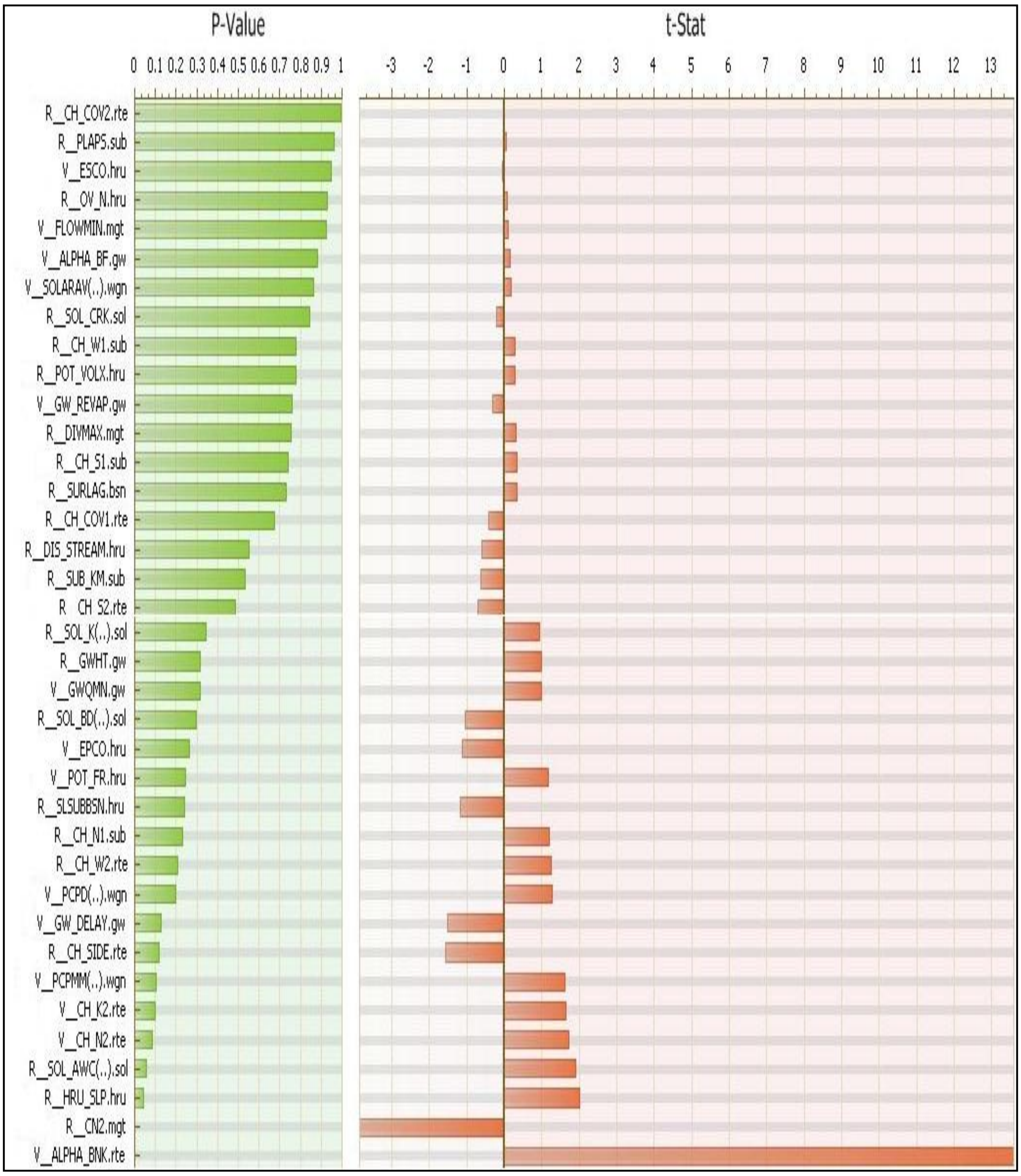


Figure 53: Ranking of sensitivity of parameters to discharge at Chimbumbu Gauging Station in the Magoye Catchment, Monze District based on SUFI-2 calibration in SWATCUP

Table 35: Sensitivity ranking of parameters to discharge at Chimbumbu Gauging Station in the Magoye Watershed, Monze District based on SWATCUP SUFI-2 calibration output.

Parameter Code	**Description**	**t-Stat**	***P*-Value**	**Sensitivity ranking**
v__ALPHA_BNK.rte	Base flow alpha factor for bank storage.	13.59	0.0000	1
r__CN2.mgt	Curve number	-3.86	0.0001	2
r__HRU_SLP.hru	Average slope steepness	2.02	0.0435	3
r__SOL_AWC.sol	Available water capacity of the soil layer	1.91	0.0570	4
v__CH_N2.rte	Manning's "n" value for the main channel	1.72	0.0854	5
v__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium.	1.65	0.0991	6
v__PCPMM(..).wgn	Average amount of precipitation falling in month. [mm/dd]	1.62	0.1061	7
r__CH_SIDE.rte	Change in horizontal distance per unit vertical distance	-1.57	0.1157	8
r__GW_DELAY.gw	Ground water delay	-1.52	0.1288	9
v__PCPD(..).wgn	Average number of days of precipitation in month.	1.29	0.1971	10
r__CH_W2.rte	Average width of main channel.	1.26	0.2073	11
r__CH_N1.sub	Manning's "n" value for the tributary channels.	1.19	0.2306	12
r__SLSUBBSN.hru	Average slope length.	-1.18	0.2384	13
v__POT_FR.hru	Fraction of HRU area that drains into the pothole.	1.16	0.2456	14
v__EPCO.hru	Plant uptake compensation factor.	-1.12	0.2644	15
r__SOL_BD(..).sol	Moist bulk density	-1.05	0.2952	16
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).	1.00	0.3159	17
r__GWHT.gw	Initial groundwater height (m)	1.00	0.3171	18
r__SOL_K.sol	Saturated hydraulic conductivity	0.94	0.3449	19
r__CH_S2.rte	Average slope of main channel.	-0.70	0.4839	20
r__SUB_KM.sub	Area of subbasin	-0.62	0.5326	21
r__DIS_STREAM.hru	Average distance to stream (m)	-0.59	0.5518	22
r__CH_COV1.rte	Channel erodibility factor	-0.42	0.6755	23
r__SURLAG.bsn	Surface Lag	0.34	0.7315	24
r__CH_S1.sub	Average slope of tributary channels.	0.33	0.7386	25
r__DIVMAX.mgt	Maximum daily irrigation diversion from the reach	0.31	0.7534	26
v__GW_REVAP.gw	Groundwater "revap" coefficient.	-0.31	0.7604	27
r__POT_VOLX.hru	Initial volume of water stored in the pothole.	0.28	0.7765	28
r__CH_W1.sub	Average width of tributary channels (m).	0.28	0.7773	29
r__SOL_CRK.sol	Crack volume potential of soil.	-0.19	0.8438	30
v__SOLARAV(..).wgn	Average daily solar radiation in month.	0.17	0.8633	31
v__ALPHA_BF.gw	Base flow alpha factor	0.15	0.8809	32
v__FLOWMIN.mgt	Minimum in-stream flow for irrigation diversions	0.09	0.9266	33
r__OV_N.hru	Manning's "n" value for overland flow	0.09	0.9275	34
v__ESCO.hru	Soil evaporation compensation factor	-0.06	0.9484	35
r__PLAPS.sub	Precipitation lapse rate.	0.05	0.9601	36
r__CH_COV2.rte	Channel cover factor	0.01	0.9951	37

8.2.4 Uncertainty analysis and their sources in the hydrological component of the model

As earlier mentioned, the calibrated model was surrounded by a number of uncertainties. It only accounted for 48-50 percent (p-factor) of uncertainties (Table 36).

Table 36: Objective function results for performance evaluation of the hydrological model based on SWATCUP SUFI-2 calibration output.

Objective functions	**Description**	**Default Simulation summary statistics**	
		Calibration period	**Validation period**
p-factor*	% of measurements bracketed by 95PPU	0.48	0.5
r-factor*	Relative width of the 95% band	1.36	1.78
R2	Coefficient of determination	0.91	0.47
NS	Nash Sutcliffe	0.91	0.41
PBIAS	Average tendency of simulated value to be larger or smaller than the observed	-3.5	11.4
MNS	Modified NS	0.82	0.54
Mean_sim*	Average of simulated variable	1.46	0.64
(Mean_obs)*	Average of observed variable	1.41	0.72
StdDev_sim*	Standard deviation of simulated variable	1.60	0.89
(StdDev_obs)*	Standard deviation of measured variable	1.57	0.98
Goal Type	Nash Sutcliffe (NS) Simulations: 1000. Iterations: 3		
Variable*	Discharge		

*Not an objective function

The sources of uncertainties were diverse, firstly, conceptual sources of uncertainties (Abbaspour, 2015), which included unaccounted for reservoirs and ditches within the catchment especially in area where brick moulding took place. These tend to trap a lot of water which may affect accuracy of the quantity of discharged especially if there is poor root zone subsurface flow. At the study site, local residents dug wells on the channel bed or near the bank during the dry season. This is a common practice in the catchment and tends to affect discharge at the outlet. The other source of uncertainty has to do with generalisation of the hydrological model to other ungauged subbasins and other catchments. The extent to which the model could be precise was uncertain given that, the input data had several empty records such that, all local weather inputs (especially rainfall) were replaced with NASA's because the former had too many data gaps.

Even though physically measured weather data were used in the last two years of simulation to test the usability of NASA weather data (Appendix B), they were susceptible to uncertainties that naturally emanate from external data sources.

Discharge data also had very wide data gaps such that most of the discharge data was based on computation from the rating curves of discharge-water depth relationships. The model is therefore susceptible to some computational limitations given that, high water depth does not always relate positively with discharge rates. Water may be stagnant and in spite of high depth flow may be zero, leading to outliers, which also compromise predictive power of the model. Some important factors such as rainfall direction and distribution are not well accounted for (currently not available in SWATCUP) influential though they might be in the generation of discharge (Leopold *et al*., 1995). The other factors which could be sources of uncertainties are; lack of consideration for stream density and frequency (currently not available in SWATCUP) both of which influence discharge (Leopold *et al*., 1995).

The other source of uncertainty was duration of calibration and validation. Calibration and validation were dictated by the period of sediment measurement at the specific study site as the study needed reflective picture of discharge behaviour within such a specific period. The simulated flows at the outlet were quite low in some instance as compared to measured data. Some of the default input parameters used in calibration and validation were not so distinct from one another, meaning that they might not have affected discharge distinctly. About 86 percent of calibration and validation input parameters were negligibly sensitive to discharge; this could partly be attributed to their lack of uniqueness. Nonetheless, it is noted that, as simulations are iterated during data analysis, p-value and even r-value tend to narrow down so as to enhance the value of chosen objective function (Abbaspour, 2015; Arnold *et al*., 2010). So one may claim too many uncertainties when in the actual sense, the uncertainties are minimal.

8.3 Sediment modelling outputs

A snapshot view of long term daily simulated sediment plotted against daily rainfall is presented in Figure 54a. It shows that in most cases, peak sediment simulation responded positively to peak rainfall events. For the period 1988-2017 (Figure 54b), the relationship was fairly good with r^2 value of 0.60, for the last two years (2016-2017) of simulation, during which calibration and validation were respectively done, there was a very strong positive relationship (r^2 =0.80) between rainfall and simulated sediment (Figure 54c, Appendix L).

Sediment yields by landcover categories are shown in Figure 54d, which shows that about 35 percent of sediment was generated in the agricultural fields, seconded by range-grassland which yielded about 26 percent of sediment. Figure 54e shows the spatial distribution of soil erosion hazards. A combined magnitude of 61 percent of erosion hazard was recorded in agricultural fields and range grassland.

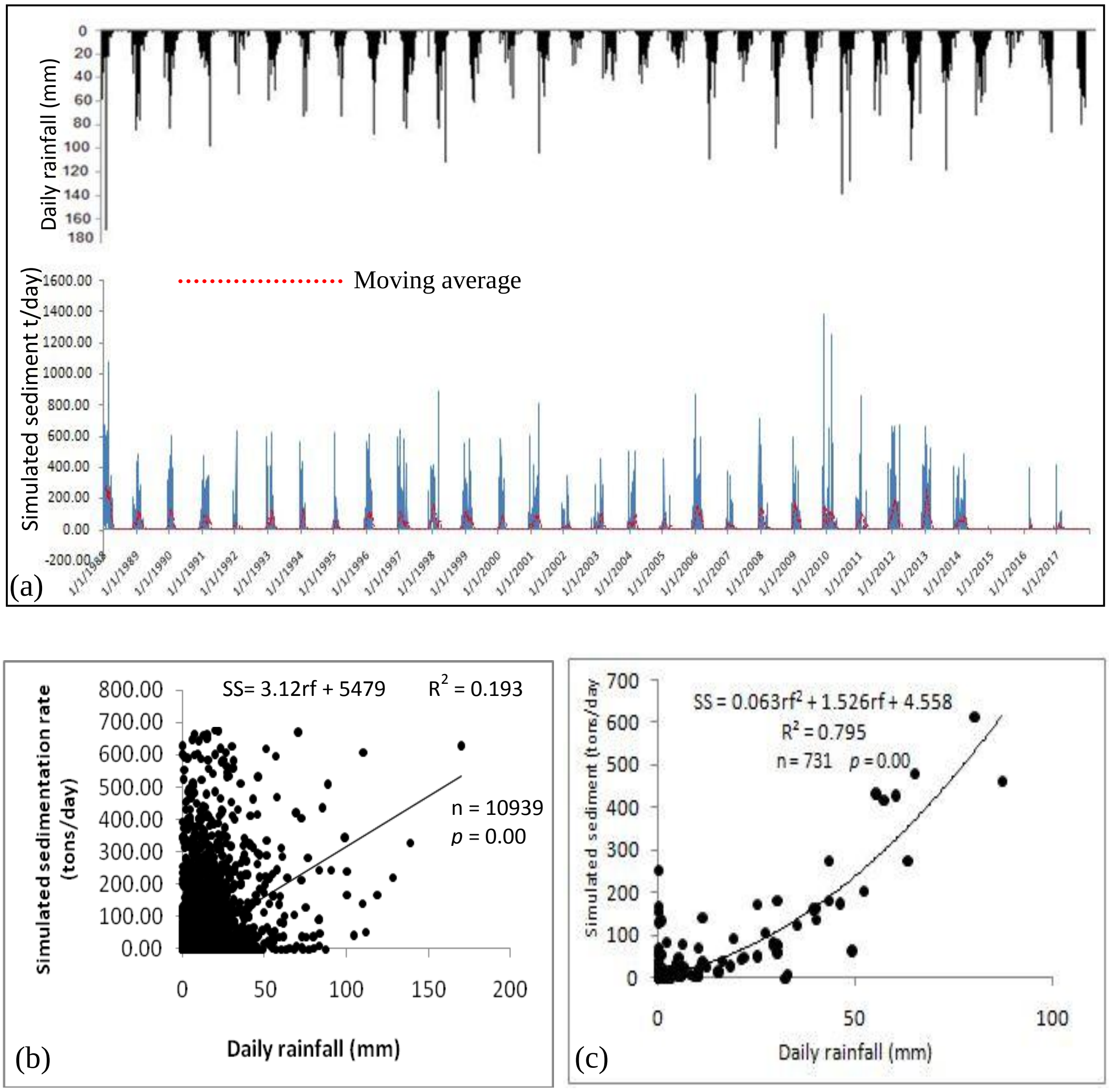


Figure 54: (a) Snapshot view of long term (1988-2017) daily simulated sediment plotted against daily rainfall ; (b) Long term relationship between rainfall and sediment loading; and (c) Short term and real time (2016-2017) relationship between rainfall and sediment loading.

Simulated erosion map (Figure 54d) fairly harmonised with the physically measured one shown in Figure 54e with rainfall, slope and land cover being the causal factors.

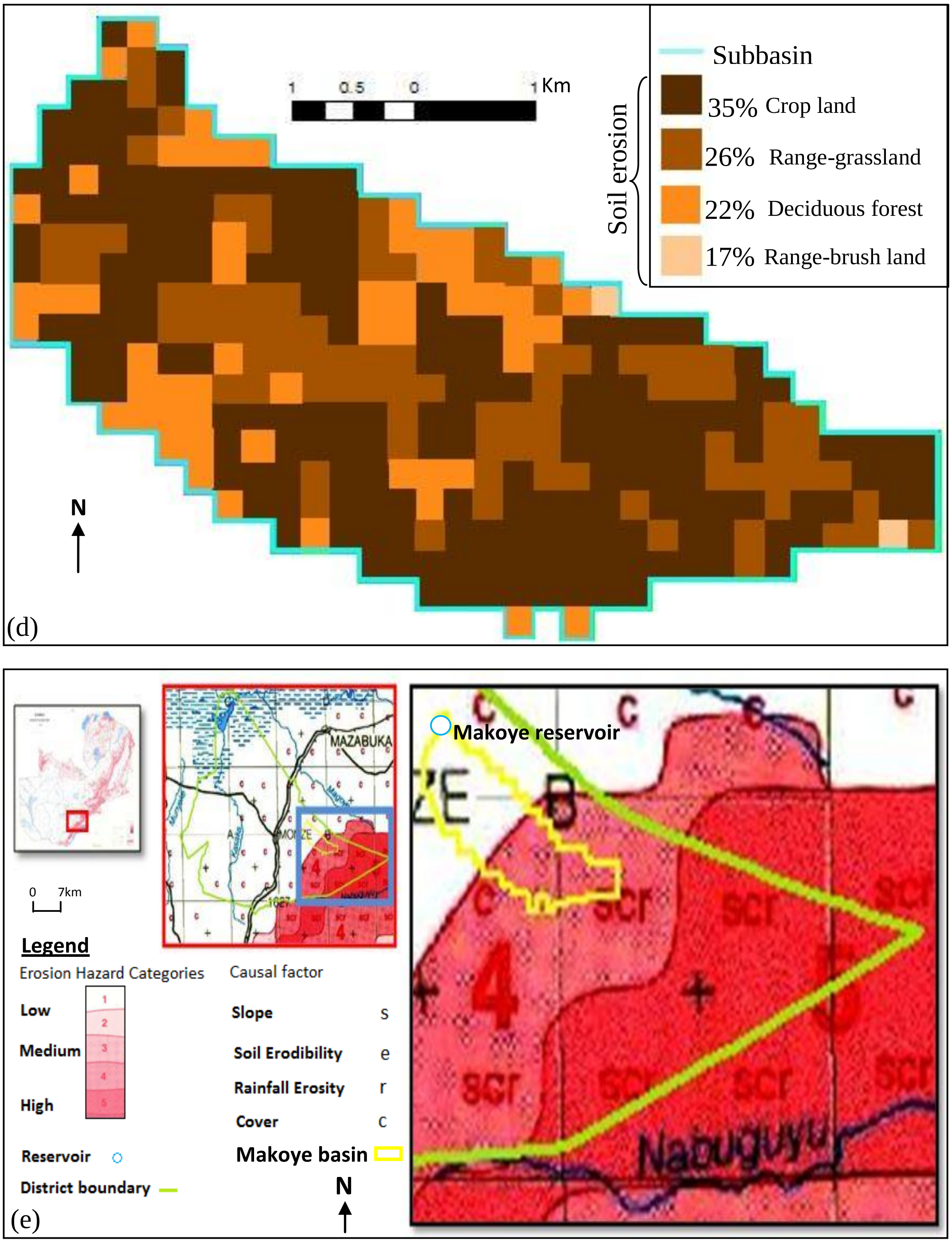


Figure 54: (d) Observed Erosion Map and (e) Observed Erosion Map (Chiti, 1987) of the Makoye Reservoir Basin.

8.3.1 Calibrated sediment model results

The observed and simulated sediment for the calibration period is presented in Figure 55a-b. During this period (2016), sediment was successfully simulated with high r^2 and NS values (0.77 each). The model also accounted for almost 60 percent of uncertainties as indicated by the p-factor of 0.57. The r-factor (thickness of the 95PPU band width) was excellent at 0.96 indicating a good closeness between measured and simulated sediment.

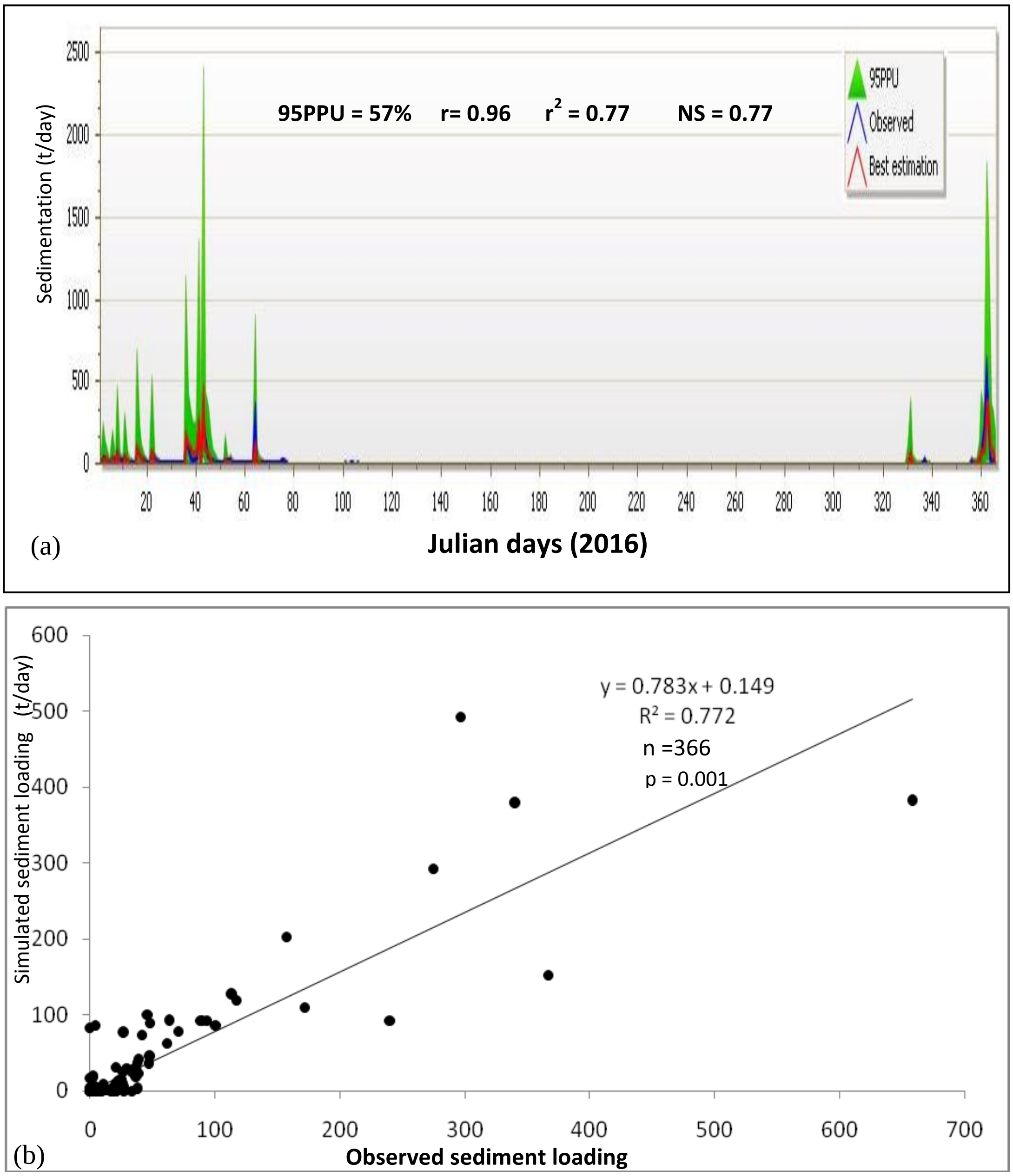


Figure 55: (a) Calibrated sediment model for Makoye Reservoir in 2016 and (b) relationship between simulated and observed sediment for the calibration period (2016) based on SWATCUP SUFI-2 calibration.

8.3.2 Validated sediment model results

Based on available data, validation of the sediment model was done for half a year (2017). Evidence in Figure 56a shows that the model performance was fair outside the calibration period as demonstrated by moderate NS value (0.49) and r^2 value of 0.44 (Figure 56b). The 95PPU was above 50 percent implying that the model accounted for a fair number of uncertainties. After controlling some outliers through deterministic approach, the predictive power of the model outside calibration period improved with r^2 at 0.71. Sediment was calibrated based on default parameters in Table 37, which influence sediment routing.

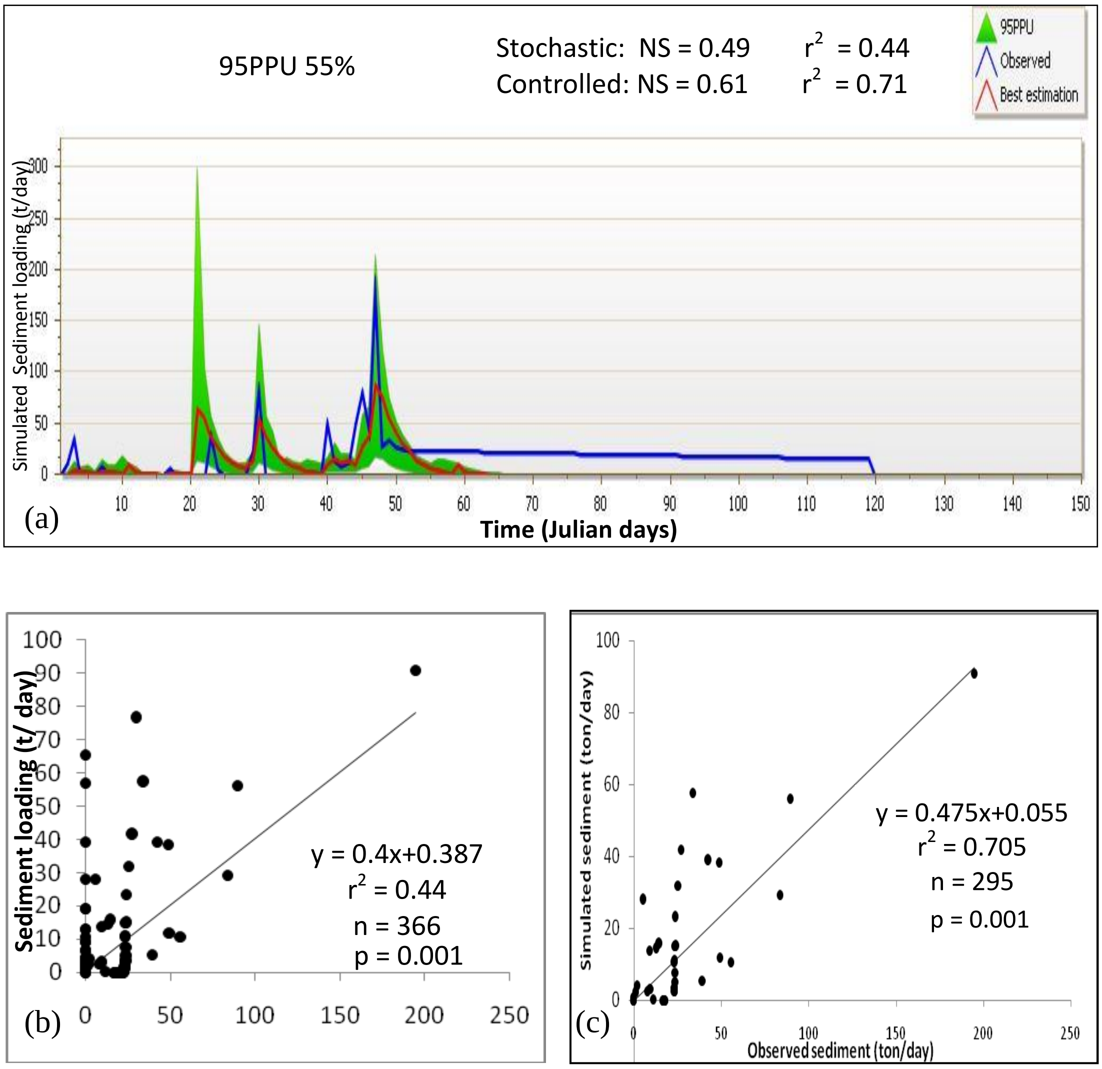


Figure 56: (a) Validated sediment model for Makoye Reservoir in 2017; (b) stochastic relationship between measured and simulated sediment and (c) controlled stochastic relationship between measured and simulated sediment for Makoye Reservoir based on SWATCUP SUFI-2

Table 37: Default and fitted parameter ranges used for sediment calibration in Makoye reservoir, based on SWATCUP SUFI-2

Parameter Name	Description	Fitted Value	New range of values		Initial range of values	
			Min value	**Max value**	**Min value**	**Max Value**
r__SPCON.bsn	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing.	0.0007	-0.0019	0.0030	0.001	0.01
r__SPEXP.bsn	Exponent parameter for calculating sediment re-entrained in channel sediment routing	1.3859	1.2053	1.4426	1	1.5
r__SURLAG.bsn	Surface runoff lag time	4.7053	2.2791	17.5379	0.05	24
r__SLSUBBSN.hru	Average slope length.	124.6025	97.2251	157.9288	10	150
r__USLE_P.mgt	USLE equation support practice factor	0.3362	0.0921	0.4625	0	1
v__CH_COV1.rte	Channel erodibility factor	0.8085	0.4326	0.8398	-0.05	0.6
v__CH_COV2.rte	Channel cover factor	0.4331	0.1448	0.8395	-0.001	1
v__USLE_C{..}.plant.dat	Min value of USLE C factor applicable to the land cover/plant.	0.5189	0.3676	0.6745	0.001	0.5
r__USLE_K(..).sol	USLE equation soil erodibility (K) factor.	0.6898	0.4534	0.8674	0	0.72
v__BIOMIX.mgt	Biological mixing efficiency	0.1607	-0.0488	0.4791	0	1
r__SOL_BD(..).sol	Moist bulk density	2.2653	1.5568	2.3816	0.9	2.5
r__HRU_SLP.hru	Average slope steepness	-0.3655	-0.4275	0.2533	0	1
v__CH_ERODMO(..).rte	Channel erodibility factor	0.3513	0.0472	0.6769	0	1
r__CH_EQN.rte	Sediment routing method	-1.1975	-2.0626	0.9517	0	4
r__CH_BED_TC.rte	Critical shear stress of channel bed (N/m2)	150.2935	-8.8886	168.9686	0	400
r__CH_BNK_TC.rte	Critical shear stress of channel bank (N/m2)	228.3676	123.3252	238.6297	0	400
r__CH_BED_D50.rte	D50 Median particle size diameter of channel bed sediment (µm)	11222.2949	6811.7183	11410.8594	0	10000
r__CH_BNK_D50.rte	D50 Median particle size diameter of channel bank sediment (µm)	461.1711	-7068.5400	1382.3147	0	10000
r__CH_BED_KD.rte	Erodibility of channel bed sediment by jet test (cm^3/N^{-s})	0.9786	-0.6474	1.2588	0.001	3.75
r__CH_BNK_KD.rte	Erodibility of channel bank sediment by jet test (cm3/N-s)	1.8257	1.7534	3.2915	0.001	3.75
r__CH_WDR.rte	Channel width-depth ratio	4.6343	3.6186	7.5705	0	10
r__ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	0.7815	0.1335	1.0175	0.5	2
r__SOL_ZMX.sol	Maximum rooting depth of soil profile.	265.4397	92.0489	311.2535	0	500
v__CH_N2.rte	Manning's "n" value for the main channel	0.2400	0.1748	0.3533	-0.01	0.3
r__OV_N.hru	Manning's "n" value for overland flow.	-0.1329	-15.5220	6.9438	0.01	30
r__RES_STLR_CO.bsn	Reservoir sediment settling coefficient	-0.4784	-0.5181	0.1778	0	1
r__CH_BED_BD.rte	Bulk density of channel bed sediment	1.5397	1.4500	1.7625	1.1	1.9
r__CH_BNK_BD.rte	Bulk density of channel bank sediment	1.3571	1.3263	1.6579	1.1	1.9
v__RSDCO.bsn	Residue decomposition coefficient.	0.0262	-0.0187	0.0394	0.02	0.1
r__CN2.mgt	Curve number of surface runoff	0.2376	0.0745	0.3002	-0.2	0.2
v__ALPHA_BF.gw	Base flow alpha factor	0.0672	-0.4912	0.1940	0	1
v__GW_DELAY.gw	Ground water delay	293.0093	265.4101	423.1205	30	450
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).	2.0568	0.9606	2.2106	0	2

8.3.3 Sensitivity analysis of parameters inputs in the sediment model

There are a myriad of factors that propel generation and delivery of sediment in catchments, Figure 57 show that SPCON, OV_N, CH_N2, CN2 and ALPHA_BF (Tables 37 and 38 for what abbreviations stand for) were the most sensitive parameters because they recorded higher t-statistics values with very small or negligible p-values (≤0.05).

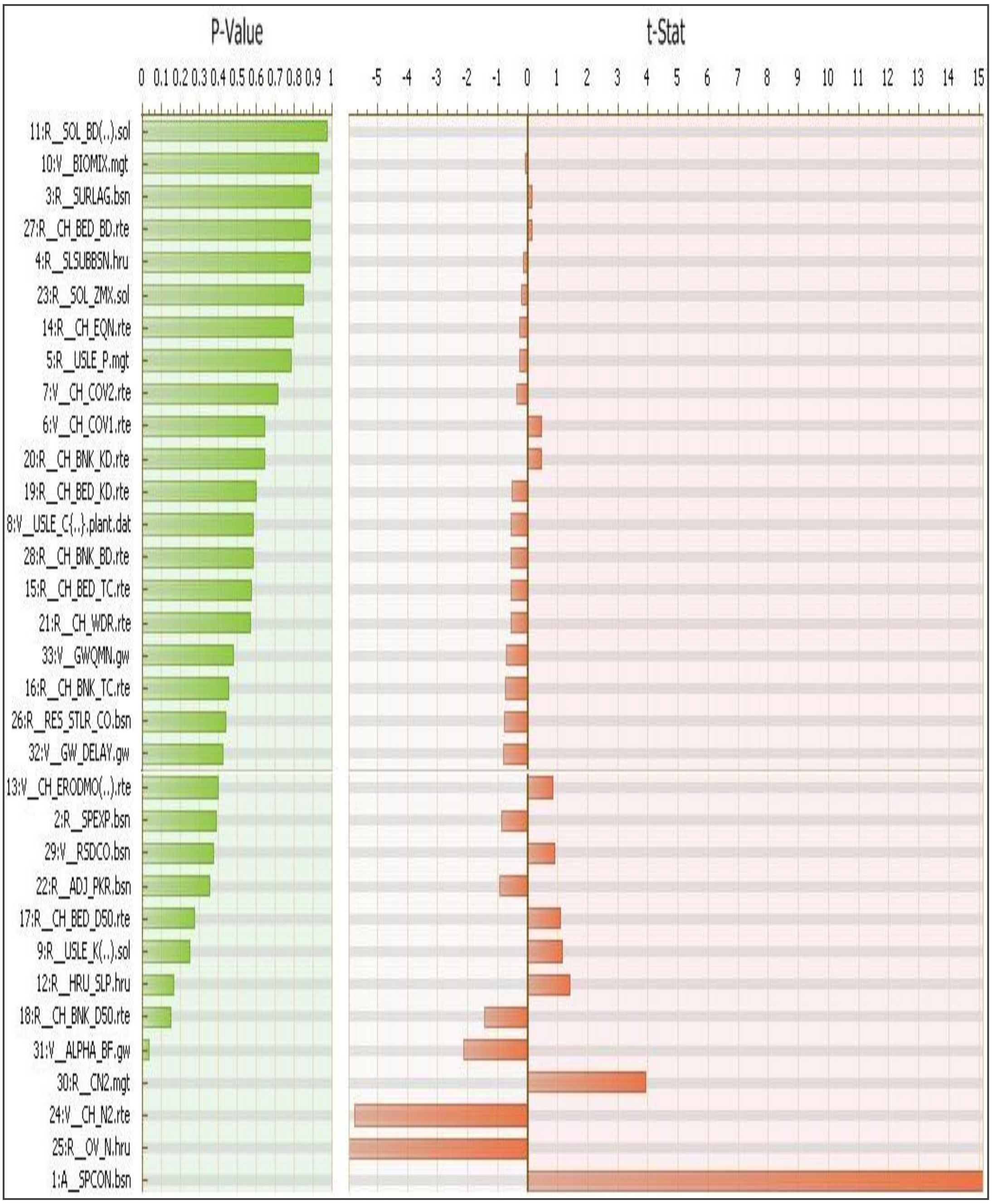


Figure 57: Ranking of parameters that were sensitive to sediment routing in the Makoye Reservoir based on SWATCUP SUFI-2 calibration.

Table 38: Sensitivity ranking of parameters used to calibrate sediment for Makoye Reservoir based SWATCUP SUFI-2 calibration output.

Parameter Name	t-Stat	p-Value	Sensitivity ranking
r__SPCON.bsn	15.1393	0	1
r__OV_N.hru	-5.9394	0.000000006	2
v__CH_N2.rte	-5.762799706	0.000000015	3
r__CN2.mgt	3.913738247	0.00010443	4
v__ALPHA_BF.gw	-2.123379145	0.03424843	5
r__CH_BNK_D50.rte	-1.4436364	0.149513196	6
r__HRU_SLP.hru	1.396203846	0.163317849	7
r__USLE_K(..).sol	1.146025962	0.252372562	8
r__CH_BED_D50.rte	1.093508096	0.274735713	9
r__ADJ_PKR.bsn	-0.924325542	0.355795226	10
v__RSDCO.bsn	0.889753646	0.374057273	11
r__SPEXP.bsn	-0.86404958	0.388005178	12
v__CH_ERODMO(..).rte	0.842767211	0.399790992	13
v__GW_DELAY.gw	-0.799055348	0.424665393	14
r__RES_STLR_CO.bsn	-0.776659228	0.437753885	15
r__CH_BNK_TC.rte	-0.745451806	0.45637446	16
v__GWQMN.gw	-0.705365038	0.480935523	17
r__CH_WDR.rte	-0.565798131	0.571803352	18
r__CH_BED_TC.rte	-0.560416524	0.575464685	19
r__CH_BNK_BD.rte	-0.547795584	0.584094554	20
v__USLE_C{..}.plant.dat	-0.544903405	0.58608063	21
r__CH_BED_KD.rte	-0.522672023	0.601450908	22
r__CH_BNK_KD.rte	0.463622819	0.643134474	23
v__CH_COV1.rte	0.460880291	0.645099507	24
v__CH_COV2.rte	-0.367558713	0.713369179	25
r__USLE_P.mgt	-0.271216775	0.786344411	26
r__CH_EQN.rte	-0.259158591	0.795627321	27
r__SOL_ZMX.sol	-0.191613372	0.848128529	28
r__SLSUBBSN.hru	-0.147333545	0.882932478	29
r__CH_BED_BD.rte	0.147067828	0.883142088	30
r__SURLAG.bsn	0.138515072	0.889893194	31
v__BIOMIX.mgt	-0.085071997	0.932240689	32
r__SOL_BD(..).sol	0.028473399	0.977296774	33

8.3.4 Uncertainty analysis of input parameters for sediment model

The calibrated sediment model only accounted for 57 percent (95PPU) of uncertainties, which means there is 43 percent of uncertainties surrounding the calibrated sediment model (Table 39). The sources of uncertainties included; some input data, conceptual and none-uniqueness of some default parameters during calibration, which shall be explained under discussion.

Table 39: Objective function results for performance evaluation of Makoye Reservoir sediment model based on SWATCUP SUFI-2 calibration output

Parameters	**Calibration**	**Validation**
	Sediment (tonnes)	
	Calibration period	**Validation period**
p-factor (95PPU)	0.57	0.55
r-factor	0.96	0.52
R^2	0.77	0.44
NS	0.77	0.49
PBIAS	20.6	53.5
Mean_sim	11.17	2.77
Mean_obs	14.07	5.97
StdDev_sim	46.78	10.32
StdDev_obs	52.48	15.13
Number of simulations	500	
Iterations	3	1
Goal type	NS	

8.4 Long-short terms analysis of Observed and simulated sediment

A cumulative comparison of measured and simulated sediment for the longest period 1988-2015 and for short periods, 2016 and 2017 is presented in Figure 58. Simulated and observed sediment sources including diverse landcover categories, especially from crop and grazing fields (Table 40). During all the periods, simulated sediment was higher than observed. However, there was no significant variation between observed and simulated sediment as indicated by very low CVs, PBIAS (%d) and p-values (Table 41). This simply reconfirms that the SWAT sediment model was successful in predicting the sediment in spite of uncertainties surrounding it.

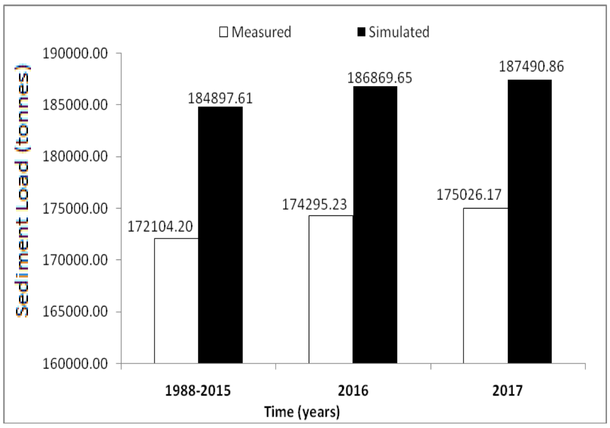


Figure 58: Cumulative comparison of measured and simulated sediment for the longest period 1988-2015; and for short periods, 2016-2017 in the Makoye Reservoir, Monze District.

Table 40: Summary statistics about simulated sediment generation and sources in the Makoye reservoir and basin (1988-2017)

Description	**(%)**
Simulated sediment generated in crop fields (1988-2017)	35
Simulated sediment generated in grazing areas (1988-2017)	26
Deciduous forest areas (1988-2017)	22
Range-brush area (1988-2017)	17
Total	**100**
30-year delivery ratio = 7.5%	

Table 41: Summary statistics of the comparisons between long-term observed and simulated sediment in the Makoye Reservoir

Period	Cumulative Measured sediment (tonnes)	Cumulative Simulated sediment (tonnes)	Percent difference between observed and simulated sediment PBIAS (*%d*)	Standard Deviation	Mean between Simulated and Observed	CV (%)	Pearson coefficient (r)	
							Coefficient	*p-value*
1988-2015	172104.20	184897.61	6.92	9046.31	178500.91	5.1	0.99	0.01
2016	174295.23	186869.65	6.73	8891.46	180582.44	4.9	0.99	0.01
2017	175026.17	187490.86	6.65	8813.87	181258.52	4.9	0.99	0.01

Source: Field measurements (2014-2017) and SWAT simulation

8.5 Illustrative models for hydro-geochemistry and sedimentation process in the Makoye Reservoir

The bathymetry, hydro-physicochemistry and sedimentation of the Magoye reservoir are illustratively summarised in Figure 59.

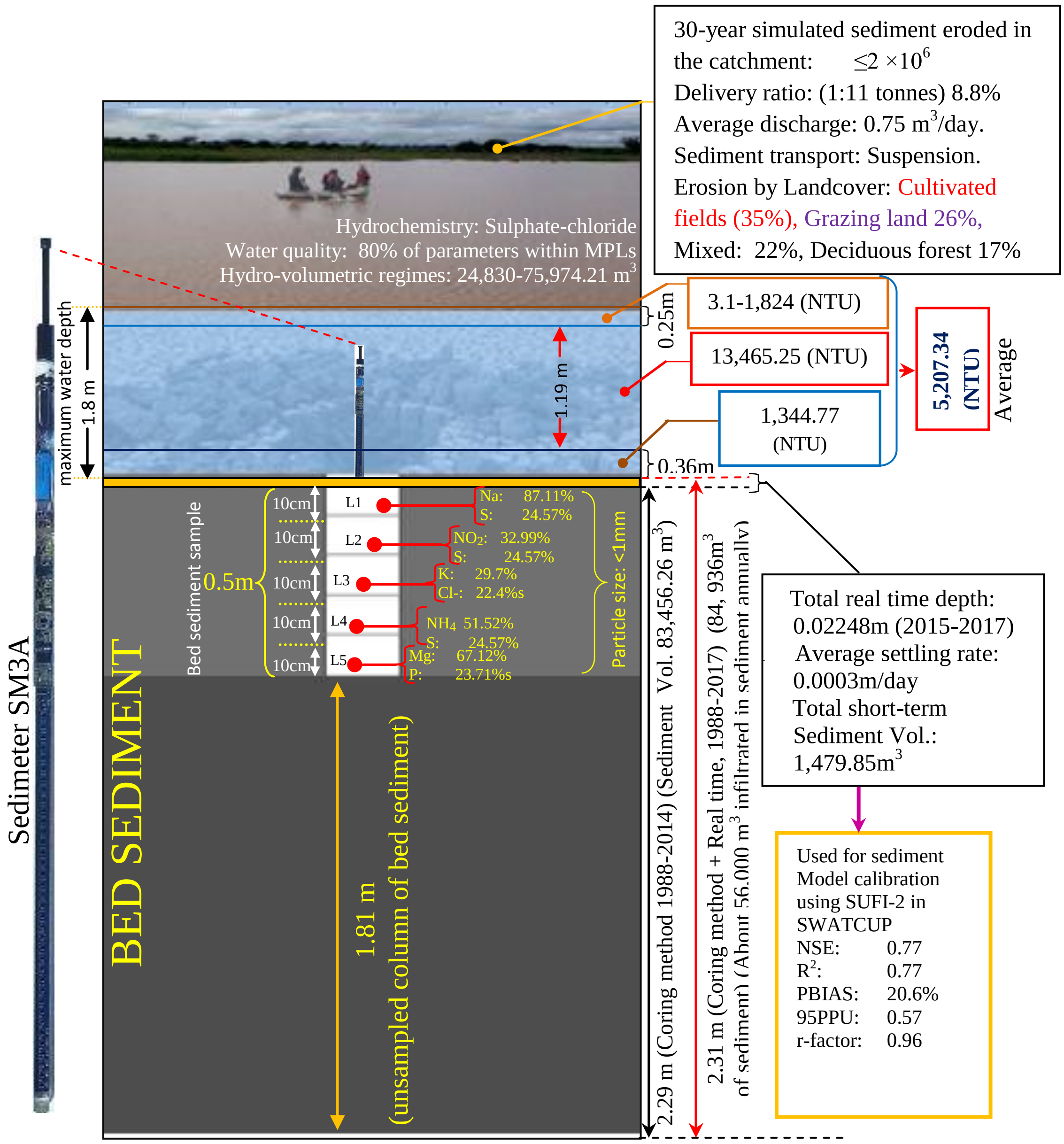


Figure 59: Illustration of sedimentation process in the Makoye Reservoir

The two dimension (2D) profiling of sedimentation demonstrated that sediment deposition was high towards the central part of the reservoir, about 25 metres away from the crest. This could be attributed to near static equilibrium of water in the main reservoir (Figure 60).

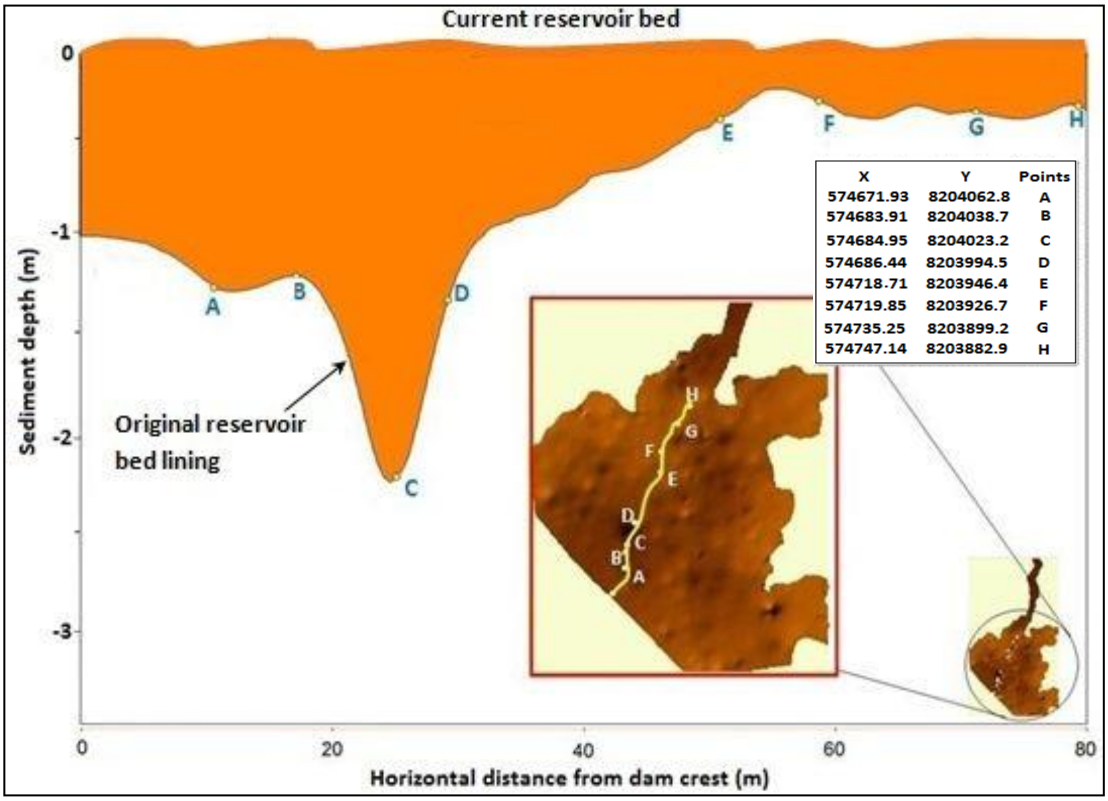


Figure 60: 2D profile of sedimentation on the Makoye Reservoir generated using Global Mapper 12 based on field measurements (2014-2016).

A complete synthesis of sedimentation process is illustrated in Figure 61a-b, which presents three dimension (3D) model. This model amplifies what is illustrated in Figures 59 and 60 above so as to clarify the understanding. Based on evidence in Figure 62 a, most of the parameters in sediment sample were variable with change in depth except iron whose steady state was pronounced especially past 10cm towards 50cm of the sampled sediment. Concentration of analysed parameters or elements in sediment samples increased with depth at lower levels. This presents a problem because at lower levels they become protected by overlying sediment, thereby complicates their removal from the reservoir where they are unwanted yet their residence time is increased by the sedimentation processes. While this illustrates that the fate of these pollutants in reservoirs is persistence for unknown life spans, it also shows how difficult it is to remove them once they enter fluvial or lacustrine systems where sediment accumulation is the norm. Their removal by mechanical means of dredging would be an expensive option. That is why pollution problems involving sediment has no easy solution.

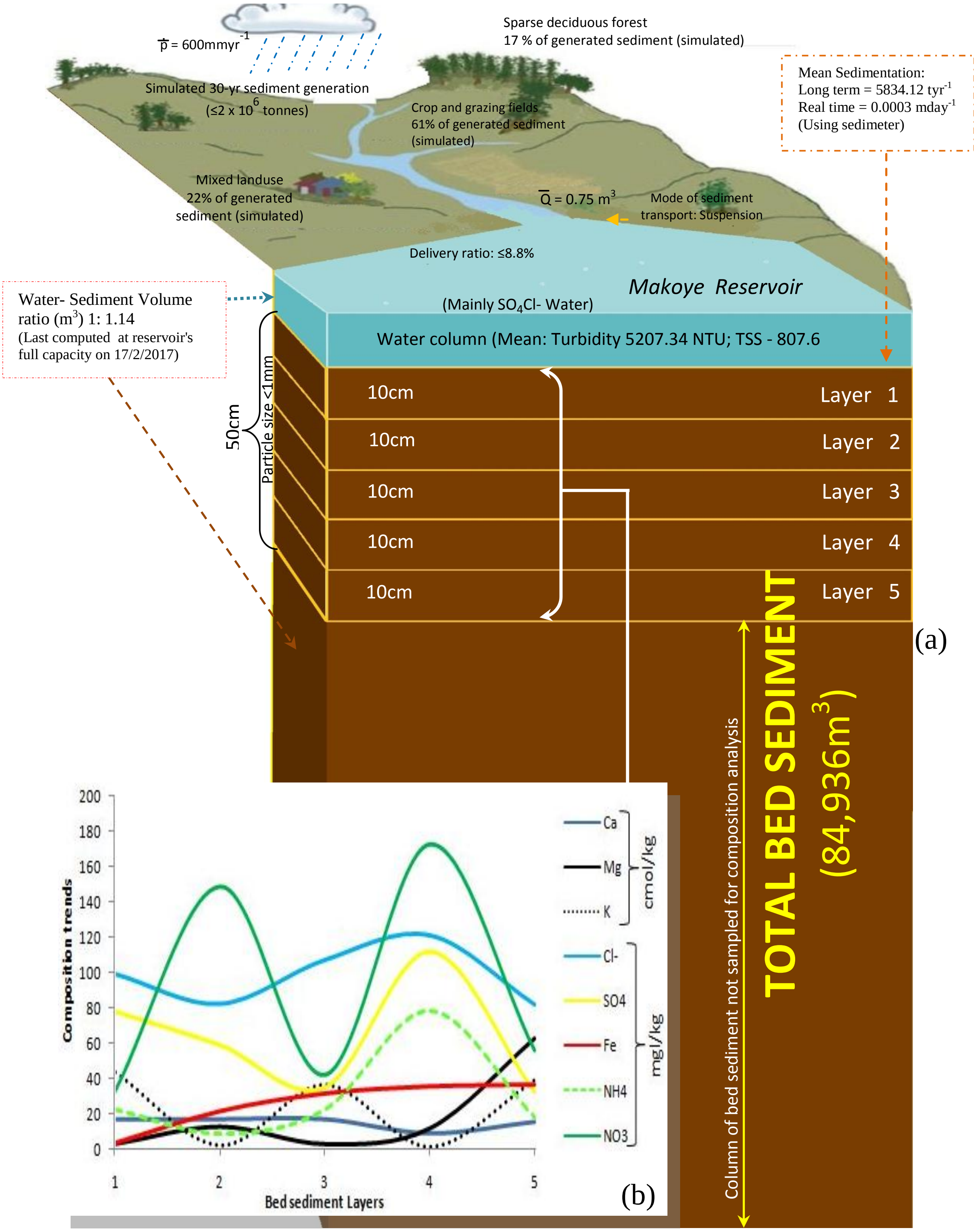


Figure 61: (a) 3D Model Synthesising the process of sedimentation in the Makoye Reservoir and (b) trends in the concentration selected metals and chemicals within the first 50cm depth of settled sediment (not to scale)

8.6 Discussion of results on sediment modelling in the Makoye Reservoir

This section discusses the results on SWAT modelling of sedimentation. It starts with discussion of reflective hydrological component of the model, relationship between rainfall and simulated sedimentation, fitting of observed and simulated sedimentation. It further discusses the parameters sensitive to sedimentation, levels of certainties and uncertainties in the sediment model, relationship between long term observed and simulated sediment, general performance evaluation of calibrated sediment SWAT model and a synoptic philosophical reflections about the study findings.

8.6.1 Reflective hydrological component of the model

Since the target catchment did not have gauging station, the study used a regionalised approach to calibrate flows at the outlet of the subbasin downstream because it had similar characteristics with the target Makoye subbasin. Recent studies (Gessese, 2008); Begou, 2016 in West Africa, Amam, 2016 in Vietnam, Halefom *et al.* (2017) in India, Ang and Oeurng *et al.*, 2018 in Cambodia, Djebou, 2018 in the USA) have successfully used this method. During the hydrologic calibration and validation period (2016-2017), the average simulated and observed dicharges were 1.46 m^3/s and 1.41 m^3/s, respectively. There was a very minimal variation (CV = two percent) between the observed and simulated discharge. Such low average daily discharges on the downstream could be partly attributed to too many reservoirs upstream which cumulatively empounded huge volumes of water. For example, Sichingabula (2018) reported that Hachaanga reservoir alone empounded over 3.5 million m^3 of water, Chuuka reservoir harvested about 13,000 m^3 whereas Kauumbu captured about 16,518 m^3. All these and other factors irrefutably contributed to the low flows on the downstream and also had an implicit influence on sediment transportation and delivery (Viessman and Lewis, 2012).

The reflective calibrated hydrological model was generally very good (Moriasi *et al.*, 2007 and Arnold *et al.* 2012) given the high NS value of 0.91 and coefficient of determination (r^2) value of 0.91. It was noted that, during calibration period, the model had very strong predictive power athough it did not satisfactorily account for some uncetainties in the hydrological system given that the 95PPU was at 48 percent. Stochastically, during the validation period, the hydrological component of the model performed quite poorly with NS and r^2 value of 0.41 and 0.47, respectively. Although Abbaspour (2007) discourages the use of deterministic approach in modelling (to minimise subjectivity), it is said that, during validation of the hydrological model component, a deterministic approach improved the model than the stochastic one. In real sense, elimination of outliers did not necessarily make the model deterministic, but simply a controlled stochastic model without outliers. This implies that, for all other subbasins within the watershed, including Makoye, a combination of both stochastic and deterministic approach would help improve predictive power of the model. This should however not be entertained during the calibration because the model demonstrated strong predictive power during the calibration period. The most sensitive parameters for hydrological component of the model at subbasin 1 were base flow alpha factor for bank storage (ALPHA_BNK.rte). ALPHA_BNK accounts for the water that enters the main channel through the channel bank. Given the gentle slope of the watershed area and subbasins in particular, it is no surprise that ALPHA_BNK was the most sensitive to discharge. In most of the reviewed literature (Begou, 2016; Amam, 2016; Halefom *et al.* 2017; Ang and Oeurng *et al.*, 2018), ALPHA_BNK is usually in the top two to three sensitive water routing methods. The second most sensitive parameter to discharge was the Curve Number (CN2.mgt), which influences surface runoff. The higher the curve number, the higher the surface runoff and vice versa (Masih, 2011). Average slope steepness, (r__HRU_SLP.hru) was the third most sensitive parameter to discharge. As earlier mentioned and in line with earlier observation by Leopold *et al*. (1995), steeper slopes tend to punctuate discharge and vice versa. The general pattern of flows during the calibration and validation periods were low and this could partly be connected to a gentle slope and rainfall as a major factor (Langbein and Schumm, 1958). Available water capacity of the soil layer (SOL_AWC.sol) was the fourth most sensitive parameter. The studies presented in Table 1 as well as Leopold *et al*. (1995) and Viessman and Lewis (2012) have widely documented that the amount of water in a soil layer tends to influence the rate of discharge with low values leading to low discharge and vice versa. Das and Saikia (2009) also acknowledge soil water content level as either retardant or propellant to discharge level.

The sensitivity of the other parameters was not statistically significant as indicated by their *p*-values above 0.05 (Abbaspour, 2007). The general conclusion is that during the calibration period, the model was very efficient in simulating discharge as closer as possible to the observed discharge as demonstrated by very good NS and r^2 values. The average %d factor or PBIAS was also very low (three percent) falling within acceptable range (≤15 percent) for a successful hydrological model (Moriasi *et al*., 2007). However, the model may not stochastically have predictive power for the period outside the calibration period or outside the spatial context within which it was developed unless it is carefully controlled by removing outliers. When evaluated from the context of a %d factor (PBIAS), the validated hydrological model was still a success given that the %d factor (11 percent) was below the prescribed range (Figure 5 above). Given the regionalised nature of the hydrologic system, declivity, landuse and pedogenic system, these reflective hydrologic model results are likely to be similar at other subbasins (such as Makoye) within the watershed.

8.6.2 Relationship between rainfall and simulated sedimentation

Sediment yield, transportation and deposition are influenced by diverse factors, but the most prominent is rainfall (Rubey, 1933; Langbein and Schumm, 1958; Leopold *et al*., 1995). In the current study, a very strong positive relationship was noted between rainfall and sedimentation as evidenced by a very strong r^2 value of 0.80. Rainfall was positively influential in the prediction of sediment more especially during the calibration and validation periods (2016 and 2017) than during the entire 30-year period. Langbein and Schumm (1958), Leopold *et al.* (1995); Sichingabula (1999); Das and Saika (2009); Viessman and Lewis (2012); among others have widely documented the influence of rainfall on sedimentation and they made similar observations to the current study. During the 30-year period, the annual average observed and simulated sedimentation rates were 5,834.21 tonnes/yr and 6249.70 tonnes/year, respectively. These annual average rates respectively translated into long term daily averages of 0.53 tonne/day and 0.57 tonne/day for measured and simulated sediment. The variation (PBIAS) between the two sets of long term averages (both annual and daily) was only five percent, which implies that the initial sediment Model in ArcSWAT was very good (Moriasi *et al.,* 2007; Arnold *et al*., 2012).

8.6.3 Fitting of observed and simulated sedimentation

The calibrated sediment model had very strong predictive power and a very close fit between observed and simulated sedimentation (r^2 and NS = 0.77). The *p* factor of 0.57 indicated that the sediment model accounted for closer to 60 percent of the uncertainties, which according to Abbaspour *et al.* (2007), was good enough for sediment calibration. Unlike during the calibration period, the sediment model's predictive power and fitting between observed and simulated sediment weakened up during validation period. This was demonstrated by moderate r^2 value of 0.44 and NSE value of 0.49. The 95PPU also reduced by two percent during the validation period as compared to the calibration period. Similar performance patterns were previously recorded in previous studies by Duru (2015) in Turkey, Djebou (2018) in Texas-USA, Pokhrel (2018) in Nepal. The main cause of this under performance could be attributed to insufficient observed sediment data (only about 6 months), which Abbaspour (2018) acknowledges as a major deterrent to successful validation especially for sediment model. It is therefore said that, had there been enough measured data the validated sediment model would have possibly been as stronger as the calibrated one. This can be supported by the evidence that, there was no huge variation in terms of fitting between simulated and observed sedimentation (CV = 1.4 percent). Arnold *et al.* (2012) recommend r^2 and NS of ≥50 for a successful sediment model, which was almost attained during validation. Elimination of outliers improved the r^2 value for the validation period from 0.44 to 0.71, thereby also improving the predictive power for the periods outside calibration and immediate hydrological space. Elimination of outliers also improved the NSE value from 0.49 to 0.61. This implies that, the sediment model would perform very well outside its immediate temporal and spatial scale by eliminating outliers. In a nutshell, SWAT successfully simulated sediment in the Makoye Reservoir.

8.6.4 Parameters sensitive to sedimentation

Sensitivity analysis is always a critical part of hydrological and sediment modelling, it is not a luxury (Abbaspour, 2015). Apart from considering landuse (especially cultivated fields consideration) in the initial simulation of sediment, other factors were considered to optimise the quantity of sediment delivered into the reservoir. There were five parameters sensitive to sedimentation in this study namely; (i) linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON), (ii) Manning's "n" value for overland flow (OV_N), (iii) Manning's "n" value for the main channel (CH_N2), (iv) Curve number of surface runoff (CN2); and (v) Base flow alpha factor (ALPHA_BF). Each of these parameters recorded higher t-statistics values with very small *p*-values (≤ 0.05). The observation of the current simulation simply reconfirms earlier and recent works by Leopold *et al*. (1995); Walling *et al.* (2001), Abbaspour (2015), Tejaswini and Sathian (2018), Pokhrel (2018) that SPCON aspects such as distance between the source of sediment and the sink (channel or reservoir), sinuosity of the channel leading into the reservoir, among others tend to influence the quantity of sediment deposited in the sinks.

Manning-related parameters such as roughness of the bank (OV_N) and channel surfaces (CH_N2) on which sediment is being transported before reaching the sink also tend to have profound influence on sediment transported and deposited (Leopold *et al*., 1995; Darboux *et al*., 2004; Abbaspour 2007). The rougher the bank and channel surfaces, the higher the surface lag and eventually, the slower the sediment delivery and vice versa. Whilst lower curve numbers tend to reduce the flow and eventually the sediment load transport, high numbers (closer to 100) usually tend to increase the volume of flow and sediment (Abbaspour, 2007).

In many instances where channel banks are not too steep, but rugged enough, base or subsurface flows can still punctuate high flows and sediment transport as earlier noted in the reflective hydrologic component of the model where ALPHA_BNK was the most sensitive to flow (Abbaspour, 2007; Das and Saikia, 2009). Generally, the parameters which this study found to be sensitive to sedimentation are the same as those noted in most of the studies earlier outlined in Table 1 above. This shows the universality of these physical processes that affect sediment generation, transportation and deposition as also widely documented by Rubey (1933), Langbein and Schumm (1958), Leopold *et al*. (1995), Das and Saikia (2009), Viessman and Lewis (2012), Sichingabula (2018), among others.

8.6.5 Levels of certainties and uncertainties in the sediment model

The certainty levels of both the calibrated and validated sediment models ranged from 54 to 58 percent, which means that, between 42 percent and 46 percent of uncertainties could not be accounted for during both calibration and validation periods of the sediment model. Abbaspour (2007) mentions that it is very challenging to account for all uncertainties in an hydrological model, but it is a very crucial requirement in view of the usefulness of the model towards water resource planning and management.

The first and foremost source of uncertainty is that, the watershed was not fully or semi-distributed with gauging stations as there was only one gauging station downstream. As a result, the system was lumped or regionalised to one and only gauging station about 20 km downstream of the location of the study area (Makoye Reservoir subbasin). Had the target subbasin had its own gauging station(s), it would have drastically reduced possible data errors and uncertainties surrounding the sediment model as it is so dependent on the accuracy of the discharge model (Abbaspour, 2015).

The input data more especially rainfall were also a source of uncertainty, if the data were temporally well distributed and captured from the immediate study area, the sediment model would have had fewer uncertainties. The model only depended on sediment data measured for only about one and half years, which meant that calibration and validation could only be done for one year and six months, respectively. Abbaspour (2018) argues that, one year calibration and validation usually produce poor results with weak predictive powers especially in temporal spaces outside the calibration.

Conceptual uncertainty could be attributed mainly to digging shallow well on the tail or throw back side of the reservoir. The dugout sediment is just heaped within the reservoir and when it rains, these could have been transported and deposited in the main reservoir, yet the equipment (Sedimeter SM3A) probably measured it as new input of sediment when in actual sense, it was possibly already part of the settled sediment. The sedimeter cannot be installed in advance on the dry bed or when the water levels are shallow, this means that, antecedent sedimentation is missed at the time the water was just beginning to accumulate, this indisputably introduced uncertainties with regard to the best estimates of sediment quantities deposited on the bed. Nevertheless, the range of accountability for uncertainties was not that poor given that, the value was at least above 50 percent (Abbaspour, 2015) and results on real time measurement also demonstrated that, peak deposition of sediment was at the peak of rainfall. Therefore, the sediment model can still be useful for future water resource management in the immediate study area and others that share similar characteristics. Uncertainties are generic in all modelling studies even previous scholars (Savabi *et al.*, 1995; Kirnak, 2002; Bhuyan *et al.*, 2002; Renschler, 2003; Zhang, 2004; Lier *et al.*, 2005; Van Rompaey *et al*., 2005, Ahmadi *et al.*, 2006; Winchell *et al.*, 2013; Kralisch *et al* 2007 and; those in Table 1) noted almost similar sources of uncertainties. Only their magnitudes vary from one spatial context to the other depending on scarcity or abundance of input data, hence the need for continuous model improvement through research.

8.6.6 Relationship between long term observed and simulated sediment

A cumulative assessment of measured and simulated sediment for the longest period (1988-2017) indicated that the simulated sediment was slightly higher compared to the measured sediment during all time periods. Nonetheless, observed and simulated sediment were very strongly and positively correlated as indicated by high Pearson correlation coefficient (r) of 0.99 and *p*-values of 0.01 in all cases. This means that there were negligible differences between long-term observed and simulated daily sedimentation and this was also confirmed by very low CVs (five percent on average). Moreover, the %d (PBIAS) were nearly within very reasonable ranges as per criteria proposed by Arnold *et.al* (2012). This simply reconfirms that the initial ArcSWAT model was very successful in predicting the sediment in spite of uncertainties surrounding it. Moreover, it also shows that, long term-based simulations than short-term ones are likely to produce better results as long as there are fewer outliers.

8.7 The immediate and wider contexts of the Makoye sediment SWAT and 3D models

In some earlier selected works on hydro-geomorphological modelling (Abbaspour 2007; Shourie, 2012) process models were developed on how flows or sediment can be simulated and calibrated. Insightful though they are, such conceptual models are abstract for beginners and are biased towards catchments with pre-existing measured data (flows, sediment, *et cetera*) in order for model calibration and validation to be carried out. This study proposed a process conceptual model for improved understanding sediment simulation and calibration for small reservoir basins with no prior sediment data (Figure 62). It was developed based on the current research protocol, but inspired by previous studies on hydrological simulation (Abbaspour 2007; Shourie, 2012).

Using a regionalised approach, the model simulated discharge not only at the main outlet of the watershed where the gauging station was located, but also in all its subbasins. This facilitated the acquisition of simulated sediment data, which was calibrated using SUFI-2 in SWATCUP using the real time sediment data measured in-situ using Sedimeter SM3A. This technique is what actually makes this model unique as it was not going to be possible in any way to calibrate sediment and it could be one of the pioneering, if not the first one in Africa and Zambia in particular.

From the illustrative model, it can be noted that sediment coring is key to successfully adapt the proposed model in other contexts with similar catchment characteristics as Makoye Reservoir. The r^2 value of the regression model showing sediment depth-load relationship (based on sediment coring) must be very strong (as closer to 1 as possible) in order to guarantee accuracy when using real time sediment depth to predict sediment loads (tonnes/day) for calibration and validation purposes.

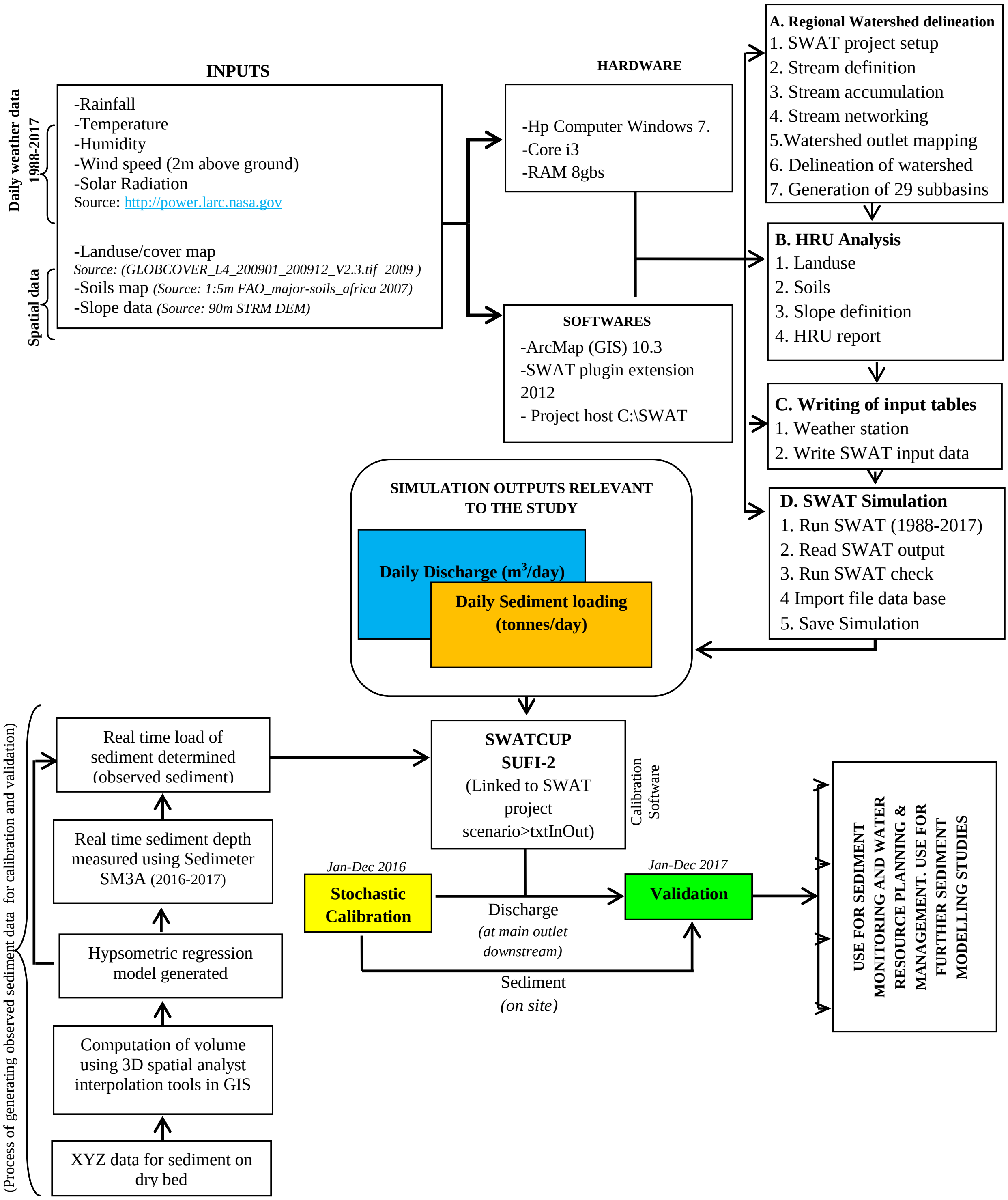


Figure 62: Conceptual model for improved understanding of simulation of sedimentation in ungauged reservoir catchment with no prior sediment data at onset of the study, developed in this study

Using the same procedure as depicted in the model above, but with area-specific observed sediment data, it is possible to calibrate and validate sediment models for other reservoir subbasins in the immediate and distant watersheds.

In spite of some uncertainties (48 percent) that surrounded the model, it can still be useful to all reservoirs and catchments that have similar characteristics (no gauging station, no pre-existing sediment) as Makoye reservoir. Since the ZMD weather data especially daily rainfall had too many gap especially in the last 50 percent of its temporal resolution, the study adopted remote sensed weather data from NASA online hub that measures all weather data in real time. The NASA weather data site provided in the conceptual model contain very comprehensive data base even for catchments that do not have any weather station. It is able to provide point data and also spatially distributed ones depending on the preference. This makes it easier to simulate both discharge and sediment even if there is no any weather data locally (often the case in most reservoir catchments in Zambia). This does not however suggest that measured data, if available, should not be used.

The Water Resource Management Authority (WARMA) in Zambia can actually use the model to generate good estimate of sediment being generated and entering not only reservoirs, but also other water bodies. For example, this study did not only generate sediment data for Makoye Reservoir, but also for other 28 reservoir catchments within radius of 20-30 km in the watershed. So, although the model was practically and conceptually developed for the study area, it intrinsically provide a methodology that can be applied to other spatial contexts as long as context-bound input data are used in the simulation. The model can be used in situations where dams are proposed for future development because it provided baseline data for the whole catchment including areas where future dams are likely to be proposed.

Rather than simply complaining about lack of long term hydrological and sediment data for most catchments in Zambia, such a model can be adapted to generate reflective comprehensive sediment data base and continuous sediment monitoring system. Without a good database for sediment data and monitoring system, it would be inconceivable to effectively manage and allocate water resources in Zambia and Makoye Basin in particular.

This also means that Zambia may not effectively implement SDG 6 on clean water and sanitation and if that happens then, SDG 1 on ending poverty cannot be achieved especially for water-dependent socio-economic activity like pastoralism in the Makoye Reservoir catchment. Eventually, even zero hunger and quality of life under water as enshrined in SDGs 2 and 14, respectively (United Nations Development Programme (UNDP), 2018), cannot be achieved effectively as they are water-dependent. This therefore challenges all water resources researchers, hydro-geoscientists, managers and decision makers both locally and internationally to vigorously engage in continuous research and generation of quality data and knowledge to guide decision making around sediment monitoring and water resource management. Moreover, they should not only look at the physical dimension of water resources, but also on the far reaching systemic links of such physical aspects on developmental plans such as those contained in the global and national agenda that relate to management of quantity and quality of water resources.

Based on the 2D model in Figure 60 above, the study noted that the highest deposition of sediment (2.31 m) occurred in the bottom set bed of the reservoir. The particle sizes were also found to be less than <1 mm thereby confirming that indeed, the bottom set bed is as earlier theorised by Ferrari and Collins (2006), the zone of a reservoir where the finest sediment particles (clay and silt) are deposited. Sedimentation process in the Makoye Reservoir involved diverse processes that systemically worked together before settling of sediment particles to the reservoir. The subsurface of Makoye Reservoir's water column was found to be highly turbid which pointed to high levels of suspended sediment and the mode (suspension) in which it was transported to the reservoir.

Similarly, the 3D sediment model (Figure 61 above) in connection with Figure 54d-e above illustrated that Makoye Catchment was susceptible to erosion hazard as demonstrated by high 30-year simulated sediment yields (≤2 million tonnes). Although this was just a simulated yield and uncalibrated due to lack of measured data, it presents an indicator of what the reality may be especially from crop and grazing fields which accounted for 61 percent of the total sediment yields in three decades from 1988. The simulated erosion hazard map in the current study fairly resonated with what Chiti (1987) earlier found in his national wide erosion mapping study. Although Chiti (1987) showed that high magnitude values (4-5) were mainly on the upstream side of the subbasin, the current study demonstrated that severity has spatial diffused further downstream mainly due to some increase in human activities in the catchment.

The long-term sediment delivery ratio into the reservoir was found to be about 8.8 percent or about 175,026.17 tonnes of sediment, which reduced the reservoir's capacity by 54 percent, with last sediment-reservoir water volume ratio of 1.4:1 (which means that, for every 2.4 m^3 space in the reservoir, 58% is occupied by sediment). Such delivery ratio is not only unique to Makoye reservoir catchment, but also in other spatial contexts. For example, Williams (1975) earlier found delivery ratio (6.1 percent) in the Elm Creek catchment in the United States of America whose magnitude was similar to that of Makoye. The delivery ratio of 8.8 percent in the Makoye Catchment also closely related with delivery ratio (9 percent) found in the Kaleya Catchment by Walling *et al.* (2001). The current finding also relates with what Roehl (1962) and Vanoni (1975) earlier found. Hence, it can be said that, such a delivery ratio as found in Makoye is not uncommon.

Uniformity of sediment particle size (<1mm) in the bed sediment sample as thick as 50cm inherently implies that, for a long period of time, the reservoir had predominantly been receiving suspended sediment. This claim is no mere overstatement as it has already been observed by earlier works of Leopold *et al.* (1995), Sichingabula (2000) and Walling *et al.* (2001).

The 50cm thick sample of sediment layer purely constituted clay, which trapped diverse chemicals and metals whose concentration varied from one sub-layer (every 10cm) to the other. The diversity of chemical and metal composition of the 50cm sediment sample entails that, different anthropogenic activities were taking place in the catchment at different time scales especially in the cultivated and razing fields which also experienced the highest magnitude of erosion and also influenced the hydrochemistry of the reservoir whose water volume was also highly variable mainly due to deposited sediment. Layer four (40cm from the bed surface) was found to be the most acidic with pH value of 3.9. The levels of acidity in the other layers (1, 2, 3 and 5) were almost same, ranging from acidity towards neutrality 5.14-5.6. Given that orthic ferralsol soil has high acidity (FAO, 2007), and that, it formed the main pedospheric base for the reservoir (Figure 47c-d above), it is not strange to record such pH levels with the deduction that, during earlier times of geomorphological processes for layer four, orthic ferralsol was probably the most eroded, transported and hence, the most deposited in layer four leading to the highest acidity levels (Derbyshire *et al.*, 1979).

In terms of metal composition in the sediment on the bed, potassium was found to be highest in the first, third and fifth layers. The most least were recorded in layers two and four. This points to fertiliser application in the soils on the agricultural fields upstream, which when transported and deposited in the reservoir bring with them such rich concentration of potassium. Sodium was only high (25 cmol/kg) in layer one of reservoir bed sediment, the other layers only constituted negligible quantities (0.3-1.18 cmol/kg). This means that in the past depositional records, there were either low fertiliser applications or low transportation and deposition of sodium-ridden sediment into the reservoir possibly due to poor rainfall. But in the most recent deposition records, evidence show high concentration of the same metal whose reason for high prevalence could be attributed to the converse of the former explanation. Calcium levels were found to be the same in the first three layers, but slightly plummeted in the forth layer (9.4 cmol/kg) and again short up in the fifth layer reaching almost the same level as in the first three layer. Magnesium was only high in the fifth layer (63.1 cmol/kg) seconded by the second and fourth layer with the least being found in layer three (3.1 cmol/kg). This scenario resonates with earlier study by Rice et al. (2002) and Bremner (1997) who noted that, the minerals in sediment tend to be variable especially in cases where the upstream anthropogenic activities vary from year to year.

The same pattern also emerged for chemical constituents, as they were also found to be unstable along the vertical column of 50 cm. Phosphorus was found to be the most negligible, ranging between 1 and 1.42 mg/kg. The most notable chemical constituents in the sediment sample were sulphur, chloride and nitrite. Sulphur recorded highest values (112, 78 and 58) in layers four, one and two; respectively. Chloride was high among all the layers in the column, but the highest concentrations (121 and 107 mg/kg) were experimentally observed in layers four and three, respectively. As earlier discussed, these two were the most influential on the hydrochemistry of the Makoye Reservoir. Nitrite was highest in layers four and two, each recording 173 mg/kg and 149 mg/kg, respectively, but generally, it was fairly distributed in all layers. All these parameters are connected to upstream agricultural activities such as crop farming and gardening as well as grazing where the sediment was coming from. For example, it is a well known fact that where cows graze, there is always high concentration of nitrate and chloride due to dung that is scattered everywhere (Korkanc *et al.*, 2017). Hence, when it rains, such are transported together with sediment into nearby depositional zone such as a reservoir bed.

All highly toxic heavy metals were found to be either negligible or non-existent. For example, cadmium was not present, but Lead was negligibly recorded in layer one (0.1 mg/kg) and layer five (0.06 mg/kg). In their study, Gioia and Nascimento (2006) noted that such anthropogenic infrastructure as dip tanks, roads and also leakages from farm machinery could be sources of lead in deposited sediment. Copper was prevalent in all layers, but only ranged between 1.5-4.4 mg/kg across the sediment column with layer four recording the highest value (4.4 mg/kg). Like lead, copper source could be attributed to road runoff as also earlier noted by Rice *et al.* (2002), but most certainly from the geology of the area. As indicated on the geology of the study area in Chapter Three, Makoye Reservoir actually sits on the Mine Series, which perhaps are the host of copper bearing minerals from which copper could have been derived. With exception of iron, which was most prevalent (41 mg/kg) in layer one and least in layer two (22 mg/kg), heavy metals were generally negligible in their concentration. Both high and low concentrations, including all the variations in compositions point to the dynamic land uses over the years and heterogeneous processes of erosion and transportation of sediment (Leopold *et al.*, 1995). Had the processes been homogeneous or temporally linear, there would have been homogeneous concentration of selected sediment parameters across all the five layers of the sediment sample. With exception of iron whose concentration was in stable equilibrium, all other parameters were variable with change in sediment depth, but the most variable was nitrate (Figure 62 above). Its instability could be attributed to denitrification, which is a anaerobic reaction that sequentially reduces nitrate into nitrite (Bremner, 1997). Iron's stability could have been influenced by the pedospheric landscape of Orthic Ferralsol under laying the point where the reservoir is actually constructed (Figure 47c).

FAO (2007) confirms that this soil is high in iron content and this, should contribute to stable presence of iron in most analysed layers of the sediment sample. Moreover, Schulte (2019) adds that iron tends to be high in sediment or soils with low pH level (3.6-5.6 in current study) and highly compacted in nature (Bulk density = 2.06 tonnes/m^3). Both the SWAT and 3D block models generally summarises the study and it depicts the idea that in order to understand the process of sedimentation, diverse processes should be examined with profundity and perspicacity. The block model is adaptable to wider spatial and temporal contexts where understanding of sedimentation may be required.

8.8 General performance evaluation of calibrated sediment SWAT model

The performance evaluation of the final calibrated model was based on the criteria set by Arnold *et al.* (2012), specifically, r^2, NSE and PBIA (termed as %d) were used. Using the r^2 and NS values, the sediment model performed very well during calibration, which shows that SWAT is viable in simulating sediment in ungauged reservoirs and basins. Although the r^2 and NSE seemed to be low during validation, they did not significantly vary (CV = 1.3 percent) from the minimum standard (50 percent) prescribed by Arnold *et al.* (2012) for sediment modelling. The calibrated sediment model was less susceptible to under estimation of sediment than the validated one. This can be confirmed by the PBIAS values of 20.6 percent during calibration compared to 53.5 percent during validation (Abbaspour, 2015). These weaknesses surrounding the model especially discrepancies expressed as PBIAS during calibration can be attributed to the uncertainties earlier discussed above. Nevertheless, by eliminating outliers from the data sets, discrepancies can be reduced so as to enhance projective power of the model. Outliers were eliminated based on how far they were from the line of best fit, the farthest were the ones removed so as to improve projective capacity.

8.9 Synoptic philosophical reflections about the study findings

The ethos of this thesis was informed by the onto-epistemic supposition that physical geographical phenomena can only be understood as closer to objectivity as scientifically possible. This rules out objective purism as claimed by pure empiricism or positivism. This was premised on the study observation that some physical processes such as geomorphic processes influencing sediment routing into the lacustrine system could not be objectified within the corpus of physical geographic epistemology in general, and that of fluvial geomorphology in particular. Hence, whilst emphasizing the technicist philosophical contingency, scientists within the broader frames of geomorphology and particularly simulation of fluvial processes and events must always endeavour to precisely account for uncertainty around the physical system being investigated. So the determinism lens as one of the epistemological assumptions in this study should not outrightly and parochially be understood to mean that, physical processes that caused certain events such sedimentation and change in water quality are all fully and perfectly understood, but that, atleast those which could possibly be known were tracked to establish causal links before arriving at scientific conclusions. No wonder p-values were indicated were necessary to show the marginal errors no matter how smaller those errors could have been.

The plurality of factors that influenced hydrogeomorphological processes and realities as noted in this study did not only raise a hermeneutic dilemma, but also created room for systemic attempting of ontological questions surrounding the science of fluvial geomorphology of ungauged small reservoirs and their catchments. Systemic and continuous ontological clarification of for example, SWAT modelling of sedimentation is a necessary precondition for the formulation of an epistemological standpoint and of methodological procedure for novice researchers in the field of geomorphology especially in the Zambian context where sediment simulation studies were not very prevalent by the time this study was done. Furthermore, the ontological stance of knowledge generated by this study should be viewed with critical empiricism, where not only the known causal factors are taken care of in the interpretation and application of findings, but also those which might not have been accounted for so us to determine the certainty of geomorphic model. Taking this into consideration stood most objectively as far as the study of Makoye Reservoir system was concerned and it determined the epistemological structure, origin and logicality of the foundations on which it could stand or fall. It is therefore proposed that the would be epistemic endeavours around the fluvial geomorphology of small ungauged reservoirs and catchments should expeditiously dive deeper into unaccounted for realities surrounding siltation causalities.

Moreover the nature of reality that emerged from this study should be treated as independent of the researcher's own biases but not the researcher. This means whilst the researcher was part of the research process, personal opinions and biases were bracketed so as not to encroach into the process of knowledge production, the measured data brought out the existing reality from which the conclusions were drawn. As much as the reality of the knowledge in this study is generalisable, its generalisability is confined to small reservoirs and their catchments which have similar characteristics as Makoye Reservoir and its catchment. In other words the external validity of the knowledge created in this study is dependent on other external realities having same anthro-biophysical features as those of the hydrologic system which was studied. This therefore rules out the notion of pure concrete universality of the knowledge created in this study. For example, the conceptual 3D model is only applicable and adaptable to other contexts outside the study area as long as they share similar characteristics and same applies to proposed reservoir management strategies.

8.10 Chapter Summary

Moriasi *et al.* (2007) say that there is a lack of a very comprehensive and universal standard to judge performance of SWAT modelling as different studies and project use different criteria. The current study used the criteria proposed by Arnold *et al*. (2012). This study concludes that, stochastically, SWAT performed very efficiently in simulating sediment pointing out that, indeed, sedimentation was a real problem that affecting the lifespan of the Makoye Reservoir and eventually, socio-economic livelihood of the people who depend on it. Over 3,200 studies some of which are mentioned above and even those hosted on the online hub known as *Science Direct* have used SWAT to simulate sediment, but none of them used real time measured depth to derive daily sedimentation with the aid of polynomial equation for calibration of sediment model. Hence, this study pioneered how Sedimeter SM3A could be integrated with coring method to derive observed sediment data in ungauged reservoir catchment so as to eventually calibrate sedimentation using SUFI-2 in SWATCUP. The conceptual model and the block model in Figures 61 and 62 above, respectively can be adapted in other spatial contexts for improved understanding of sedimentation process as long as its ontological milieu as explained above is taken into consideration.

CHAPTER NINE: CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based on the pieces of evidence earlier presented on bathymetry and in the context of Objective One, the study concluded that Makoye Reservoir had a highly unstable bathymetry at multi-temporal scales due to various physical processes, but more especially sedimentation, which was found to be trapping over 50,000 m^3 of water before reaching asymptotic limit for water to accumulate in the reservoir. The unstable bathymetry was characterised by reduced water volumes, unpredictable hydrological regimes and reduced water depths. The reservoir's water supply was on average, incapable of meeting the animals' water demands especially during the warm-dry season.

Premised on Objectives Two and Three, which focused on long and short-term (real time) quantification of sediment, the study concluded that, sedimentation was a serious problem in the reservoir and its magnitude was high as compared to similar reservoirs studied by earlier scholars. This heavy burden of sediment had already compromised the storage capacity by over 50 percent and threatens the reservoir's useful life and consequently, the sustainability of access to water resource especially for cattle. The study also concluded that, due to high sedimentation rate, the reservoir may possibly not last more than three decades and this may silently punctuate future water crisis, which may also affect social livelihood, unless sediment control measures are put in place.

In line with Objective Four, the study further concluded that, water in the Makoye Reservoir was safe for animal consumption because the concentration of most (80 percent) of its physico-chemical parameters were on average, within prescribed MPLs for animal watering. Although most physico-chemical parameters were within MPLs, iron, total phosphate, phosphorus and ammonia were on average, beyond prescribed MPLs for livestock. The levels of concentration for different parameters spatio-temporally varied, which means that, understanding water quality should be done not only across the entire water body, but also at different seasonal scales. Hydro-geochemically, water was highly mixed and sulphate-chloride water was the most prevalent type of water influenced by the geochemistry of sediment/soils from the cultivated fields and grazing land on the upstream of the subbasin. Furthermore and in line with Objective Five, the study concluded that SWAT was very efficient at simulating sediment in ungauged reservoirs. The efficiency was highly noted (r^2=0.77; NSE=0.77) during calibration than during validation period. This implies that the model can perform very well within spatial-temporal scale it was generated than in those outside it. The developed process sediment model can be applicable in both immediate and wider contexts as long as appropriate input data are used.

Based on Objective Six, sedimentation was generally observed to be a silent, yet very complex process that involves diverse sub-processes and therefore, the illustrative models especially the 3D model designed in this study can be used as a mirror in understanding sedimentation processes in other spatial and temporal contexts. It can also help determine factors such as landuse changes as well as erosion, transportation and deposition processes influencing the stability and dynamics of sediment layering in terms of sediment composition and particle sizes. The study generally concluded that, although sediment may be a threat and detrimental to water quality, quantity and lifespan of a reservoir in general, it could also be a benefit because many of the analysed chemical, physical and metal parameters in water (influenced by sediment) were within acceptable limits prescribed by FAO for livestock watering. Based on some key findings of the study, the following section presents some recommendations.

9.2 Recommendations

The following are the recommendations from this study:

i. the bathymetry and volume of water in the Makoye Reservoir was found to be highly variable with about 54 percent of the reservoir storage taken by sediment reducing useful life to less than three decades. The study recommends stopping upstream activities and dredging the reservoir so as to stabilise the equilibrium of its bathymetry and address capacity loss or possibly constructing another dam down stream. However, the cost-benefit of the two options need to be carefully considered;

ii. the highest records of real time sedimentation were measured during peak rainfall period, therefore, it is methodologically recommended that peak rainfall period be adopted as best time to use a sedimeter in measuring real time sedimentation;

iii. a continuous spatial-temporal monitoring of water quality in reservoirs is a recommended because water physico-chemistry is never in static equilibrium as also noted in this study;

iv. there is need to explore social-hydrogeomorphological research particularly in view of the understanding that the use of the watershed by the anthropogenic activities was negatively influencing the dam sedimentation rates;

v. SWAT was found to be efficient (both r^2 and NSE=0.77) in simulating sedimentation in ungauged Makoye Reservoir catchment, it is therefore, recommended to be used in simulation of hydrological systems in other catchments with hydrological characteristics similar to Makoye Reservoir.

vi. the study found that, cultivated fields and grazing areas were the most hazardous (61%) in terms of erosion and sediment yields. Therefore, sediment control measures and community awareness must be put in place to reduce sediment deposition into the Makoye Reservoir. For example, a deliberate programme of integrated watershed management can be put in place led by community members with support from WARMA;

vii. in order to ensure water security and satisfy the demands for animal consumption, there is need for installation of alternative or reserve sources of water such as boreholes and to improve watershed management literacy; and

viii. given the reduced useful life for the Makoye Reservoir, the study recommends that sediment control and monitoring policy and strategy should be developed and implemented in order to reduce sedimentation that threatens sustainable supply of water resources.

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APPENDICES

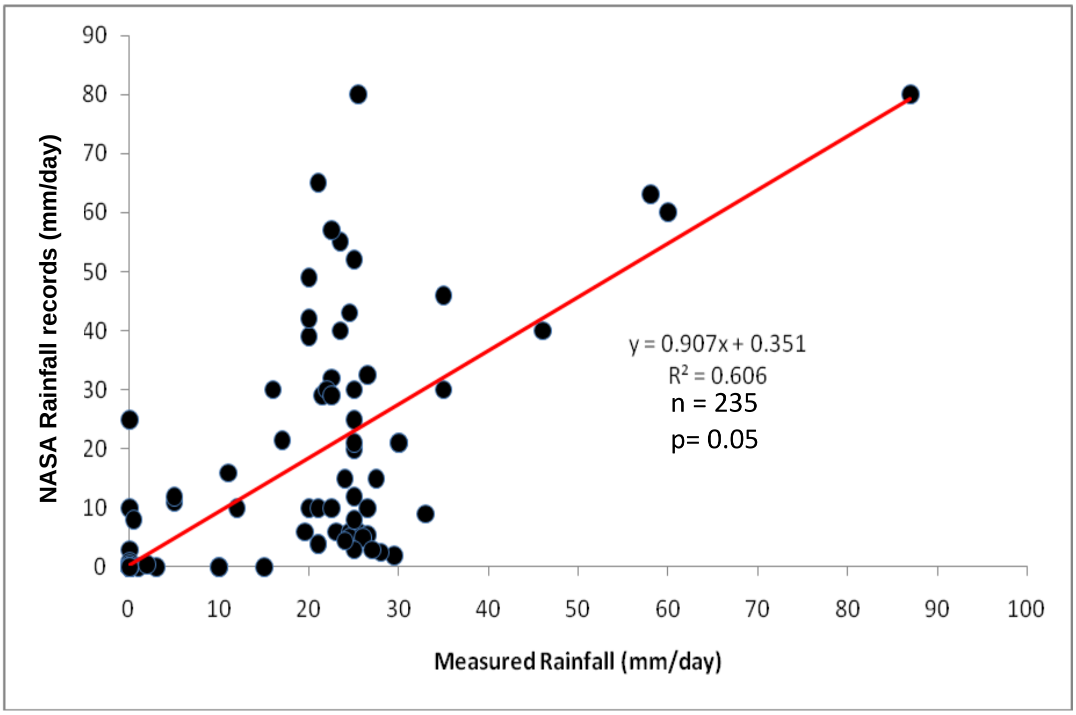
Appendix A: Listing of Reservoirs in Monze District

NO.	RESERVOIR NAME	PROVINCE	DISTRICT
1	Nteme-Choongo	Southern	Monze
2	Makatapila	Southern	Monze
3	Kaya	Southern	Monze
4	Monzwe	Southern	Monze
5	Munyenze	Southern	Monze
6	Makatapila-B	Southern	Monze
7	Hamatuli	Southern	Monze
8	Luyaba Calvet	Southern	Monze
9	Luyaba	Southern	Monze
10	Hatambala	Southern	Monze
11	Munguza/Kalobe	Southern	Monze
12	Kanundwe	Southern	Monze
13	Hachanga	Southern	Monze
14	Nanjilile_Namakube	Southern	Monze
15	Lweeta	Southern	Monze
16	Hameja choni	Southern	Monze
17	Hichani Weir	Southern	Monze
18	Gilbert	Southern	Monze
19	Naba Jafeti	Southern	Monze
20	Chuuka	Southern	Monze
21	Ntambo weir	Southern	Monze
22	Hakabilo	Southern	Monze
23	Chokole	Southern	Monze
24	Chibinda	Southern	Monze
25	Choombwa	Southern	Monze
26	Kaumbu	Southern	Monze
27	Hachisala	Southern	Monze
28	Mpanda	Southern	Monze
29	Hachikuyu/ Kafwefwe	Southern	Monze
30	Bbole	Southern	Monze
31	Hamapande	Southern	Monze
32	Muchimwa	Southern	Monze
33	Kazungula	Southern	Monze
34	Sikasiwa	Southern	Monze
35	Chuula	Southern	Monze
36	Mukachali /Kabbudula farm	Southern	Monze
37	Lweendo	Southern	Monze
38	Mulumbwa	Southern	Monze
39	Mayaba/ St. Marys	Southern	Monze
40	Simukale	Southern	Monze
41	Nchobezyi / Hanamaila	Southern	Monze
42	Mainza B	Southern	Monze
43	Katete	Southern	Monze

44	Lijati-Bbuyu	Southern	Monze
45	Nkandela	Southern	Monze
46	Namazakala	Southern	Monze
47	Hankombo	Southern	Monze
48	Chisuwo	Southern	Monze
49	Mutebele	Southern	Monze
50	Singonya	Southern	Monze
51	Choobe Weir	Southern	Monze
52	Chikuni	Southern	Monze
53	Kanyemba	Southern	Monze
54	Chiyobola	Southern	Monze
55	Chipongwe	Southern	Monze
56	Chipembele	Southern	Monze
57	Lasiti	Southern	Monze
58	Mombelela	Southern	Monze
59	Rusangu B	Southern	Monze
60	Rusangu A	Southern	Monze
61	Muchaili-Nabuyanda	Southern	Monze
62	Namanondo	Southern	Monze
63	Mailosi/ (Miles)	Southern	Monze
64	Filimoni	Southern	Monze
65	Kaunga	Southern	Monze
66	Namilongwe Central	Southern	Monze
67	Namilongwe West	Southern	Monze
68	Chido	Southern	Monze
69	Kabuyu	Southern	Monze
70	Hachiti	Southern	Monze
71	Mwaala	Southern	Monze
72	Hamudebwe	Southern	Monze
73	Habilo	Southern	Monze
74	Simwendengwe	Southern	Monze
75	Hakwangala	Southern	Monze
76	Chiyuna	Southern	Monze
77	Bulanda	Southern	Monze
78	Jalila	Southern	Monze
79	Maimpa	Southern	Monze
80	Dip Tank	Southern	Monze
81	Seleketi-A	Southern	Monze
82	Sekeleti-B	Southern	Monze
83	Hagwanama-Muwe	Southern	Monze
84	Hambweka	Southern	Monze
85	Chompa	Southern	Monze
86	LittleWonder Farm-A	Southern	Monze
87	Little Wonder Farm-B	Southern	Monze

88	Makoye Reservoir	Southern	Monze
89	Hamaundu	Southern	Monze
90	Hakamata	Southern	Monze
91	Hikaunu	Southern	Monze
92	Chindolo	Southern	Monze
93	Habumpindu	Southern	Monze
94	Halwindi	Southern	Monze
95	Kanenga	Southern	Monze
96	Silwilili	Southern	Monze

Appendix B: Relationship between the onsite Measured Rainfall (at Makoye Reservoir) and Nasa Rainfall Record on Selected Days During The Warm-Wet Seasons 2015/2016; 2016/2017 and October-December, 2017.



Source: Field measurements (2015-2017) and power.larc.nasa.gov/common/php/Agroclimatology (December, 2017)

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
10/25/2015	0	0
10/26/2015	0	0
10/27/2015	0	0
10/28/2015	0	0
10/29/2015	0	0
10/30/2015	0	0
10/31/2015	0	0
11/1/2015	0	0
11/2/2015	0	0
11/3/2015	0	0
11/4/2015	0	0
11/5/2015	0	0
11/6/2015	0	0
11/7/2015	0	0
11/8/2015	0	0
11/9/2015	0	0
11/10/2015	0	0
11/11/2015	0	0
11/12/2015	0	0
11/13/2015	0	0
11/14/2015	0	0
11/15/2015	0	0
11/16/2015	0	0
11/17/2015	0	0
11/18/2015	0	0
11/19/2015	0	0
11/20/2015	0	0
11/21/2015	0	0
11/22/2015	0	0
11/23/2015	0	0
11/24/2015	0	0
11/25/2015	0	0
11/26/2015	0	0
11/27/2015	0	0
11/28/2015	0	0
11/29/2015	0	0
11/30/2015	0	0
12/1/2015	0	0
12/2/2015	25	30
12/3/2015	11	16
12/4/2015	20	10
12/5/2015	0	0

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
12/6/2015	0	0
12/7/2015	0	0
12/8/2015	0	0
12/9/2015	0	0
12/10/2015	0	0
12/11/2015	0	0
12/12/2015	0	0
12/13/2015	0	0
12/14/2015	0	0
12/15/2015	0	0
12/16/2015	0	0
12/17/2015	0	0
12/18/2015	0	0
12/19/2015	0	0
12/20/2015	15	0
12/21/2015	0	0
12/22/2015	0	0
12/23/2015	35	30
12/24/2015	0	0
12/25/2015	0	10
12/26/2015	0	0
12/27/2015	0	25
12/28/2015	10	0
12/29/2015	0	0
12/30/2015	0	0
12/31/2015	30	21
1/1/2016	16	30
1/2/2016	10	0
1/3/2016	0	0
1/4/2016	25	20
1/5/2016	0	0
1/6/2016	35	46
1/7/2016	0	0
1/8/2016	0	0
1/9/2016	30	21
1/10/2016	0	0
1/11/2016	0	0
1/12/2016	0	0
1/13/2016	0	0
1/14/2016	46	40
1/15/2016	0	0
1/16/2016	0	0

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
1/17/2016	0	0
1/18/2016	0	0
1/19/2016	0	3
1/20/2016	0	0
1/21/2016	0	0
1/22/2016	0	0
1/23/2016	0	1
1/24/2016	0	1
1/25/2016	0	0
1/26/2016	0	0
1/27/2016	3	0
1/28/2016	0	0
1/29/2016	0	0
1/30/2016	0	0
1/31/2016	1	0
2/1/2016	0	0
2/2/2016	0	0
2/3/2016	58	63
2/4/2016	25	25
2/5/2016	0	0.5
2/6/2016	0	0
2/7/2016	17	21.5
2/8/2016	60	60
2/9/2016	5	11
2/10/2016	87	80
2/11/2016	0	0
2/12/2016	2	0.5
2/13/2016	5	12
2/14/2016	0	0
2/15/2016	0	0
2/16/2016	0	0
2/17/2016	0	0
2/18/2016	0	0
2/19/2016	25	12
2/20/2016	0.5	8
2/21/2016	12	10
2/22/2016	0	0
2/23/2016	0	0
2/24/2016	0	0
2/25/2016	0	0
2/26/2016	0	0
2/27/2016	0	0

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
2/28/2016	0	0
2/29/2016	0	0
3/1/2016	0	0
3/2/2016	0	0
3/3/2016	0	0
3/4/2016	0	0
3/5/2016	0	0
3/6/2016	0	0
3/7/2016	22.5	32
3/8/2016	26.5	32.5
3/9/2016	29.5	2
3/10/2016	20	49
3/11/2016	21	10
3/12/2016	21.5	29
3/13/2016	23	6
3/14/2016	33	9
3/15/2016	26.5	10
3/16/2016	25	52
3/17/2016	28	2.5
28/12/2016	24	15
30/12/2016	25.5	80
1/1/2017	24.5	43
2/1/2017	24.5	6
3/1/2017	25.5	6
7/1/2017	27.5	15
9/1/2017	24.5	5
11/1/2017	26.5	5.5
15/01/2017	25	8
16/01/2017	25	21
17/01/2017	19.5	6
18/01/2017	21	4
20/01/2017	20	39
21/01/2017	23.5	55
23/01/2017	26	5
26/01/2017	23.5	40
27/01/2017	22	30
28/01/2017	22.5	10
29/01/2017	22.5	57
3/2/2017	25	3
5/2/2017	22.5	29
6/2/2017	24	4.5
7/2/2017	21	4

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
8/2/2017	27	3
9/2/2017	21	65
16/2/2017	20	42
10/29/2017	0	0
10/30/2017	0	0
10/31/2017	0	0
11/1/2017	0	0
11/2/2017	0	0
11/3/2017	0	0
11/4/2017	0	0
11/5/2017	0	0
11/6/2017	0	0
11/7/2017	0	0
11/8/2017	0	0
11/9/2017	0	0
11/10/2017	0	0
11/11/2017	0	0
11/12/2017	0	0
11/13/2017	0	0
11/14/2017	0	0
11/15/2017	0	0
11/16/2017	0	0
11/17/2017	0	0
11/18/2017	0	0
11/19/2017	0	0
11/20/2017	0	0
11/21/2017	0	0
11/22/2017	0	0
11/23/2017	0	0
11/24/2017	0	0
11/25/2017	0	0
11/26/2017	0	0
11/27/2017	0	0
11/28/2017	0	0
11/29/2017	0	0
11/30/2017	0	0
12/1/2017	0	0
12/2/2017	0	0
12/3/2017	0	0
12/4/2017	0	0
12/5/2017	0	0
12/6/2017	0	0

Appendix C: Onsite Measured and NASA Rainfall Records Used To Plot Relationship Graph In Appendix B for Makoye reservoir basin

Date	Measured rainfall (mm)	NASA Rainfall record (mm)
12/7/2017	0	0
12/8/2017	0	0
12/9/2017	0	0
12/10/2017	0	0
12/11/2017	0	0
12/12/2017	0	0
12/13/2017	0	0
12/14/2017	0	0
12/15/2017	0	0
12/16/2017	0	0
12/17/2017	0	0
12/18/2017	0	0
12/19/2017	0	0
12/20/2017	0	0
12/21/2017	0	0
12/22/2017	0	0
12/23/2017	0	0
12/24/2017	0	0
12/25/2017	0	0
12/26/2017	0	0
12/27/2017	0	0
12/28/2017	0	0
12/29/2017	0	0
12/30/2017	0	0
12/31/2017	0	0

Appendix D: Sample Of Weather Data Input Format For The First Year Of Simulation water and sediment at Chimbumbu Gauging Station in the Magoye Basin

	WEATHER INPUT PARAMETERS USED				
	Rainfall p-161278.txt	**Max and Min temperature t-161278.txt**	**Relative humidity r-161278.txt**	**Radiation s-161278.txt**	**Wind speed w-161278.txt**
Date	19880101	19880101	19880101	19880101	19880101
1-Jan-88	28.46	20.38,19.18	0.71	19.066	7.91
2-Jan-88	58.63	19.93,19.2	0.71	29.95	9.98
3-Jan-88	4.88	20.28,19.3	0.62	26.53	7.55
4-Jan-88	9	21.4,20.38	0.55	28.19	5.27
5-Jan-88	6.2	20.64,20.05	0.5	30.92	2.83
6-Jan-88	14.3	20.01,19.03	0.66	27.14	5.9
7-Jan-88	21.75	19.2,18.69	0.81	31.5	10.72
8-Jan-88	11.98	20.16,19.02	0.73	28.33	8.07
9-Jan-88	19.53	20.75,19.61	0.65	32.22	4.45
10-Jan-88	19.85	20.59,19.46	0.6	33.23	4.41
11-Jan-88	8.37	19.31,18.86	0.56	26.35	5.86
12-Jan-88	11.31	20.34,19.2	0.67	28.01	4.18
13-Jan-88	10.25	20.29,19.63	0.7	31.82	3.75
14-Jan-88	14.83	20.03,19.23	0.67	31.21	4.52
15-Jan-88	9.74	18.45,17.51	0.66	29.92	6.93
16-Jan-88	22.7	18.52,17.38	0.63	28.51	9.66
17-Jan-88	30.27	19.64,17.61	0.64	27.72	8.42
18-Jan-88	10.32	19.5,18.7	0.66	27.58	6.82
19-Jan-88	9.32	18.25,17.66	0.76	28.12	7.03
20-Jan-88	35.35	18.46,17.85	0.69	30.92	9.44
21-Jan-88	14.73	19.77,18.55	0.67	30.2	11.08
22-Jan-88	3.66	19.81,18.62	0.73	25.38	9.1
23-Jan-88	22.39	19.55,18.48	0.71	26.42	6.41
24-Jan-88	9.31	19.2,18.62	0.71	32.22	7.15
25-Jan-88	8.75	18.47,17.19	0.72	32.44	4.44
26-Jan-88	0	18.88,17.5	0.66	31.03	2.81
27-Jan-88	2.88	19.43,18.68	0.66	31.18	7.69
28-Jan-88	0.2	19.4,18.38	0.64	27.94	10.26
29-Jan-88	11.29	17.78,17.04	0.74	27.94	10.33
30-Jan-88	23.34	19.07,17.32	0.78	28.76	10.95
31-Jan-88	3.83	18.78,17.86	0.83	27.61	8.43
1-Feb-88	1.17	18.56,17.49	0.78	28.04	6.82
2-Feb-88	1.49	18.91,17.55	0.78	29.84	8.23
3-Feb-88	21.98	18.39,17.63	0.69	29.59	9.4
4-Feb-88	20.07	18.49,16.91	0.71	28.94	9.75
5-Feb-88	100.03	18.41,17.5	0.77	27.61	9.51
6-Feb-88	90.61	18.23,17.47	0.8	25.7	8.93
7-Feb-88	59.99	18.55,17.65	0.69	28.01	12.8
8-Feb-88	10.43	18.72,17.81	0.69	27.04	12.61
9-Feb-88	13.04	18.85,18.1	0.71	28.62	10.41
10-Feb-88	21.63	18.28,17.17	0.85	28.91	9.72
11-Feb-88	21.37	18.09,17	0.82	28.8	9.15
12-Feb-88	15.82	19.31,18.06	0.77	27.14	8.43
13-Feb-88	17.31	18.01,17.41	0.88	26.39	4.22

STANDARD FORMAT FOR ENTRY OF WEATHER DATA TEXT	
Parameter description	**Order of presentation**
PRECIPITATION (pcp.txt)	ID,NAME,LAT,LONG,ELEVATION 1,p-161278,-16.080,27.813,1201
TEMPERATURE (tmp.txt)	ID,NAME,LAT,LONG,ELEVATION 1,t-161278,-16.080,27.813,1201
RELATIVE HUMIDITY (rh.txt)	ID,NAME,LAT,LONG,ELEVATION 1,rh-161278,-16.080,27.813,1201
SOLAR RADIATION (solar.txt)	ID,NAME,LAT,LONG,ELEVATION 1,t-161278,-16.080,27.813,1201
WIND SPEED (wind.txt)	ID,NAME,LAT,LONG,ELEVATION 1,t-161278,-16.080,27.813,1201

14-Feb-88	31.71	19.49,18.41	0.78	27.72	5.52
15-Feb-88	19.84	20.09,18.51	0.59	29.3	8.64
16-Feb-88	33.1	18.42,17.63	0.59	30.31	3.85
17-Feb-88	169.75	17.7,16.76	0.63	30.38	1.7
18-Feb-88	19.97	18.41,17.87	0.67	29.12	4.05
19-Feb-88	14.24	17.97,17.29	0.83	30.38	3.42
20-Feb-88	5.96	19.35,17.9	0.84	32.29	5.54
21-Feb-88	9.65	19.1,18.15	0.81	31.18	2.97
22-Feb-88	21.98	17.6,17.09	0.83	30.42	3
23-Feb-88	20.99	17.75,17.12	0.85	30.06	3.08
24-Feb-88	17.09	18.19,17.63	0.89	31.46	3.42
25-Feb-88	13.48	18.17,16.66	0.91	29.99	1.12
26-Feb-88	12.9	17.72,16.17	0.91	29.88	1.63
27-Feb-88	15.39	16.42,15.81	0.96	31.86	4.79
28-Feb-88	7.04	16.66,15.73	0.79	30.74	10
29-Feb-88	19.61	16.57,15.91	0.69	30.13	7.05
1-Mar-88	19.49	16.32,15.49	0.72	28.87	4.91
2-Mar-88	15.12	17.18,15.96	0.77	29.63	8.06
3-Mar-88	5.73	18.01,17.43	0.76	30.35	7.44
4-Mar-88	5.24	17.57,16.97	0.75	29.09	6.26
5-Mar-88	17.49	16.74,16.15	0.68	27.36	4.84
6-Mar-88	10.48	16.69,15.94	0.7	29.84	8.15
7-Mar-88	18.49	17.12,16.76	0.64	30.96	9.13
8-Mar-88	22.28	17.51,16.88	0.68	30.78	7.34
9-Mar-88	10.09	17.28,16.33	0.75	28.51	5.99
10-Mar-88	21.85	18.47,17.79	0.71	25.38	7.21
11-Mar-88	2.05	20.25,18.71	0.71	27.11	7.03
12-Mar-88	10.78	20.42,19.85	0.72	29.77	7.02
13-Mar-88	11.17	20.49,18.78	0.8	28.76	4.16
14-Mar-88	0.58	18.43,17.27	0.85	29.3	5.69
15-Mar-88	0.5	18.81,17.81	0.79	30.1	9.24
16-Mar-88	1.78	17.47,16.84	0.81	28.94	8.7
17-Mar-88	2.76	17.05,16.34	0.82	29.02	6.68
18-Mar-88	0	17.43,16.77	0.84	25.7	5.25
19-Mar-88	1.27	18.1,16.63	0.87	26.17	5.87
20-Mar-88	1.41	18.29,16.8	0.94	26.1	5.25
21-Mar-88	0.01	18.6,17.63	0.79	25.45	9.87
22-Mar-88	0.91	18.69,17.78	0.73	25.45	12
23-Mar-88	1	19.31,18.09	0.75	25.96	12.06
24-Mar-88	0.57	19.81,18.34	0.8	25.92	11.69
25-Mar-88	3.76	21.53,20.73	0.67	25.67	7.38
26-Mar-88	1.49	20.78,19.51	0.68	24.88	7.26
27-Mar-88	0	19.2,17.32	0.88	26.03	6.8
28-Mar-88	0.53	20.82,19.84	0.72	32.15	9.51

29-Mar-88	0.12	19.84,19.5	0.72	34.42	9
30-Mar-88	2.37	18.91,18.05	0.8	28.91	9.6
31-Mar-88	1.38	17.67,17.34	0.84	27.18	11.05
1-Apr-88	5.37	17.83,16.97	0.75	27.4	11.58
2-Apr-88	2.4	18.16,16.91	0.73	27.61	9.79
3-Apr-88	0	17.94,17.36	0.72	28.48	6.7
4-Apr-88	0	18.08,17.37	0.61	31.21	5.46
5-Apr-88	0.76	17.19,16.81	0.67	31.68	5.66
6-Apr-88	0.32	16.58,16.25	0.74	31.75	4.28
7-Apr-88	0	18.27,17.04	0.75	28.01	4.91
8-Apr-88	0.04	19.01,17.67	0.69	27.18	4.53
9-Apr-88	0	18.46,17.53	0.68	26.71	3.82
10-Apr-88	0.02	18.33,17.52	0.7	27.14	5.51
11-Apr-88	2.03	18.82,17.8	0.7	27.04	6.1
12-Apr-88	3.78	18.44,18	0.73	26.03	7.21
13-Apr-88	6.22	19.26,18.31	0.8	25.56	7.4
14-Apr-88	1.13	18.65,17.63	0.84	26.32	6.37
15-Apr-88	0	19.38,18.4	0.8	28.84	6.45
16-Apr-88	0	18.72,18.22	0.81	31.14	4.46
17-Apr-88	0.06	18.45,17.79	0.82	30.85	2.55
18-Apr-88	1.57	19.52,18.68	0.81	30.02	2.61
19-Apr-88	2.91	19.05,17.46	0.89	28.37	4.46
20-Apr-88	2.25	19.45,18.35	0.67	27.5	3.8
21-Apr-88	0.01	19.17,18.65	0.76	29.2	3
22-Apr-88	1.71	18.85,17.95	0.79	27.65	6.32
23-Apr-88	0.04	18.85,18.02	0.74	28.15	9.46
24-Apr-88	0.16	19.63,18.29	0.75	27.18	10.61
25-Apr-88	0	18.21,17.43	0.77	26.93	10.83
26-Apr-88	0.03	18.52,17.72	0.76	30.46	8.38
27-Apr-88	0.62	18.54,18.22	0.76	28.3	8.53
28-Apr-88	0.03	18.95,18.36	0.71	27.04	8.85
29-Apr-88	0.55	18.84,17.98	0.72	26.42	8.89
30-Apr-88	0	18.51,17.82	0.74	26.89	7.66
1-May-88	0.29	18.35,17.44	0.76	30.02	5.92
2-May-88	0	18.92,18.02	0.76	28.19	5.83
3-May-88	0.59	18.63,18.1	0.7	29.59	3.59
4-May-88	0.05	19.6,19.14	0.82	30.28	7.73
5-May-88	0	19.45,19.21	0.75	29.38	7.93
6-May-88	0.04	19.32,18.84	0.75	28.44	5.74
7-May-88	0	19.54,18.48	0.75	28.37	2.75
8-May-88	0.05	19.24,18.86	0.7	29.84	4.67
9-May-88	0.14	19.01,18.65	0.75	29.95	8.99
10-May-88	0.12	19.3,18.62	0.77	27.83	10.45
11-May-88	0	18.64,18.07	0.73	28.48	9.07

12-May-88	0	19.28,18.46	0.75	30.31	6.89
13-May-88	0	19.14,18.39	0.72	29.99	4.34
14-May-88	0	20.31,18.65	0.73	29.63	2.14
15-May-88	0	20.4,19.18	0.72	28.22	3.03
16-May-88	0	19.95,19.7	0.71	28.3	4.24
17-May-88	0	19.04,18.54	0.73	28.08	3.79
18-May-88	0	18.61,18.41	0.69	26.89	4.43
19-May-88	0	19.8,18.64	0.62	26.6	3.42
20-May-88	0.16	19.23,18.8	0.67	32.04	3.69
21-May-88	0	20.31,19.03	0.72	30.31	3.09
22-May-88	0	19.85,19.1	0.85	29.41	2.95
23-May-88	0	19.94,19.12	0.75	32.36	3.81
24-May-88	0	20.79,20.33	0.71	29.74	4.54
25-May-88	0	20.04,19.72	0.73	28.15	7.08
26-May-88	0	19.85,19.37	0.75	30.13	8.88
27-May-88	0	19.34,18.9	0.75	28.48	7.62
28-May-88	0	19.73,18.95	0.75	27.68	6.62
29-May-88	0	20.03,19.31	0.73	28.26	6.61
30-May-88	0	20.83,20.08	0.74	29.88	7.85
31-May-88	0	20.75,19.88	0.73	30.96	8.44
1-Jun-88	0	20.67,19.8	0.73	27.4	7.87
2-Jun-88	0	21.01,19.76	0.75	28.37	6.57
3-Jun-88	0	20.23,19.65	0.72	28.73	4.71
4-Jun-88	0	20,19.12	0.77	30.02	6.2
5-Jun-88	0	19.96,19.75	0.75	32.9	7.48
6-Jun-88	0	19.87,19.49	0.76	31.57	7.73
7-Jun-88	0	21.94,20.35	0.7	32.22	7.11
8-Jun-88	0	22.51,20.71	0.69	33.84	4.64
9-Jun-88	0.16	21.02,20.25	0.74	29.99	3.85
10-Jun-88	0.03	19.9,19.67	0.7	28.84	3.47
11-Jun-88	0	20.51,19.67	0.68	27.76	3.24
12-Jun-88	0	21.39,20.47	0.68	27.83	3.71
13-Jun-88	0	21.1,20.41	0.71	28.48	5.07
14-Jun-88	0	20.77,19.65	0.71	27.47	5.3
15-Jun-88	0	20.54,19.94	0.73	28.51	5.13
16-Jun-88	0	21.07,20.47	0.7	28.94	6.37
17-Jun-88	0	20.33,19.65	0.71	28.62	7.53
18-Jun-88	0	20.17,19.41	0.74	28.58	6.73
19-Jun-88	0	20.13,19.58	0.72	29.05	5.1
20-Jun-88	0.91	19.99,19.61	0.73	28.48	5.77
21-Jun-88	0.25	19.97,19.54	0.76	29.02	6.97
22-Jun-88	0.08	21.06,20.43	0.76	30.85	7.26
23-Jun-88	0	20.5,19.93	0.76	29.77	5.87
24-Jun-88	0	20.3,19.83	0.76	28.73	6.18

25-Jun-88	0	21.6,20.17	0.7	31.03	5.73
26-Jun-88	0	21.78,20.8	0.71	31.86	5.97
27-Jun-88	0	21.12,20.51	0.72	31.14	7.3
28-Jun-88	0	20.93,20.15	0.74	28.76	7.18
29-Jun-88	0	21.64,21.19	0.77	30.64	6.51
30-Jun-88	0	21.89,21.51	0.79	32.58	3.68
1-Jul-88	0	21.86,21.36	0.82	32.33	5.81
2-Jul-88	0	21.37,21.03	0.75	28.62	9.65
3-Jul-88	0	20.73,20.04	0.78	28.73	9.08
4-Jul-88	0	20.8,20.34	0.74	29.66	6.26
5-Jul-88	0	21.7,20.6	0.8	30.24	5.36
6-Jul-88	0	21.42,20.89	0.79	30.49	8.18
7-Jul-88	0	21.65,20.7	0.75	29.09	11.76
8-Jul-88	0	21.28,20.38	0.78	29.52	12.57
9-Jul-88	0	21.21,20.42	0.79	29.77	10.5
10-Jul-88	0	20.65,19.97	0.77	29.56	8.87
11-Jul-88	0	21.74,20.99	0.76	29.95	7.8
12-Jul-88	0	21,20.3	0.86	33.41	3.72
13-Jul-88	0	22.11,21.03	0.86	35.42	3.92
14-Jul-88	0	22.53,21.14	0.88	32.11	6.6
15-Jul-88	0	22.58,21.74	0.83	30.42	8.33
16-Jul-88	0	22.65,21.93	0.84	29.59	6.46
17-Jul-88	0	22.17,21.44	0.71	29.84	6.7
18-Jul-88	0	22.16,21.41	0.76	31.82	8.37
19-Jul-88	0	22.99,21.64	0.74	29.84	10.01
20-Jul-88	0	21.6,20.59	0.77	29.81	10
21-Jul-88	0	22.43,21.3	0.77	29.45	8.9
22-Jul-88	0	22.69,21.84	0.74	28.94	8.73
23-Jul-88	0	22.73,22.05	0.79	29.3	9.78
24-Jul-88	0	22.58,21.43	0.78	28.51	9.65
25-Jul-88	0	21.63,20.68	0.74	29.45	8.34
26-Jul-88	0	21.78,20.74	0.73	28.55	8.3
27-Jul-88	0	23.59,22.32	0.73	29.66	8.64
28-Jul-88	0	24.18,23.15	0.75	30.17	8.98
29-Jul-88	0	23.03,22.13	0.84	29.56	10.83
30-Jul-88	0	22.88,21.97	0.84	29.59	9.28
31-Jul-88	0	23.89,22.48	0.86	30.28	8.15
1-Aug-88	0	23.43,22.19	0.87	30.38	6.96
2-Aug-88	0.53	23.1,22.39	0.78	30.6	4.31
3-Aug-88	0.76	23.74,22.12	0.77	30.96	4.66
4-Aug-88	0	24.17,22.34	0.73	30.31	5.74
5-Aug-88	0	22.79,21.88	0.72	30.17	7.64
6-Aug-88	0	23.63,21.61	0.75	30.96	9.04
7-Aug-88	0	22.49,21.53	0.75	29.27	11.01

8-Aug-88	0	22.53,21.68	0.74	29.27	10.7
9-Aug-88	0	23.39,21.61	0.73	28.76	9.76
10-Aug-88	0	22.53,21.53	0.7	28.04	9.95
11-Aug-88	0	23.51,22.21	0.75	28.98	9.13
12-Aug-88	0	22.52,22.03	0.75	29.23	8.92
13-Aug-88	0	23.11,21.6	0.74	29.34	9.86
14-Aug-88	0	21.98,21.48	0.75	28.4	9.98
15-Aug-88	0	22.42,21.72	0.73	32.18	8.65
16-Aug-88	0	22.98,22.25	0.78	31.03	8.56
17-Aug-88	0	25,22.64	0.77	31.75	9
18-Aug-88	0	24.89,24.43	0.71	31.93	8.39
19-Aug-88	0	23.56,22.6	0.8	29.09	9.46
20-Aug-88	0	23.01,21.93	0.77	29.45	9.9
21-Aug-88	0	23,22.15	0.86	33.88	6.97
22-Aug-88	0	22.62,21.63	0.88	33.73	9.4
23-Aug-88	0	23.09,21.94	0.83	30.06	9.88
24-Aug-88	0	23.24,21.42	0.86	30.38	9.22
25-Aug-88	0	22.99,21.91	0.76	32.22	4.65
26-Aug-88	0	22.41,21.66	0.78	30.96	5.19
27-Aug-88	0	23.35,22	0.85	30.42	8.36
28-Aug-88	0	23.64,22.78	0.82	32.54	9.7
29-Aug-88	0	24.19,22.63	0.8	30.92	9.3
30-Aug-88	0	22.76,21.24	0.8	29.41	10.65
31-Aug-88	0	22.25,21.23	0.78	29.27	11.54
1-Sep-88	0	22.58,21.47	0.75	29.16	9.91
2-Sep-88	0	24.58,22.05	0.78	29.74	8.03
3-Sep-88	0	24.25,23.71	0.74	31.68	6.34
4-Sep-88	0	23.14,22.31	0.71	31.64	5.99
5-Sep-88	0	21.55,20.89	0.75	30.42	5.67
6-Sep-88	0	21.79,20.63	0.76	30.24	4.34
7-Sep-88	0	21.89,21.02	0.77	31.72	4.81
8-Sep-88	0	23.12,21.86	0.82	33.8	5.02
9-Sep-88	0	22.88,22.05	0.91	35.24	4.86
10-Sep-88	0	24.12,22.19	0.93	30.13	5.39
11-Sep-88	0	23.95,22.65	0.83	29.34	9.21
12-Sep-88	0	23.14,22.44	0.76	30.6	8.53
13-Sep-88	0	22.71,21.85	0.82	32.8	5.62
14-Sep-88	0	24.12,22.59	0.85	32.54	5.21
15-Sep-88	0	23.58,22.49	0.8	31.93	7.57
16-Sep-88	0	22.83,21.95	0.72	31.82	7.75
17-Sep-88	0	22.6,21.3	0.73	30.35	8.39
18-Sep-88	0	22.56,21.35	0.73	32.65	7.96
19-Sep-88	0	21.94,21.21	0.82	34.45	7.36
20-Sep-88	0	23.05,22.45	0.75	34.96	6.95

21-Sep-88	0	23.63,22.09	0.71	31.43	6.54
22-Sep-88	0	23.07,21.73	0.74	29.66	7.23
23-Sep-88	0	22.67,21.45	0.75	30.06	6.34
24-Sep-88	0	23.27,21.65	0.71	31.75	3.62
25-Sep-88	0	23.05,21.97	0.72	30.64	1.98
26-Sep-88	0	22.46,21.73	0.76	29.16	2.15
27-Sep-88	0	23.04,21.8	0.73	30.2	4.25
28-Sep-88	0	22.49,21.86	0.72	31.07	5.57
29-Sep-88	0	22.39,21.77	0.71	28.87	6.26
30-Sep-88	0	23.25,21.3	0.76	28.73	7.28
1-Oct-88	0	22.2,20.42	0.75	30.31	7.92
2-Oct-88	0.01	21.3,20.39	0.71	30.28	4.58
3-Oct-88	0.67	21.93,20.35	0.73	30.02	2.22
4-Oct-88	0.74	22.06,20.5	0.79	30.1	2.27
5-Oct-88	0.2	22.78,22.2	0.7	31.72	3.38
6-Oct-88	0.01	22.94,21.79	0.72	30.24	4.05
7-Oct-88	0	22.78,21.87	0.71	29.2	5.37
8-Oct-88	0	22.19,21.78	0.73	29.27	5.61
9-Oct-88	0	22.26,21.54	0.74	30.56	4.14
10-Oct-88	0	22.57,21.34	0.72	28.66	4.5
11-Oct-88	1.52	22.61,21.62	0.72	29.56	5.93
12-Oct-88	1.12	23.77,22.47	0.74	30.49	4.48
13-Oct-88	0.82	23.67,22.14	0.79	32.72	3.71
14-Oct-88	0.06	22.71,21.67	0.85	31.97	5.5
15-Oct-88	1.29	23.12,21.56	0.74	30.85	4.18
16-Oct-88	0	23.23,22.41	0.71	32.26	6.99
17-Oct-88	0	22.3,21.59	0.75	29.59	5.24
18-Oct-88	0	22.3,21.4	0.69	28.98	2.51
19-Oct-88	0	21.98,21.3	0.74	29.16	3.11
20-Oct-88	0	21.17,20.77	0.87	29.59	5.26
21-Oct-88	0	23.22,21.22	0.83	31.5	4.32
22-Oct-88	0	23.91,22.75	0.72	32.94	5.72
23-Oct-88	0	22.45,20.62	0.81	28.01	5.44
24-Oct-88	0	22.05,21.46	0.81	30.35	2.36
25-Oct-88	0	20.58,19.74	0.97	31.93	2.45
26-Oct-88	0	22.08,21.03	0.86	29.81	4.35
27-Oct-88	1.24	21.58,20.71	0.87	32.65	2.52
28-Oct-88	0	21.04,20.56	0.87	32.72	1.78
29-Oct-88	0.01	23.36,21.87	0.81	32.69	4.47
30-Oct-88	0.05	22.9,22.31	0.85	32.72	1.57
31-Oct-88	0.08	21.91,19.31	0.96	32.54	1.7
1-Nov-88	0.37	20.99,20.22	0.86	30.82	3.3
2-Nov-88	0.5	22.04,20.39	0.84	31.64	6.26
3-Nov-88	0.34	22.12,21.61	0.79	33.37	6.55

4-Nov-88	0	21.79,21.3	0.86	31.9	9.74
5-Nov-88	0	23.23,22.36	0.75	32	10.72
6-Nov-88	0	23.69,22.72	0.73	32.11	8.07
7-Nov-88	0	22.48,21.85	0.77	32.58	6.19
8-Nov-88	0	22.75,22.23	0.77	32.83	6.49
9-Nov-88	0	22.45,21.04	0.73	31.72	6.89
10-Nov-88	0	21.47,20.45	0.7	28.26	6.8
11-Nov-88	0	22.51,21.49	0.73	30.67	3.91
12-Nov-88	0	21.4,20.98	0.76	33.12	1.73
13-Nov-88	0	21.3,20.57	0.81	31.07	4.66
14-Nov-88	0	23.1,21.41	0.79	30.24	6.36
15-Nov-88	0	22.49,21.45	0.73	29.52	5.64
16-Nov-88	0	20.54,19.75	0.81	29.45	6.04
17-Nov-88	0	21.48,20.08	0.71	28.19	5.73
18-Nov-88	0.6	21.1,20.28	0.71	27.72	6.01
19-Nov-88	6.9	21.13,20.21	0.7	28.91	4.4
20-Nov-88	5.86	22.52,20.62	0.64	27.86	3.51
21-Nov-88	16.73	23.18,21.88	0.64	29.92	2.81
22-Nov-88	20.13	22.31,21.34	0.67	31.93	2
23-Nov-88	14.68	21.88,21.63	0.74	32.87	5.11
24-Nov-88	5.02	22.37,21.74	0.81	32.94	4.45
25-Nov-88	3.13	22.24,21.66	0.76	33.05	6.1
26-Nov-88	4.24	20.44,19.87	0.7	30.31	6.24
27-Nov-88	24.22	20.04,19.81	0.73	30.92	6.68
28-Nov-88	32.53	20.58,19.94	0.73	29.88	7.72
29-Nov-88	3.16	20.27,19.93	0.71	27.36	5.68
30-Nov-88	0.08	21.34,20.89	0.55	26.78	4.22
1-Dec-88	0	21.38,20.6	0.58	30.56	2.59
2-Dec-88	0	19.88,19.48	0.63	30.85	2.91
3-Dec-88	0	21.96,20.08	0.73	31.21	5.9
4-Dec-88	0	21.12,20.52	0.8	30.85	6.68
5-Dec-88	0	21.32,20.63	0.74	30.1	5.79
6-Dec-88	0.5	21.17,20.67	0.68	28.48	8.29
7-Dec-88	0.91	20.26,19.6	0.77	32.4	7.56
8-Dec-88	21.23	22.06,20.85	0.76	31.72	7.14
9-Dec-88	36.16	22.86,21.81	0.63	33.88	9.31
10-Dec-88	10.73	22.83,20.78	0.6	31.93	7.69
11-Dec-88	1.29	21.12,20.43	0.54	28.3	5.92
12-Dec-88	10.62	20.67,20.09	0.5	27.76	4.48
13-Dec-88	4.14	19.4,18.91	0.59	31.75	4.7
14-Dec-88	0.83	19.5,18.41	0.67	28.22	5.32
15-Dec-88	0	19.79,19.17	0.7	28.51	6.16
16-Dec-88	0	19.86,19	0.67	29.05	3.76
17-Dec-88	10.38	19.25,18.79	0.66	31.61	2.72

18-Dec-88	1.5	20.21,19.19	0.73	30.92	2.97
19-Dec-88	0	20.84,19.82	0.59	25.56	8.17
20-Dec-88	0.56	19.93,19.1	0.53	30.78	8.7
21-Dec-88	0.7	20.5,19.88	0.54	30.6	3.45
22-Dec-88	2.96	19.17,18.52	0.64	27.07	3.05
23-Dec-88	11.87	18.96,18.16	0.6	27.07	5.28
24-Dec-88	7.35	19,18.42	0.56	28.73	7.96
25-Dec-88	14.59	21.13,19.03	0.46	25.16	7.61
26-Dec-88	17.36	21.31,20.33	0.58	26.35	9.88
27-Dec-88	22.78	20.93,20.17	0.68	32.04	6.48
28-Dec-88	20.62	19.6,18.91	0.74	29.84	3.35
29-Dec-88	18.29	20.21,18.98	0.72	26.93	4.87
30-Dec-88	16.89	21.21,19.79	0.6	26.14	10.28
31-Dec-88	14.31	20.81,19.55	0.59	29.88	11.6

APPENDIX E : Format for Observed Discharge Data used in regionalized Calibration and Validation of water flows at Chimbumbu Gauging Station of Magoye basin

How to select data to be pasted in SWATCUP

ID	DAILY OBSERVED VALUES (Observed_rch.txt)			Month	Year	Time	DAILY observed values 2016-2016 -> 6575	
	FLOW_OUT_SERIES	FLOW_OUT	Day (Julian)				FLOW_OUT	GH (m)
1	FLOW_OUT_001_2016	0.000	001	1	2016	1-Jan-16	0	0.39
2	FLOW_OUT_002_2016	2.010	002	1	2016	2-Jan-16	2.01	0.48
3	FLOW_OUT_003_2016	2.730	003	1	2016	3-Jan-16	2.73	0.51
4	FLOW_OUT_004_2016	2.400	004	1	2016	4-Jan-16	2.4	0.49
5	FLOW_OUT_005_2016	3.480	005	1	2016	5-Jan-16	3.48	0.54
6	FLOW_OUT_006_2016	3.480	006	1	2016	6-Jan-16	3.48	0.54
7	FLOW_OUT_007_2016	2.790	007	1	2016	7-Jan-16	2.79	0.51
8	FLOW_OUT_008_2016	2.640	008	1	2016	8-Jan-16	2.64	0.50
9	FLOW_OUT_009_2016	3.100	009	1	2016	9-Jan-16	3.1	0.52
10	FLOW_OUT_010_2016	2.680	010	1	2016	10-Jan-16	2.68	0.51
11	FLOW_OUT_011_2016	3.010	011	1	2016	11-Jan-16	3.01	0.52
12	FLOW_OUT_012_2016	4.400	012	1	2016	12-Jan-16	4.4	0.58
13	FLOW_OUT_013_2016	2.650	013	1	2016	13-Jan-16	2.65	0.50
14	FLOW_OUT_014_2016	2.400	014	1	2016	14-Jan-16	2.4	0.49
15	FLOW_OUT_015_2016	3.240	015	1	2016	15-Jan-16	3.24	0.53
16	FLOW_OUT_016_2016	4.330	016	1	2016	16-Jan-16	4.33	0.58
17	FLOW_OUT_017_2016	2.950	017	1	2016	17-Jan-16	2.95	0.52
18	FLOW_OUT_018_2016	3.450	018	1	2016	18-Jan-16	3.45	0.54
19	FLOW_OUT_019_2016	3.770	019	1	2016	19-Jan-16	3.77	0.55
20	FLOW_OUT_020_2016	2.620	020	1	2016	20-Jan-16	2.62	0.50
21	FLOW_OUT_021_2016	3.570	021	1	2016	21-Jan-16	3.57	0.55
22	FLOW_OUT_022_2016	3.350	022	1	2016	22-Jan-16	3.35	0.54
23	FLOW_OUT_023_2016	3.090	023	1	2016	23-Jan-16	3.09	0.52
24	FLOW_OUT_024_2016	2.870	024	1	2016	24-Jan-16	2.87	0.51
25	FLOW_OUT_025_2016	3.740	025	1	2016	25-Jan-16	3.74	0.55
26	FLOW_OUT_026_2016	2.700	026	1	2016	26-Jan-16	2.7	0.51
27	FLOW_OUT_027_2016	2.690	027	1	2016	27-Jan-16	2.69	0.51
28	FLOW_OUT_028_2016	4.700	028	1	2016	28-Jan-16	4.7	0.60
29	FLOW_OUT_029_2016	2.710	029	1	2016	29-Jan-16	2.71	0.51
30	FLOW_OUT_030_2016	3.720	030	1	2016	30-Jan-16	3.72	0.55
31	FLOW_OUT_031_2016	2.730	031	1	2016	31-Jan-16	2.73	0.51
32	FLOW_OUT_032_2016	3.740	032	2	2016	1-Feb-16	3.74	0.55
33	FLOW_OUT_033_2016	2.750	033	2	2016	2-Feb-16	2.75	0.51
34	FLOW_OUT_034_2016	2.760	034	2	2016	3-Feb-16	2.76	0.51
35	FLOW_OUT_035_2016	2.760	035	2	2016	4-Feb-16	2.76	0.51
36	FLOW_OUT_036_2016	3.780	036	2	2016	5-Feb-16	3.78	0.56
37	FLOW_OUT_037_2016	3.480	037	2	2016	6-Feb-16	3.48	0.54
38	FLOW_OUT_038_2016	3.290	038	2	2016	7-Feb-16	3.29	0.53
39	FLOW_OUT_039_2016	3.030	039	2	2016	8-Feb-16	3.03	0.52

40	FLOW_OUT_040_2016	3.170	040	2	2016	9-Feb-16	3.17	0.53
41	FLOW_OUT_041_2016	3.100	041	2	2016	10-Feb-16	3.1	0.52
42	FLOW_OUT_042_2016	4.450	042	2	2016	11-Feb-16	4.45	0.59
43	FLOW_OUT_043_2016	4.400	043	2	2016	12-Feb-16	4.4	0.58
44	FLOW_OUT_044_2016	3.510	044	2	2016	13-Feb-16	3.51	0.54
45	FLOW_OUT_045_2016	3.200	045	2	2016	14-Feb-16	3.2	0.53
46	FLOW_OUT_046_2016	3.180	046	2	2016	15-Feb-16	3.18	0.53
47	FLOW_OUT_047_2016	3.070	047	2	2016	16-Feb-16	3.07	0.52
48	FLOW_OUT_048_2016	3.030	048	2	2016	17-Feb-16	3.03	0.52
49	FLOW_OUT_049_2016	3.020	049	2	2016	18-Feb-16	3.02	0.52
50	FLOW_OUT_050_2016	3.020	050	2	2016	19-Feb-16	3.02	0.52
51	FLOW_OUT_051_2016	3.020	051	2	2016	20-Feb-16	3.02	0.52
52	FLOW_OUT_052_2016	3.480	052	2	2016	21-Feb-16	3.48	0.54
53	FLOW_OUT_053_2016	3.120	053	2	2016	22-Feb-16	3.12	0.53
54	FLOW_OUT_054_2016	3.500	054	2	2016	23-Feb-16	3.5	0.54
55	FLOW_OUT_055_2016	3.070	055	2	2016	24-Feb-16	3.07	0.52
56	FLOW_OUT_056_2016	3.060	056	2	2016	25-Feb-16	3.06	0.52
57	FLOW_OUT_057_2016	3.050	057	2	2016	26-Feb-16	3.05	0.52
58	FLOW_OUT_058_2016	3.050	058	2	2016	27-Feb-16	3.05	0.52
59	FLOW_OUT_059_2016	3.060	059	2	2016	28-Feb-16	3.06	0.52
60	FLOW_OUT_060_2016	5.060	060	2	2016	29-Feb-16	5.06	0.61
61	FLOW_OUT_061_2016	3.060	061	3	2016	1-Mar-16	3.06	0.52
62	FLOW_OUT_062_2016	3.060	062	3	2016	2-Mar-16	3.06	0.52
63	FLOW_OUT_063_2016	3.060	063	3	2016	3-Mar-16	3.06	0.52
64	FLOW_OUT_064_2016	3.030	064	3	2016	4-Mar-16	3.03	0.52
65	FLOW_OUT_065_2016	3.130	065	3	2016	5-Mar-16	3.13	0.53
66	FLOW_OUT_066_2016	3.010	066	3	2016	6-Mar-16	3.01	0.52
67	FLOW_OUT_067_2016	3.950	067	3	2016	7-Mar-16	3.95	0.56
68	FLOW_OUT_068_2016	4.930	068	3	2016	8-Mar-16	4.93	0.61
69	FLOW_OUT_069_2016	3.920	069	3	2016	9-Mar-16	3.92	0.56
70	FLOW_OUT_070_2016	3.920	070	3	2016	10-Mar-16	3.92	0.56
71	FLOW_OUT_071_2016	3.910	071	3	2016	11-Mar-16	3.91	0.56
72	FLOW_OUT_072_2016	4.910	072	3	2016	12-Mar-16	4.91	0.61
73	FLOW_OUT_073_2016	2.910	073	3	2016	13-Mar-16	2.91	0.52
74	FLOW_OUT_074_2016	3.900	074	3	2016	14-Mar-16	3.9	0.56
75	FLOW_OUT_075_2016	4.900	075	3	2016	15-Mar-16	4.9	0.61
76	FLOW_OUT_076_2016	2.900	076	3	2016	16-Mar-16	2.9	0.52
77	FLOW_OUT_077_2016	3.900	077	3	2016	17-Mar-16	3.9	0.56
78	FLOW_OUT_078_2016	3.890	078	3	2016	18-Mar-16	3.89	0.56
79	FLOW_OUT_079_2016	3.890	079	3	2016	19-Mar-16	3.89	0.56
80	FLOW_OUT_080_2016	2.890	080	3	2016	20-Mar-16	2.89	0.52
81	FLOW_OUT_081_2016	2.890	081	3	2016	21-Mar-16	2.89	0.52
82	FLOW_OUT_082_2016	2.880	082	3	2016	22-Mar-16	2.88	0.51

83	FLOW_OUT_083_2016	2.870	083	3	2016	23-Mar-16	2.87	0.51
84	FLOW_OUT_084_2016	2.870	084	3	2016	24-Mar-16	2.87	0.51
85	FLOW_OUT_085_2016	2.870	085	3	2016	25-Mar-16	2.87	0.51
86	FLOW_OUT_086_2016	2.860	086	3	2016	26-Mar-16	2.86	0.51
87	FLOW_OUT_087_2016	4.860	087	3	2016	27-Mar-16	4.86	0.60
88	FLOW_OUT_088_2016	2.860	088	3	2016	28-Mar-16	2.86	0.51
89	FLOW_OUT_089_2016	2.850	089	3	2016	29-Mar-16	2.85	0.51
90	FLOW_OUT_090_2016	2.840	090	3	2016	30-Mar-16	2.84	0.51
91	FLOW_OUT_091_2016	3.840	091	3	2016	31-Mar-16	3.84	0.56
92	FLOW_OUT_092_2016	2.840	092	4	2016	1-Apr-16	2.84	0.51
93	FLOW_OUT_093_2016	3.830	093	4	2016	2-Apr-16	3.83	0.56
94	FLOW_OUT_094_2016	2.830	094	4	2016	3-Apr-16	2.83	0.51
95	FLOW_OUT_095_2016	3.820	095	4	2016	4-Apr-16	3.82	0.56
96	FLOW_OUT_096_2016	3.810	096	4	2016	5-Apr-16	3.81	0.56
97	FLOW_OUT_097_2016	3.810	097	4	2016	6-Apr-16	3.81	0.56
98	FLOW_OUT_098_2016	3.800	098	4	2016	7-Apr-16	3.8	0.56
99	FLOW_OUT_099_2016	3.800	099	4	2016	8-Apr-16	3.8	0.56
100	FLOW_OUT_100_2016	1.800	100	4	2016	9-Apr-16	1.8	0.47
101	FLOW_OUT_101_2016	3.790	101	4	2016	10-Apr-16	3.79	0.56
102	FLOW_OUT_102_2016	2.780	102	4	2016	11-Apr-16	2.78	0.51
103	FLOW_OUT_103_2016	2.780	103	4	2016	12-Apr-16	2.78	0.51
104	FLOW_OUT_104_2016	2.770	104	4	2016	13-Apr-16	2.77	0.51
105	FLOW_OUT_105_2016	2.770	105	4	2016	14-Apr-16	2.77	0.51
106	FLOW_OUT_106_2016	2.760	106	4	2016	15-Apr-16	2.76	0.51
107	FLOW_OUT_107_2016	2.750	107	4	2016	16-Apr-16	2.75	0.51
108	FLOW_OUT_108_2016	2.750	108	4	2016	17-Apr-16	2.75	0.51
109	FLOW_OUT_109_2016	2.740	109	4	2016	18-Apr-16	2.74	0.51
110	FLOW_OUT_110_2016	2.740	110	4	2016	19-Apr-16	2.74	0.51
111	FLOW_OUT_111_2016	2.730	111	4	2016	20-Apr-16	2.73	0.51
112	FLOW_OUT_112_2016	2.720	112	4	2016	21-Apr-16	2.72	0.51
113	FLOW_OUT_113_2016	2.720	113	4	2016	22-Apr-16	2.72	0.51
114	FLOW_OUT_114_2016	2.710	114	4	2016	23-Apr-16	2.71	0.51
115	FLOW_OUT_115_2016	2.710	115	4	2016	24-Apr-16	2.71	0.51
116	FLOW_OUT_116_2016	2.690	116	4	2016	25-Apr-16	2.69	0.51
117	FLOW_OUT_117_2016	2.690	117	4	2016	26-Apr-16	2.69	0.51
118	FLOW_OUT_118_2016	2.680	118	4	2016	27-Apr-16	2.68	0.51
119	FLOW_OUT_119_2016	2.680	119	4	2016	28-Apr-16	2.68	0.51
120	FLOW_OUT_120_2016	2.670	120	4	2016	29-Apr-16	2.67	0.51
121	FLOW_OUT_121_2016	2.660	121	4	2016	30-Apr-16	2.66	0.50
122	FLOW_OUT_122_2016	2.660	122	5	2016	1-May-16	2.66	0.50
123	FLOW_OUT_123_2016	2.650	123	5	2016	2-May-16	2.65	0.50
124	FLOW_OUT_124_2016	2.650	124	5	2016	3-May-16	2.65	0.50
125	FLOW_OUT_125_2016	2.640	125	5	2016	4-May-16	2.64	0.50

126	FLOW_OUT_126_2016	2.630	126	5	2016	5-May-16	2.63	0.50
127	FLOW_OUT_127_2016	1.620	127	5	2016	6-May-16	1.62	0.46
128	FLOW_OUT_128_2016	1.620	128	5	2016	7-May-16	1.62	0.46
129	FLOW_OUT_129_2016	1.610	129	5	2016	8-May-16	1.61	0.46
130	FLOW_OUT_130_2016	1.600	130	5	2016	9-May-16	1.6	0.46
131	FLOW_OUT_131_2016	1.690	131	5	2016	10-May-16	1.69	0.46
132	FLOW_OUT_132_2016	1.680	132	5	2016	11-May-16	1.68	0.46
133	FLOW_OUT_133_2016	1.680	133	5	2016	12-May-16	1.68	0.46
134	FLOW_OUT_134_2016	1.670	134	5	2016	13-May-16	1.67	0.46
135	FLOW_OUT_135_2016	1.660	135	5	2016	14-May-16	1.66	0.46
136	FLOW_OUT_136_2016	1.650	136	5	2016	15-May-16	1.65	0.46
137	FLOW_OUT_137_2016	1.640	137	5	2016	16-May-16	1.64	0.46
138	FLOW_OUT_138_2016	1.640	138	5	2016	17-May-16	1.64	0.46
139	FLOW_OUT_139_2016	1.630	139	5	2016	18-May-16	1.63	0.46
140	FLOW_OUT_140_2016	1.620	140	5	2016	19-May-16	1.62	0.46
141	FLOW_OUT_141_2016	1.600	141	5	2016	20-May-16	1.6	0.46
142	FLOW_OUT_142_2016	1.580	142	5	2016	21-May-16	1.58	0.46
143	FLOW_OUT_143_2016	1.570	143	5	2016	22-May-16	1.57	0.46
144	FLOW_OUT_144_2016	1.560	144	5	2016	23-May-16	1.56	0.46
145	FLOW_OUT_145_2016	1.550	145	5	2016	24-May-16	1.55	0.45
146	FLOW_OUT_146_2016	1.530	146	5	2016	25-May-16	1.53	0.45
147	FLOW_OUT_147_2016	1.510	147	5	2016	26-May-16	1.51	0.45
148	FLOW_OUT_148_2016	1.500	148	5	2016	27-May-16	1.5	0.45
149	FLOW_OUT_149_2016	1.490	149	5	2016	28-May-16	1.49	0.45
150	FLOW_OUT_150_2016	1.470	150	5	2016	29-May-16	1.47	0.45
151	FLOW_OUT_151_2016	1.440	151	5	2016	30-May-16	1.44	0.45
152	FLOW_OUT_152_2016	1.430	152	5	2016	31-May-16	1.43	0.45
153	FLOW_OUT_153_2016	1.410	153	6	2016	1-Jun-16	1.41	0.45
154	FLOW_OUT_154_2016	1.390	154	6	2016	2-Jun-16	1.39	0.45
155	FLOW_OUT_155_2016	0.310	155	6	2016	3-Jun-16	0.31	0.40
156	FLOW_OUT_156_2016	0.270	156	6	2016	4-Jun-16	0.27	0.40
157	FLOW_OUT_157_2016	0.260	157	6	2016	5-Jun-16	0.26	0.40
158	FLOW_OUT_158_2016	0.250	158	6	2016	6-Jun-16	0.25	0.40
159	FLOW_OUT_159_2016	0.240	159	6	2016	7-Jun-16	0.24	0.40
160	FLOW_OUT_160_2016	0.210	160	6	2016	8-Jun-16	0.21	0.39
161	FLOW_OUT_161_2016	0.160	161	6	2016	9-Jun-16	0.16	0.39
162	FLOW_OUT_162_2016	0.080	162	6	2016	10-Jun-16	0.08	0.39
163	FLOW_OUT_163_2016	0.060	163	6	2016	11-Jun-16	0.06	0.39
164	FLOW_OUT_164_2016	0.060	164	6	2016	12-Jun-16	0.06	0.39
165	FLOW_OUT_165_2016	0.030	165	6	2016	13-Jun-16	0.03	0.39
166	FLOW_OUT_166_2016	0.040	166	6	2016	14-Jun-16	0.04	0.39
167	FLOW_OUT_167_2016	0.010	167	6	2016	15-Jun-16	0.01	0.39
168	FLOW_OUT_168_2016	0.000	168	6	2016	16-Jun-16	0	0.39

169	FLOW_OUT_169_2016	0.000	169	6	2016	17-Jun-16	0	0.39
170	FLOW_OUT_170_2016	0.000	170	6	2016	18-Jun-16	0	0.39
171	FLOW_OUT_171_2016	0.000	171	6	2016	19-Jun-16	0	0.39
172	FLOW_OUT_172_2016	0.000	172	6	2016	20-Jun-16	0	0.39
173	FLOW_OUT_173_2016	0.000	173	6	2016	21-Jun-16	0	0.39
174	FLOW_OUT_174_2016	0.000	174	6	2016	22-Jun-16	0	0.39
175	FLOW_OUT_175_2016	0.000	175	6	2016	23-Jun-16	0	0.39
176	FLOW_OUT_176_2016	0.000	176	6	2016	24-Jun-16	0	0.39
177	FLOW_OUT_177_2016	0.000	177	6	2016	25-Jun-16	0	0.39
178	FLOW_OUT_178_2016	0.000	178	6	2016	26-Jun-16	0	0.39
179	FLOW_OUT_179_2016	0.000	179	6	2016	27-Jun-16	0	0.39
180	FLOW_OUT_180_2016	0.000	180	6	2016	28-Jun-16	0	0.39
181	FLOW_OUT_181_2016	0.000	181	6	2016	29-Jun-16	0	0.39
182	FLOW_OUT_182_2016	0.000	182	6	2016	30-Jun-16	0	0.39
183	FLOW_OUT_183_2016	0.000	183	7	2016	1-Jul-16	0	0.39
184	FLOW_OUT_184_2016	0.000	184	7	2016	2-Jul-16	0	0.39
185	FLOW_OUT_185_2016	0.000	185	7	2016	3-Jul-16	0	0.39
186	FLOW_OUT_186_2016	0.000	186	7	2016	4-Jul-16	0	0.39
187	FLOW_OUT_187_2016	0.000	187	7	2016	5-Jul-16	0	0.39
188	FLOW_OUT_188_2016	0.000	188	7	2016	6-Jul-16	0	0.39
189	FLOW_OUT_189_2016	0.000	189	7	2016	7-Jul-16	0	0.39
190	FLOW_OUT_190_2016	0.000	190	7	2016	8-Jul-16	0	0.39
191	FLOW_OUT_191_2016	0.000	191	7	2016	9-Jul-16	0	0.39
192	FLOW_OUT_192_2016	0.000	192	7	2016	10-Jul-16	0	0.39
193	FLOW_OUT_193_2016	0.000	193	7	2016	11-Jul-16	0	0.39
194	FLOW_OUT_194_2016	0.000	194	7	2016	12-Jul-16	0	0.39
195	FLOW_OUT_195_2016	0.000	195	7	2016	13-Jul-16	0	0.39
196	FLOW_OUT_196_2016	0.000	196	7	2016	14-Jul-16	0	0.39
197	FLOW_OUT_197_2016	0.000	197	7	2016	15-Jul-16	0	0.39
198	FLOW_OUT_198_2016	0.000	198	7	2016	16-Jul-16	0	0.39
199	FLOW_OUT_199_2016	0.000	199	7	2016	17-Jul-16	0	0.39
200	FLOW_OUT_200_2016	0.000	200	7	2016	18-Jul-16	0	0.39
201	FLOW_OUT_201_2016	0.000	201	7	2016	19-Jul-16	0	0.39
202	FLOW_OUT_202_2016	0.000	202	7	2016	20-Jul-16	0	0.39
203	FLOW_OUT_203_2016	0.000	203	7	2016	21-Jul-16	0	0.39
204	FLOW_OUT_204_2016	0.000	204	7	2016	22-Jul-16	0	0.39
205	FLOW_OUT_205_2016	0.000	205	7	2016	23-Jul-16	0	0.39
206	FLOW_OUT_206_2016	0.000	206	7	2016	24-Jul-16	0	0.39
207	FLOW_OUT_207_2016	0.000	207	7	2016	25-Jul-16	0	0.39
208	FLOW_OUT_208_2016	0.000	208	7	2016	26-Jul-16	0	0.39
209	FLOW_OUT_209_2016	0.000	209	7	2016	27-Jul-16	0	0.39
210	FLOW_OUT_210_2016	0.000	210	7	2016	28-Jul-16	0	0.39
211	FLOW_OUT_211_2016	0.000	211	7	2016	29-Jul-16	0	0.39

212	FLOW_OUT_212_2016	0.000	212	7	2016	30-Jul-16	0	0.39
213	FLOW_OUT_213_2016	0.000	213	7	2016	31-Jul-16	0	0.39
214	FLOW_OUT_214_2016	0.000	214	8	2016	1-Aug-16	0	0.39
215	FLOW_OUT_215_2016	0.000	215	8	2016	2-Aug-16	0	0.39
216	FLOW_OUT_216_2016	0.000	216	8	2016	3-Aug-16	0	0.39
217	FLOW_OUT_217_2016	0.000	217	8	2016	4-Aug-16	0	0.39
218	FLOW_OUT_218_2016	0.000	218	8	2016	5-Aug-16	0	0.39
219	FLOW_OUT_219_2016	0.000	219	8	2016	6-Aug-16	0	0.39
220	FLOW_OUT_220_2016	0.000	220	8	2016	7-Aug-16	0	0.39
221	FLOW_OUT_221_2016	0.000	221	8	2016	8-Aug-16	0	0.39
222	FLOW_OUT_222_2016	0.000	222	8	2016	9-Aug-16	0	0.39
223	FLOW_OUT_223_2016	0.000	223	8	2016	10-Aug-16	0	0.39
224	FLOW_OUT_224_2016	0.000	224	8	2016	11-Aug-16	0	0.39
225	FLOW_OUT_225_2016	0.000	225	8	2016	12-Aug-16	0	0.39
226	FLOW_OUT_226_2016	0.000	226	8	2016	13-Aug-16	0	0.39
227	FLOW_OUT_227_2016	0.000	227	8	2016	14-Aug-16	0	0.39
228	FLOW_OUT_228_2016	0.000	228	8	2016	15-Aug-16	0	0.39
229	FLOW_OUT_229_2016	0.000	229	8	2016	16-Aug-16	0	0.39
230	FLOW_OUT_230_2016	0.000	230	8	2016	17-Aug-16	0	0.39
231	FLOW_OUT_231_2016	0.000	231	8	2016	18-Aug-16	0	0.39
232	FLOW_OUT_232_2016	0.000	232	8	2016	19-Aug-16	0	0.39
233	FLOW_OUT_233_2016	0.000	233	8	2016	20-Aug-16	0	0.39
234	FLOW_OUT_234_2016	0.000	234	8	2016	21-Aug-16	0	0.39
235	FLOW_OUT_235_2016	0.000	235	8	2016	22-Aug-16	0	0.39
236	FLOW_OUT_236_2016	0.000	236	8	2016	23-Aug-16	0	0.39
237	FLOW_OUT_237_2016	0.000	237	8	2016	24-Aug-16	0	0.39
238	FLOW_OUT_238_2016	0.000	238	8	2016	25-Aug-16	0	0.39
239	FLOW_OUT_239_2016	0.000	239	8	2016	26-Aug-16	0	0.39
240	FLOW_OUT_240_2016	0.000	240	8	2016	27-Aug-16	0	0.39
241	FLOW_OUT_241_2016	0.000	241	8	2016	28-Aug-16	0	0.39
242	FLOW_OUT_242_2016	0.000	242	8	2016	29-Aug-16	0	0.39
243	FLOW_OUT_243_2016	0.000	243	8	2016	30-Aug-16	0	0.39
244	FLOW_OUT_244_2016	0.000	244	8	2016	31-Aug-16	0	0.39
245	FLOW_OUT_245_2016	0.000	245	9	2016	1-Sep-16	0	0.39
246	FLOW_OUT_246_2016	0.000	246	9	2016	2-Sep-16	0	0.39
247	FLOW_OUT_247_2016	0.000	247	9	2016	3-Sep-16	0	0.39
248	FLOW_OUT_248_2016	0.000	248	9	2016	4-Sep-16	0	0.39
249	FLOW_OUT_249_2016	0.000	249	9	2016	5-Sep-16	0	0.39
250	FLOW_OUT_250_2016	0.000	250	9	2016	6-Sep-16	0	0.39
251	FLOW_OUT_251_2016	0.000	251	9	2016	7-Sep-16	0	0.39
252	FLOW_OUT_252_2016	0.000	252	9	2016	8-Sep-16	0	0.39
253	FLOW_OUT_253_2016	0.000	253	9	2016	9-Sep-16	0	0.39
254	FLOW_OUT_254_2016	0.000	254	9	2016	10-Sep-16	0	0.39

255	FLOW_OUT_255_2016	0.000	255	9	2016	11-Sep-16	0	0.39
256	FLOW_OUT_256_2016	0.000	256	9	2016	12-Sep-16	0	0.39
257	FLOW_OUT_257_2016	0.000	257	9	2016	13-Sep-16	0	0.39
258	FLOW_OUT_258_2016	0.000	258	9	2016	14-Sep-16	0	0.39
259	FLOW_OUT_259_2016	0.000	259	9	2016	15-Sep-16	0	0.39
260	FLOW_OUT_260_2016	0.000	260	9	2016	16-Sep-16	0	0.39
261	FLOW_OUT_261_2016	0.000	261	9	2016	17-Sep-16	0	0.39
262	FLOW_OUT_262_2016	0.000	262	9	2016	18-Sep-16	0	0.39
263	FLOW_OUT_263_2016	0.000	263	9	2016	19-Sep-16	0	0.39
264	FLOW_OUT_264_2016	0.000	264	9	2016	20-Sep-16	0	0.39
265	FLOW_OUT_265_2016	0.000	265	9	2016	21-Sep-16	0	0.39
266	FLOW_OUT_266_2016	0.000	266	9	2016	22-Sep-16	0	0.39
267	FLOW_OUT_267_2016	0.000	267	9	2016	23-Sep-16	0	0.39
268	FLOW_OUT_268_2016	0.000	268	9	2016	24-Sep-16	0	0.39
269	FLOW_OUT_269_2016	0.000	269	9	2016	25-Sep-16	0	0.39
270	FLOW_OUT_270_2016	0.000	270	9	2016	26-Sep-16	0	0.39
271	FLOW_OUT_271_2016	0.000	271	9	2016	27-Sep-16	0	0.39
272	FLOW_OUT_272_2016	0.000	272	9	2016	28-Sep-16	0	0.39
273	FLOW_OUT_273_2016	0.000	273	9	2016	29-Sep-16	0	0.39
274	FLOW_OUT_274_2016	0.000	274	9	2016	30-Sep-16	0	0.39
275	FLOW_OUT_275_2016	0.000	275	10	2016	1-Oct-16	0	0.39
276	FLOW_OUT_276_2016	0.000	276	10	2016	2-Oct-16	0	0.39
277	FLOW_OUT_277_2016	0.000	277	10	2016	3-Oct-16	0	0.39
278	FLOW_OUT_278_2016	0.000	278	10	2016	4-Oct-16	0	0.39
279	FLOW_OUT_279_2016	0.000	279	10	2016	5-Oct-16	0	0.39
280	FLOW_OUT_280_2016	0.000	280	10	2016	6-Oct-16	0	0.39
281	FLOW_OUT_281_2016	0.000	281	10	2016	7-Oct-16	0	0.39
282	FLOW_OUT_282_2016	0.000	282	10	2016	8-Oct-16	0	0.39
283	FLOW_OUT_283_2016	0.000	283	10	2016	9-Oct-16	0	0.39
284	FLOW_OUT_284_2016	0.000	284	10	2016	10-Oct-16	0	0.39
285	FLOW_OUT_285_2016	0.000	285	10	2016	11-Oct-16	0	0.39
286	FLOW_OUT_286_2016	0.000	286	10	2016	12-Oct-16	0	0.39
287	FLOW_OUT_287_2016	0.000	287	10	2016	13-Oct-16	0	0.39
288	FLOW_OUT_288_2016	0.000	288	10	2016	14-Oct-16	0	0.39
289	FLOW_OUT_289_2016	0.000	289	10	2016	15-Oct-16	0	0.39
290	FLOW_OUT_290_2016	0.000	290	10	2016	16-Oct-16	0	0.39
291	FLOW_OUT_291_2016	0.000	291	10	2016	17-Oct-16	0	0.39
292	FLOW_OUT_292_2016	0.000	292	10	2016	18-Oct-16	0	0.39
293	FLOW_OUT_293_2016	0.000	293	10	2016	19-Oct-16	0	0.39
294	FLOW_OUT_294_2016	0.000	294	10	2016	20-Oct-16	0	0.39
295	FLOW_OUT_295_2016	0.000	295	10	2016	21-Oct-16	0	0.39
296	FLOW_OUT_296_2016	0.000	296	10	2016	22-Oct-16	0	0.39
297	FLOW_OUT_297_2016	0.000	297	10	2016	23-Oct-16	0	0.39

298	FLOW_OUT_298_2016	0.000	298	10	2016	24-Oct-16	0	0.39
299	FLOW_OUT_299_2016	0.000	299	10	2016	25-Oct-16	0	0.39
300	FLOW_OUT_300_2016	0.000	300	10	2016	26-Oct-16	0	0.39
301	FLOW_OUT_301_2016	0.000	301	10	2016	27-Oct-16	0	0.39
302	FLOW_OUT_302_2016	0.000	302	10	2016	28-Oct-16	0	0.39
303	FLOW_OUT_303_2016	0.000	303	10	2016	29-Oct-16	0	0.39
304	FLOW_OUT_304_2016	0.000	304	10	2016	30-Oct-16	0	0.39
305	FLOW_OUT_305_2016	0.000	305	10	2016	31-Oct-16	0	0.39
306	FLOW_OUT_306_2016	0.000	306	11	2016	1-Nov-16	0	0.39
307	FLOW_OUT_307_2016	0.000	307	11	2016	2-Nov-16	0	0.39
308	FLOW_OUT_308_2016	0.000	308	11	2016	3-Nov-16	0	0.39
309	FLOW_OUT_309_2016	0.000	309	11	2016	4-Nov-16	0	0.39
310	FLOW_OUT_310_2016	0.000	310	11	2016	5-Nov-16	0	0.39
311	FLOW_OUT_311_2016	0.000	311	11	2016	6-Nov-16	0	0.39
312	FLOW_OUT_312_2016	0.000	312	11	2016	7-Nov-16	0	0.39
313	FLOW_OUT_313_2016	0.000	313	11	2016	8-Nov-16	0	0.39
314	FLOW_OUT_314_2016	0.000	314	11	2016	9-Nov-16	0	0.39
315	FLOW_OUT_315_2016	0.000	315	11	2016	10-Nov-16	0	0.39
316	FLOW_OUT_316_2016	0.000	316	11	2016	11-Nov-16	0	0.39
317	FLOW_OUT_317_2016	0.000	317	11	2016	12-Nov-16	0	0.39
318	FLOW_OUT_318_2016	0.000	318	11	2016	13-Nov-16	0	0.39
319	FLOW_OUT_319_2016	0.000	319	11	2016	14-Nov-16	0	0.39
320	FLOW_OUT_320_2016	0.000	320	11	2016	15-Nov-16	0	0.39
321	FLOW_OUT_321_2016	0.000	321	11	2016	16-Nov-16	0	0.39
322	FLOW_OUT_322_2016	0.000	322	11	2016	17-Nov-16	0	0.39
323	FLOW_OUT_323_2016	0.000	323	11	2016	18-Nov-16	0	0.39
324	FLOW_OUT_324_2016	0.000	324	11	2016	19-Nov-16	0	0.39
325	FLOW_OUT_325_2016	0.000	325	11	2016	20-Nov-16	0	0.39
326	FLOW_OUT_326_2016	0.000	326	11	2016	21-Nov-16	0	0.39
327	FLOW_OUT_327_2016	0.000	327	11	2016	22-Nov-16	0	0.39
328	FLOW_OUT_328_2016	0.000	328	11	2016	23-Nov-16	0	0.39
329	FLOW_OUT_329_2016	0.000	329	11	2016	24-Nov-16	0	0.39
330	FLOW_OUT_330_2016	0.000	330	11	2016	25-Nov-16	0	0.39
331	FLOW_OUT_331_2016	0.640	331	11	2016	26-Nov-16	0.64	0.41
332	FLOW_OUT_332_2016	2.100	332	11	2016	27-Nov-16	2.1	0.48
333	FLOW_OUT_333_2016	1.700	333	11	2016	28-Nov-16	1.7	0.46
334	FLOW_OUT_334_2016	0.000	334	11	2016	29-Nov-16	0	0.39
335	FLOW_OUT_335_2016	0.000	335	11	2016	30-Nov-16	0	0.39
336	FLOW_OUT_336_2016	0.000	336	12	2016	1-Dec-16	0	0.39
337	FLOW_OUT_337_2016	0.000	337	12	2016	2-Dec-16	0	0.39
338	FLOW_OUT_338_2016	0.000	338	12	2016	3-Dec-16	0	0.39
339	FLOW_OUT_339_2016	0.000	339	12	2016	4-Dec-16	0	0.39
340	FLOW_OUT_340_2016	0.000	340	12	2016	5-Dec-16	0	0.39

341	FLOW_OUT_341_2016	0.000	341	12	2016	6-Dec-16	0	0.39
342	FLOW_OUT_342_2016	0.000	342	12	2016	7-Dec-16	0	0.39
343	FLOW_OUT_343_2016	0.000	343	12	2016	8-Dec-16	0	0.39
344	FLOW_OUT_344_2016	0.000	344	12	2016	9-Dec-16	0	0.39
345	FLOW_OUT_345_2016	0.000	345	12	2016	10-Dec-16	0	0.39
346	FLOW_OUT_346_2016	3.100	346	12	2016	11-Dec-16	3.1	0.52
347	FLOW_OUT_347_2016	4.000	347	12	2016	12-Dec-16	4	0.57
348	FLOW_OUT_348_2016	2.400	348	12	2016	13-Dec-16	2.4	0.49
349	FLOW_OUT_349_2016	3.900	349	12	2016	14-Dec-16	3.9	0.56
350	FLOW_OUT_350_2016	2.900	350	12	2016	15-Dec-16	2.9	0.52
351	FLOW_OUT_351_2016	2.400	351	12	2016	16-Dec-16	2.4	0.49
352	FLOW_OUT_352_2016	3.500	352	12	2016	17-Dec-16	3.5	0.54
353	FLOW_OUT_353_2016	3.180	353	12	2016	18-Dec-16	3.18	0.53
354	FLOW_OUT_354_2016	3.900	354	12	2016	19-Dec-16	3.9	0.56
355	FLOW_OUT_355_2016	4.200	355	12	2016	20-Dec-16	4.2	0.57
356	FLOW_OUT_356_2016	2.300	356	12	2016	21-Dec-16	2.3	0.49
357	FLOW_OUT_357_2016	3.600	357	12	2016	22-Dec-16	3.6	0.55
358	FLOW_OUT_358_2016	2.800	358	12	2016	23-Dec-16	2.8	0.51
359	FLOW_OUT_359_2016	2.630	359	12	2016	24-Dec-16	2.63	0.50
360	FLOW_OUT_360_2016	3.100	360	12	2016	25-Dec-16	3.1	0.52
361	FLOW_OUT_361_2016	3.080	361	12	2016	26-Dec-16	3.08	0.52
362	FLOW_OUT_362_2016	3.490	362	12	2016	27-Dec-16	3.49	0.54
363	FLOW_OUT_363_2016	3.470	363	12	2016	28-Dec-16	3.47	0.54
364	FLOW_OUT_364_2016	4.180	364	12	2016	29-Dec-16	4.18	0.57
365	FLOW_OUT_365_2016	4.090	365	12	2016	30-Dec-16	4.09	0.57
366	FLOW_OUT_366_2016	0.830	366	12	2016	31-Dec-16	0.83	0.42

APPENDIX F: Ethical Clearance Letter for the Study

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road | P.O. Box 32379 | Lusaka 10101 | **Tel:** +260-211-290 258/291 777
Fax: +260-1-290 258/253 952 | **Email:** director@drgs.unza.zm | **Website:** www.unza.zm

Approval of Study

11th April, 2019

REF. NO. NASREC: 2019-MAR-004

Mr. Manoah Muchanga
The University of Zambia
School of Natural Sciences
Department of Geography and
Environmental Studies
P.O. Box 32379
LUSAKA

Dear Mr. Muchanga,

RE: "DETERMINATION OF SEDIMENT AND WATER QUALITY AND QUALITY FOR SWAT MODELLING OF SEDIMENTATION IN THE MAKOYE RESERVOUR, SOUTHERN PROVINCE"

The University of Zambia Natural and Applied Sciences Research Ethics Committee IRB has approved the study noting that there are no ethical concerns.

On behalf of The University of Zambia Natural and Applied Sciences Research Ethics Committee IRB, we would like to wish you all the success as you carry out your study.

In future ensure that you submit an application for ethical approval early enough.

Yours faithfully,

Dr. E. Mwanaumo
CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE IRB

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

Excellence in Teaching, Research and Community Service

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
1	28.9	2.41	2.41	23.86	1	28.495	1.5	1.5	25.4	1	26.57	1.37	1.37	25.35
2	29.99	3.06	5.48	25.72	2	29.503	1.83	3.33	26.9	2	27.22	1.13	2.5	24.4
3	26.35	4.59	10.06	28.90	3	31.519	2.41	5.74	29.4	3	26.57	1.06	3.56	25.15
4	25.13	4.15	14.21	29.59	4	32.023	2.24	7.98	29.9	4	27.11	1.14	4.7	24.65
5	24.88	3.09	17.30	29.37	5	31.855	1.98	9.96	29.8	5	30.74	1.31	6.01	24.3
6	27.65	3.54	20.84	29.70	6	32.107	3.55	13.5	30	6	27.22	1.5	7.51	25.15
7	27.4	3.94	24.78	30.33	7	32.611	2.5	16	30.6	7	27.9	1.31	8.82	24.15
8	26.96	4.41	29.19	30.23	8	32.527	2.22	18.2	30.5	8	27.61	1.39	10.21	24.65
9	28.94	4.71	33.91	31.02	9	33.199	1.75	20	31.1	9	26.75	1.24	11.45	24.45
10	29.02	4.56	38.47	30.92	10	33.115	1.85	21.8	31	10	27.18	1.21	12.66	23
11	30.28	3.95	42.42	29.81	11	32.191	2.51	24.3	30.1	11	28.94	1.37	14.03	25.06
12	30.67	2.81	45.23	28.30	12	31.099	2.76	27.1	28.9	12	29.95	1.17	15.2	24.06
13	29.81	1.21	46.44	21.82	13	27.487	1.15	28.3	23.8	13	28.15	1.34	16.54	24.1
14	27.68	1.23	47.67	21.28	14	27.235	1.02	29.3	23.4	14	29.27	1.22	17.76	22.1
15	26.78	1.21	48.89	22.34	15	27.739	1.11	30.4	24.2	15	31.14	1.22	18.98	21
16	27.22	1.92	50.81	24.81	16	28.999	1.44	31.8	26.2	16	29.12	1.43	20.41	25.55
17	28.37	2.35	53.16	24.34	17	28.747	1.71	33.5	25.8	17	26.21	1.33	21.74	24.4
18	30.28	1.85	55.01	24.81	18	28.999	1.84	35.4	26.2	18	27.65	1.29	23.03	23.23
19	28.94	0.49	55.50	16.38	19	25.135	0.64	36	19.7	19	29.12	1.32	24.35	25
20	28.91	0.55	56.05	15.95	20	24.967	0.68	36.7	19.4	20	28.19	1.09	25.44	22.17
21	28.94	2.86	58.92	26.15	21	29.755	2.09	38.8	27.2	21	29.23	1.2	26.64	23.86
22	29.12	3.22	62.14	27.40	22	30.511	2.17	41	28.2	22	28.58	1.3	27.94	23.86
23	27.83	2.27	64.41	25.57	23	29.419	1.6	42.6	26.7	23	27.76	1.5	29.44	27.53
24	28.22	2.67	67.07	26.44	24	29.923	2.04	44.6	27.4	24	29.27	1.63	31.07	28.17
25	28.94	2.75	69.82	26.72	25	30.091	2.36	47	27.7	25	29.38	1.3	32.37	26.86
26	26.28	1.19	71.02	21.64	26	27.403	1.49	48.4	23.7	26	29.56	1.27	33.64	26.86
27	26.32	1.01	72.02	20.36	27	26.815	1.11	49.6	22.7	27	29.95	1.44	35.08	29.37
28	27.14	2.33	74.35	25.86	28	29.587	2.43	52	27	28	29.48	0.53	35.61	11.9
29	29.23	1.90	76.26	24.18	29	28.663	2.22	54.2	25.7	29	31.1	1.4	37.01	26.15
30	29.56	1.73	77.99	24.96	30	29.083	2.46	56.7	26.3	30	29.3	1.4	38.41	28.17
31	31.64	2.00	79.99	27.53	31	30.595	2.86	59.5	28.3	31	28.87	1.5	39.91	28.78
32	31.1	3.08	83.06	29.37	32	31.855	2.6	62.1	29.8	32	29.48	1.36	41.27	25.42
33	32.29	2.90	85.96	27.66	33	30.679	2.31	64.4	28.4	33	28.94	1.24	42.51	26.86
34	31.28	2.74	88.70	27.53	34	30.595	2.51	66.9	28.3	34	27.54	0.76	43.27	17.42
35	30.6	2.21	90.90	26.86	35	30.175	2.14	69.1	27.8	35	27.32	0.54	43.81	14.2

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
36	31.93	2.11	93.01	25.57	36	29.419	1.85	70.9	26.7	36	27.58	0.67	44.48	17.42
37	32.15	2.42	95.43	26.58	37	30.007	2.14	73.1	27.5	37	28.62	0.77	45.25	18.43
38	31.5	1.92	97.35	25.27	38	29.251	2.07	75.1	26.5	38	26.86	1.49	46.74	28.78
39	31.03	1.52	98.86	23.03	39	28.075	1.5	76.6	24.8	39	27.5	1.68	48.42	29.92
40	28.01	1.30	100.16	27.79	40	30.763	2.76	79.4	28.5	40	27.43	0.66	49.08	15.3
41	29.59	1.53	101.70	26.44	41	29.923	2.47	81.9	27.4	41	29.05	1.07	50.15	21.28
42	28.12	1.30	103.00	24.50	42	28.831	1.95	83.8	25.9	42	29.74	1.87	52.02	30.44
43	28.19	2.41	105.41	29.37	43	31.855	3.14	87	29.8	43	28.98	1.84	53.86	28.17
44	26.86	2.57	107.98	26.44	44	29.923	2.03	89	27.4	44	26.39	1.28	55.14	29.37
45	26.64	2.89	110.87	27.40	45	30.511	2.63	91.6	28.2	45	27.79	1.08	56.22	26.86
46	27.9	1.82	112.69	24.34	46	28.747	2.69	94.3	25.8	46	30.1	0.73	56.95	16.38
47	29.66	2.41	115.10	27.26	47	30.427	4.04	98.4	28.1	47	28.3	1.25	58.2	27.53
48	27.68	0.83	115.93	18.43	48	25.975	1.29	99.6	21.2	48	27.32	0.63	58.83	18.95
49	26.64	3.87	119.80	27.53	49	30.595	3.43	103	28.3	49	26.57	1.61	60.44	27.53
50	27.22	3.46	123.26	27.53	50	30.595	4.04	107	28.3	50	28.58	1.24	61.68	23.03
51	27.68	2.59	125.85	25.12	51	29.167	2.64	110	26.4	51	27.79	0.6	62.28	14.2
52	28.4	2.43	128.29	27.53	52	30.595	1.95	112	28.3	52	28.19	1.08	63.36	21.28
53	29.09	3.06	131.35	30.02	53	32.359	2.41	114	30.3	53	27.86	1.01	64.37	21.28
54	29.88	3.16	134.51	29.37	54	31.855	3.56	118	29.8	54	29.74	1.1	65.47	22.88
55	28.87	1.82	136.33	23.36	55	28.243	2.02	120	25	55	28.66	1.25	66.72	24.38
56	26.5	1.74	138.07	22.34	56	27.739	1.86	122	24.2	56	27.47	1.43	68.15	25.78
57	25.88	2.97	141.04	26.99	57	30.259	2.75	124	27.9	57	30.02	1.6	69.75	27.07
58	27.11	3.16	144.20	27.79	58	30.763	3.04	127	28.5	58	29.27	1.71	71.46	28.26
59	27.79	2.82	147.02	27.66	59	30.679	2.55	130	28.4	59	28.37	1.77	73.23	29.35
60	27.22	2.77	149.79	27.79	60	30.763	3.56	133	28.5	60	27.58	1.81	75.04	30.33
61	27.76	2.79	152.58	28.42	61	31.183	3.48	137	29	61	28.55	1.61	76.65	29.02
62	28.37	2.67	155.25	29.48	62	31.939	3.16	140	29.9	62	28.12	1.71	78.36	27.53
63	27.29	2.86	158.12	29.92	63	32.275	3.58	144	30.2	63	27.07	1.38	79.74	25.27
64	26.57	2.51	160.62	29.37	64	31.855	2.99	147	29.8	64	29.38	1.44	81.18	26.15
65	27.94	2.06	162.68	27.40	65	30.511	2.45	149	28.2	65	30.28	1.67	82.85	28.3
66	32.08	1.34	164.02	22.34	66	27.739	1.85	151	24.2	66	27.68	1.71	84.56	29.81
67	28.98	1.28	165.29	21.10	67	27.151	1.78	153	23.3	67	27.25	1.52	86.08	29.37
68	26.5	0.95	166.24	20.73	68	26.983	1.65	154	23	68	28.69	1.23	87.31	25.42
69	27.11	1.77	168.01	26.01	69	29.671	3.07	157	27.1	69	28.94	1.07	88.38	23.03
70	26.78	1.54	169.55	25.15	70	28.915	2.44	160	26	70	27.25	1.18	89.56	24.18

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
71	25.74	2.10	171.65	26.72	71	30.091	2.89	163	27.7	71	28.94	1.11	90.67	23.03
72	27.5	2.92	174.57	27.53	72	30.595	2.41	165	28.3	72	27.07	1.13	91.8	21.64
73	27.18	3.40	177.97	29.37	73	31.855	2.57	168	29.8	73	29.41	1.27	93.07	22.34
74	26.39	2.98	180.95	30.23	74	32.527	2.31	170	30.5	74	27.94	1.12	94.19	23.03
75	25.67	2.44	183.39	28.66	75	31.351	2.91	173	29.2	75	28.08	1.24	95.43	26.01
76	27.36	2.44	185.83	29.02	76	31.603	2.84	176	29.5	76	29.02	1.5	96.93	29.02
77	29.81	1.72	187.55	23.03	77	27.359	1.06	177	23.6	77	28.8	1.32	98.25	30.83
78	27.83	2.49	190.04	27.40	78	30.511	2.28	179	28.2	78	28.69	1.58	99.83	30.92
79	28.98	1.90	191.94	24.96	79	29.083	1.67	181	26.3	79	26.96	1.48	101.31	27.79
80	27.47	1.85	193.79	27.40	80	30.511	1.95	183	28.2	80	27.86	1.21	102.52	22.86
81	29.45	1.79	195.59	24.34	81	28.747	1.94	185	25.8	81	28.04	1.6	104.12	26.44
82	27.79	1.77	197.36	24.65	82	28.915	1.62	186	26	82	28.4	1.79	105.91	27.26
83	28.01	1.87	199.23	24.96	83	29.083	2.12	188	26.3	83	28.44	1.86	107.77	28.78
84	28.04	2.16	201.39	25.27	84	29.251	2.76	191	26.5	84	28.76	1.44	109.21	29.37
85	28.91	2.35	203.74	25.42	85	29.335	2.46	194	26.6	85	28.69	1.2	110.41	27.4
86	27.94	2.04	205.78	26.15	86	29.755	2.42	196	27.2	86	27.29	1.14	111.55	26.44
87	28.01	2.46	208.24	29.48	87	31.939	3.38	199	29.9	87	27.36	1.45	113	27.53
88	28.51	2.27	210.51	28.30	88	31.099	2.93	202	28.9	88	25.96	1.36	114.36	26.99
89	27.86	2.62	213.13	29.37	89	31.855	2.84	205	29.8	89	27.04	1.41	115.77	27.26
90	27.18	2.42	215.54	28.78	90	31.435	2.69	208	29.3	90	27.47	1.5	117.27	27.53
91	30.31	2.08	217.63	26.99	91	30.259	3.05	211	27.9	91	27.94	1.51	118.78	28.3
92	30.78	1.72	219.35	26.01	92	29.671	2.47	213	27.1	92	28.3	1.38	120.16	28.9
93	30.13	0.77	220.12	19.60	93	26.479	0.99	214	22.1	93	27.79	1.53	121.69	29.81
94	29.12	1.00	221.12	20.55	94	26.899	1.01	215	22.9	94	27.65	1.52	123.21	28.54
95	28.58	0.85	221.97	19.99	95	26.647	1.02	216	22.4	95	26.89	0.88	124.09	21.1
96	29.02	1.04	223.01	21.64	96	27.403	1.06	218	23.7	96	28.12	1.06	125.15	23.86
97	28.84	1.28	224.28	23.20	97	28.159	1.67	219	24.9	97	27.54	1.35	126.5	28.78
98	26.39	1.33	225.62	26.15	98	29.755	2.6	222	27.2	98	29.56	1.35	127.85	28.9
99	26.86	1.34	226.96	26.58	99	30.007	3.06	225	27.5	99	28.44	1.42	129.27	30.02
100	27.4	2.41	229.36	28.30	100	31.099	3.25	228	28.9	100	28.66	1.24	130.51	31.11
101	27.58	2.51	231.88	28.30	101	31.099	2.18	230	28.9	101	30.71	1.29	131.8	29.81
102	27.43	1.60	233.48	27.40	102	30.511	1.79	232	28.2	102	29.2	1.12	132.92	25.86
103	27.94	1.35	234.83	25.27	103	29.251	1.48	234	26.5	103	30.31	1.13	134.05	24.18
104	28.26	0.59	235.43	17.42	104	25.555	0.64	234	20.5	104	30.31	1.4	135.45	26.86
105	27.76	0.99	236.41	21.46	105	27.319	0.95	235	23.6	105	30.56	1.43	136.88	26.86

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	**Radiation MJ $m^{-2}d^{-1}$**	**Evapo. (m3/day)**	**Cum. Evapo.**	**Daily Mean Temp**	**Julian Day**	**Radiation MJ $m^{-2}d^{-1}$**	**Evapo. (m3/day)**	**Cum. Evapo.**	**Daily Mean Temp**	**Julian Day**	**Radiation MJ $m^{-2}d^{-1}$**	**Evapo. (m3/day)**	**Cum. Evapo.**	**Daily Mean Temp**
106	27.54	1.70	238.11	24.65	106	28.915	1.32	236	26	106	28.91	1.34	138.22	27.53
107	27.18	1.71	239.83	25.42	107	29.335	1.3	238	26.6	107	28.01	1.13	139.35	27.4
108	27.79	1.81	241.64	25.27	108	29.251	1.23	239	26.5	108	29.2	1.21	140.56	28.9
109	29.56	2.71	244.35	27.66	109	30.679	2.45	241	28.4	109	31.03	1.45	142.01	30.54
110	29.77	2.05	246.40	24.65	110	28.915	1.82	243	26	110	29.74	1.52	143.53	29.7
111	28.22	1.85	248.24	25.12	111	29.167	1.37	245	26.4	111	29.02	1.43	144.96	29.92
112	27.76	1.65	249.90	25.27	112	29.251	1.32	246	26.5	112	29.38	1.32	146.28	27.53
113	29.23	1.74	251.63	26.15	113	29.755	1.39	247	27.2	113	30.02	1.45	147.73	29.81
114	28.12	1.68	253.32	27.53	114	30.595	1.95	249	28.3	114	29.74	1.08	148.81	24.35
115	28.37	1.39	254.71	27.26	115	30.427	2.5	252	28.1	115	29.92	1	149.81	23.03
116	28.69	1.09	255.80	23.86	116	28.495	1.67	253	25.4	116	31.39	1.02	150.83	23.2
117	30.06	1.14	256.94	22.69	117	27.907	1.4	255	24.5	117	30.13	0.91	151.74	22.69
118	28.37	1.71	258.65	24.81	118	28.999	1.7	257	26.2	118	30.38	0.96	152.7	23.2
119	28.4	1.89	260.54	25.57	119	29.419	1.82	258	26.7	119	30.24	1.09	153.79	24.5
120	28.4	2.15	262.69	27.53	120	30.595	2.31	261	28.3	120	29.81	1.15	154.94	24.02
121	28.04	2.15	264.84	29.48	121	31.939	3.64	264	29.9	121	29.2	1.08	156.02	23.03
122	27.5	1.68	266.52	29.81	122	32.191	3.58	268	30.1	122	29.56	0.92	156.94	21.1
123	29.2	1.82	268.34	29.14	123	31.687	2.7	271	29.6	123	29.2	0.98	157.92	22.52
124	31.54	1.77	270.11	28.17	124	31.015	2.08	273	28.8	124	31.21	0.89	158.81	20.36
125	31.43	1.97	272.08	29.02	125	31.603	2.38	275	29.5	125	29.88	1.32	160.13	27.26
126	28.98	1.75	273.83	29.14	126	31.687	2.35	277	29.6	126	31.07	0.92	161.05	20.55
127	28.94	1.91	275.74	29.81	127	32.191	2.67	280	30.1	127	29.05	0.82	161.87	19.8
128	27.47	1.09	276.83	23.53	128	28.327	1.44	282	25.2	128	32.36	1.08	162.95	23.36
129	27.43	0.81	277.64	21.82	129	27.487	1.13	283	23.8	129	32	1.18	164.13	24.96
130	30.31	1.00	278.64	22.52	130	27.823	1.31	284	24.4	130	30.17	1.31	165.44	26.72
131	31	0.98	279.61	22.52	131	27.823	1.59	286	24.4	131	29.77	1.47	166.91	28.05
132	32.04	1.29	280.90	24.34	132	28.747	1.71	287	25.8	132	30.64	1.4	168.31	27.53
133	30.42	0.96	281.86	23.36	133	28.243	1.32	289	25	133	29.27	1.28	169.59	26.15
134	31.18	1.62	283.48	26.44	134	29.923	2.04	291	27.4	134	28.76	1.04	170.63	23.2
135	32.47	2.23	285.71	27.53	135	30.595	2.9	294	28.3	135	29.99	1.05	171.68	23.86
136	32.11	1.98	287.69	26.72	136	30.091	2.7	296	27.7	136	29.41	1.13	172.81	25.57
137	29.92	1.43	289.11	25.57	137	29.419	2.17	298	26.7	137	29.59	1.34	174.15	28.17
138	29.48	1.18	290.30	24.65	138	28.915	2	300	26	138	29.3	1.46	175.61	27.66
139	28.48	1.57	291.86	26.01	139	29.671	2.41	303	27.1	139	29.74	1.3	176.91	25.86
140	27.76	2.20	294.06	26.86	140	30.175	2.45	305	27.8	140	31.5	0.92	177.83	21.28

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
141	27.32	2.10	296.17	26.86	141	30.175	1.98	307	27.8	141	32.11	0.96	178.79	21.28
142	27.65	2.16	298.33	28.17	142	31.015	2.22	309	28.8	142	31.21	1.17	179.96	23.86
143	28.15	1.31	299.64	23.86	143	28.495	1.38	311	25.4	143	29.95	1.16	181.12	24.34
144	28.04	1.03	300.67	22.34	144	27.739	1.07	312	24.2	144	29.81	1.1	182.22	23.86
145	30.46	1.30	301.97	24.02	145	28.579	1.3	313	25.5	145	30.06	0.63	182.85	16.38
146	28.58	1.38	303.35	26.01	146	29.671	1.59	315	27.1	146	29.84	0.94	183.79	22.34
147	28.48	1.17	304.53	24.65	147	28.915	1.29	316	26	147	29.3	0.99	184.78	24.34
148	28.94	1.06	305.58	23.69	148	28.411	1.38	318	25.3	148	29.77	1.1	185.88	26.15
149	28.62	0.61	306.19	19.80	149	26.563	0.82	318	22.3	149	31.82	1.41	187.29	27.92
150	28.87	1.24	307.43	24.34	150	28.747	1.62	320	25.8	150	30.74	1.34	188.63	26.86
151	28.3	0.56	307.98	19.80	151	26.563	1.03	321	22.3	151	30.89	0.93	189.56	22.17
152	27.9	1.20	309.18	23.53	152	28.327	1.54	323	25.2	152	29.59	0.76	190.32	20.18
153	30.74	0.95	310.14	22.17	153	27.655	1.06	324	24.1	153	29.63	0.73	191.05	19.8
154	30.56	0.68	310.82	20.18	154	26.731	0.8	324	22.6	154	29.23	0.6	191.65	19.41
155	29.81	0.58	311.40	19.80	155	26.563	0.77	325	22.3	155	29.12	0.26	191.91	15.3
156	31.9	0.63	312.03	19.41	156	26.395	0.68	326	22	156	28.76	0.41	192.32	16.38
157	31.57	0.30	312.33	15.30	157	24.715	0.36	326	18.9	157	29.92	0.89	193.21	21.82
158	29.88	0.30	312.63	16.38	158	25.135	0.4	327	19.7	158	32.29	1	194.21	22.86
159	31.79	0.90	313.52	21.82	159	27.487	0.91	327	23.8	159	29.52	1.06	195.27	24.18
160	33.23	1.17	314.70	22.86	160	27.991	1	328	24.6	160	28.44	1.12	196.39	25.86
161	29.77	1.16	315.86	24.18	161	28.663	1.23	330	25.7	161	28.69	0.39	196.78	16.17
162	29.74	1.30	317.16	25.86	162	29.587	1.48	331	27	162	29.48	0.49	197.27	16.8
163	30.38	0.54	317.70	16.17	163	25.051	0.32	332	19.5	163	29.48	0.5	197.77	16.59
164	30.46	0.53	318.23	16.80	164	25.303	0.37	332	20	164	30.42	0.3	198.07	11.9
165	30.17	0.43	318.66	16.59	165	25.219	0.39	332	19.8	165	30.89	0.7	198.77	18.23
166	29.74	0.05	318.71	11.90	166	23.455	0.08	332	16.3	166	33.66	0.47	199.24	15.09
167	29.3	0.41	319.12	18.23	167	25.891	0.45	333	21.1	167	33.26	0.97	200.21	21.64
168	29.23	0.16	319.28	15.09	168	24.631	0.31	333	18.7	168	30.78	0.98	201.19	23.45
169	29.16	0.77	320.04	21.64	169	27.403	1.27	334	23.7	169	29.48	0.95	202.14	23.03
170	28.58	1.13	321.17	24.65	170	28.915	1.92	336	26	170	30.17	0.9	203.04	21.64
171	29.92	0.96	322.13	23.03	171	28.075	1.32	338	24.8	171	30.74	0.92	203.96	22.17
172	32	0.85	322.98	21.64	172	27.403	0.88	339	23.7	172	31.82	1.03	204.99	23.86
173	31.75	0.98	323.97	22.17	173	27.655	0.87	339	24.1	173	34.13	1.26	206.25	26.15
174	29.23	1.21	325.18	23.86	174	28.495	1.13	341	25.4	174	36.04	1.45	207.7	28.17
175	29.52	1.49	326.67	26.15	175	29.755	1.62	342	27.2	175	34.52	1.34	209.04	27.53

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
176	30.35	1.65	328.32	28.17	176	31.015	2.25	344	28.8	176	34.49	1.33	210.37	27.4
177	30.78	1.78	330.09	27.53	177	30.595	2.15	347	28.3	177	34.88	1.3	211.67	26.72
178	30.64	1.63	331.73	27.40	178	30.511	2.38	349	28.2	178	32.11	1.18	212.85	25.86
179	30.96	1.50	333.22	26.72	179	30.091	1.72	351	27.7	179	31.82	1.1	213.95	24.96
180	33.12	1.43	334.65	25.86	180	29.587	1.44	352	27	180	31.28	0.99	214.94	23.53
181	31.97	1.23	335.88	24.96	181	29.083	1.29	353	26.3	181	30	1.39	216.33	26.15
182	30.06	0.94	336.82	23.53	182	28.327	1.13	354	25.2	182	29.34	0.92	217.25	22.4
183	30.67	1.01	337.83	23.53	183	28.327	1.24	356	25.2	183	29.74	0.91	218.16	22.54
184	30.24	1.24	339.07	24.34	184	28.747	1.3	357	25.8	184	29.63	0.87	219.03	22.53
185	29.02	1.40	340.47	25.27	185	29.251	1.38	358	26.5	185	29.05	0.82	219.85	22.56
186	29.02	1.29	341.76	25.42	186	29.335	1.38	360	26.6	186	30.2	0.89	220.74	22.72
187	32.72	1.47	343.23	26.30	187	29.839	1.58	361	27.3	187	30.38	0.91	221.65	22.64
188	35.68	0.94	344.17	23.20	188	28.159	1.17	363	24.9	188	29.27	0.91	222.56	22.63
189	31.21	0.70	344.86	22.34	189	27.739	1.09	364	24.2	189	29.84	0.85	223.41	22.35
190	30.06	1.08	345.95	25.12	190	29.167	1.4	365	26.4	190	31.46	0.89	224.3	22.76
191	29.63	0.90	346.85	24.18	191	28.663	1.11	366	25.7	191	30.89	0.89	225.19	22.73
192	30.1	0.67	347.52	22.52	192	27.823	0.85	367	24.4	192	30.2	0.91	226.1	22.64
193	30.92	0.61	348.13	22.17	193	27.655	0.8	368	24.1	193	30.13	0.88	226.98	22.61
194	32.87	0.69	348.82	22.17	194	27.655	0.87	369	24.1	194	32.8	0.91	227.89	22.89
195	32.08	0.79	349.61	23.03	195	28.075	1.04	370	24.8	195	33.8	0.9	228.79	23.12
196	31.79	1.27	350.88	25.57	196	29.419	1.57	371	26.7	196	34.99	0.9	229.69	23.07
197	30.82	0.88	351.76	23.86	197	28.495	1.13	372	25.4	197	32.54	0.86	230.55	22.9
198	29.99	0.24	352.00	18.03	198	25.807	0.41	373	20.9	198	32	0.87	231.42	22.96
199	29.84	0.52	352.52	21.64	199	27.403	0.73	374	23.7	199	31.07	0.82	232.24	22.59
200	30.02	0.12	352.64	17.42	200	25.555	0.29	374	20.5	200	29.99	0.82	233.06	22.49
201	30.46	0.16	352.80	18.43	201	25.975	0.34	374	21.2	201	31.68	0.85	233.91	22.48
202	32.94	0.43	353.23	20.73	202	26.983	0.56	375	23	202	30.96	0.91	234.82	22.67
203	32.58	0.60	353.83	22.17	203	27.655	0.8	376	24.1	203	30.78	0.94	235.76	22.58
204	32.15	1.00	354.83	24.65	204	28.915	1.34	377	26	204	29.63	0.86	236.62	22.72
205	30.17	1.03	355.85	24.96	205	29.083	1.46	378	26.3	205	33.05	0.89	237.51	22.98
206	30.1	0.64	356.49	23.20	206	28.159	1.02	379	24.9	206	33.62	0.89	238.4	22.99
207	29.88	0.72	357.21	22.69	207	27.907	0.8	380	24.5	207	33.3	0.9	239.3	23.2
208	29.38	0.28	357.49	19.41	208	26.395	0.4	381	22	208	32.58	0.9	240.2	23.48
209	30.64	0.48	357.98	21.64	209	27.403	0.63	381	23.7	209	31.25	0.96	241.16	24.21
210	31.39	0.70	358.67	23.03	210	28.075	0.98	382	24.8	210	31.72	0.93	242.09	23.88

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
211	30.1	0.66	359.33	22.86	211	27.991	0.93	383	24.6	211	31.18	0.82	242.91	23.16
212	31.1	0.59	359.92	21.28	212	27.235	0.8	384	23.4	212	27.235	0.84	243.75	23.42
213	31.39	0.77	360.69	21.82	213	27.487	0.73	385	23.8	213	27.487	0.89	244.64	23.83
214	30.13	1.14	361.83	24.50	214	28.831	1.18	386	25.9	214	28.831	1.14	245.78	25.91
215	31.36	0.79	362.61	21.28	215	27.235	0.68	386	23.4	215	27.235	0.89	246.67	23.42
216	32.94	0.99	363.60	23.20	216	28.159	1	387	24.9	216	28.159	1.01	247.68	24.9
217	33.3	1.05	364.66	24.18	217	28.663	1.04	389	25.7	217	28.663	1.02	248.7	25.66
218	32.72	1.26	365.91	25.86	218	29.587	1.29	390	27	218	29.587	1.12	249.82	26.98
219	32.98	1.05	366.96	24.96	219	29.083	1.09	391	26.3	219	29.083	0.99	250.81	26.27
220	33.91	0.28	367.24	19.99	220	26.647	0.48	391	22.4	220	26.647	0.65	251.46	22.43
221	33.8	0.12	367.36	17.62	221	22.279	0.01	391	13.7	221	22.279	0.09	251.55	13.7
222	36.76	0.73	368.10	22.17	222	27.655	0.66	392	24.1	222	27.655	0.87	252.42	24.11
223	35.39	1.86	369.96	27.40	223	30.511	1.56	394	28.2	223	30.511	1.35	253.77	28.19
224	36.54	2.14	372.09	27.79	224	30.763	1.81	395	28.5	224	30.763	1.41	255.18	28.5
225	37.48	2.39	374.48	29.14	225	31.687	2.23	398	29.6	225	31.687	1.51	256.69	29.58
226	35.53	1.99	376.47	28.17	226	31.015	1.72	399	28.8	226	31.015	1.35	258.04	28.8
227	32.98	1.40	377.87	25.27	227	29.251	1.19	401	26.5	227	29.251	1.11	259.15	26.51
228	31.75	2.05	379.92	28.42	228	31.183	2.08	403	29	228	31.183	1.42	260.57	29
229	31.36	1.90	381.81	28.90	229	31.519	2.05	405	29.4	229	31.519	1.43	262	29.39
230	31.46	1.99	383.80	29.70	230	32.107	2.1	407	30	230	32.107	1.43	263.43	30.03
231	32.15	1.16	384.96	24.65	231	28.915	1.05	408	26	231	28.915	1.01	264.44	26.03
232	35.53	1.47	386.43	24.81	232	28.999	1.18	409	26.2	232	28.999	1.02	265.46	26.15
233	34.92	1.75	388.18	26.44	233	29.923	1.47	410	27.4	233	29.923	1.19	266.65	27.43
234	32.26	2.28	390.46	28.54	234	31.267	1.91	412	29.1	234	31.267	1.4	268.05	29.1
235	30.64	2.97	393.43	30.63	235	32.863	2.37	415	30.8	235	32.863	1.54	269.59	30.79
236	31.25	3.93	397.36	33.54	236	36.139	3.02	418	33.3	236	36.139	1.72	271.31	33.29
237	31.57	3.04	400.40	31.81	237	33.955	2.6	420	31.8	237	33.955	1.56	272.87	31.77
238	31.39	2.31	402.70	29.81	238	32.191	2.34	423	30.1	238	32.191	1.46	274.33	30.12
239	30.31	2.12	404.82	29.48	239	31.939	2.24	425	29.9	239	31.939	1.46	275.79	29.85
240	30.53	1.62	406.44	27.66	240	30.679	1.65	427	28.4	240	30.679	1.35	277.14	28.4
241	31.57	1.51	407.95	27.40	241	30.511	1.48	428	28.2	241	30.511	1.33	278.47	28.19
242	32.4	1.54	409.48	27.53	242	30.595	1.6	430	28.3	242	30.595	1.38	279.85	28.29
243	32.65	1.76	411.24	28.54	243	31.267	2.04	432	29.1	243	31.267	1.51	281.36	29.1
244	32.51	2.31	413.55	30.54	244	32.779	2.76	435	30.7	244	32.779	1.81	283.17	30.71
245	31.68	2.98	416.53	31.81	245	33.955	3.5	438	31.8	245	33.955	1.94	285.11	31.77

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
246	31.54	1.80	418.33	27.26	246	30.427	1.79	440	28.1	246	30.427	1.3	286.41	28.08
247	31.21	2.68	421.02	31.11	247	33.283	2.46	442	31.2	247	33.283	1.51	287.92	31.19
248	31.46	2.29	423.30	31.89	248	34.039	2.78	445	31.8	248	34.039	1.63	289.55	31.84
249	32.83	1.94	425.24	30.63	249	32.863	2.39	447	30.8	249	32.863	1.49	291.04	30.79
250	32.69	2.22	427.46	30.73	250	32.947	2.53	450	30.9	250	32.947	1.54	292.58	30.87
251	31.82	2.39	429.85	30.83	251	33.031	2.54	452	31	251	33.031	1.58	294.16	30.95
252	31.5	2.32	432.17	30.73	252	32.947	2.58	455	30.9	252	32.947	1.61	295.77	30.87
253	32.76	2.33	434.50	30.83	253	33.031	2.78	458	31	253	33.031	1.77	297.54	30.95
254	33.62	2.22	436.72	32.13	254	34.291	3.72	462	32	254	34.291	1.93	299.47	32.04
255	32.51	1.97	438.69	32.50	255	34.711	3.48	465	32.4	255	34.711	1.89	301.36	32.36
256	32.98	1.65	440.33	30.02	256	32.359	2.29	467	30.3	256	32.359	1.53	302.89	30.29
257	32.54	2.05	442.39	31.11	257	33.283	2.65	470	31.2	257	33.283	1.59	304.48	31.19
258	32.08	2.23	444.61	32.21	258	34.375	3.53	474	32.1	258	34.375	1.79	306.27	32.11
259	31.36	1.80	446.41	29.70	259	32.107	3.13	477	30	259	32.107	1.65	307.92	30.03
260	31.39	1.90	448.31	30.73	260	32.947	3.38	480	30.9	260	32.947	1.8	309.72	30.87
261	35.24	1.70	450.01	27.53	261	30.595	2.12	482	28.3	261	30.595	1.44	311.16	28.29
262	33.62	2.36	452.36	29.14	262	31.687	2.38	485	29.6	262	31.687	1.5	312.66	29.58
263	31.97	3.02	455.38	31.56	263	33.703	2.75	487	31.6	263	33.703	1.62	314.28	31.56
264	33.62	2.61	457.99	32.43	264	34.627	2.98	490	32.3	264	34.627	1.66	315.94	32.3
265	33.77	2.06	460.04	32.57	265	34.795	3.47	494	32.4	265	34.795	1.81	317.75	32.43
266	33.48	1.95	461.99	33.03	266	35.383	4.4	498	32.8	266	35.383	2.05	319.8	32.83
267	35.71	2.50	464.49	33.64	267	36.307	5.23	503	33.4	267	36.307	2.17	321.97	33.38
268	34.81	2.39	466.87	33.64	268	36.307	4.7	508	33.4	268	36.307	2.1	324.07	33.38
269	34.88	3.04	469.91	32.71	269	34.963	4.18	512	32.6	269	34.963	1.95	326.02	32.55
270	32.08	2.88	472.79	31.56	270	33.703	3.62	516	31.6	270	33.703	2.06	328.08	31.56
271	31.64	2.64	475.43	32.57	271	34.795	3.74	520	32.4	271	34.795	1.91	329.99	32.43
272	30.6	1.67	477.10	32.78	272	35.047	3.13	523	32.6	272	35.047	1.79	331.78	32.61
273	31.03	2.03	479.13	33.43	273	35.971	2.82	526	33.2	273	35.971	1.7	333.48	33.2
274	33.16	2.70	481.83	33.73	274	36.475	2.97	529	33.5	274	36.475	1.71	335.19	33.47
275	33.98	1.94	483.77	30.23	275	32.527	2.14	531	30.5	275	32.527	1.43	336.62	30.46
276	34.88	2.35	486.12	31.47	276	33.619	2.25	533	31.5	276	33.619	1.46	338.08	31.49
277	35.17	2.42	488.54	32.50	277	34.711	2.29	535	32.4	277	34.711	1.5	339.58	32.36
278	35.57	3.01	491.55	33.33	278	35.803	3.4	539	33.1	278	35.803	1.82	341.4	33.1
279	33.55	3.05	494.60	33.59	279	36.223	3	542	33.3	279	36.223	1.73	343.13	33.34
280	32.54	3.45	498.05	33.27	280	35.719	2.81	544	33	280	35.719	1.7	344.83	33.04

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
281	31.61	2.82	500.87	33.21	281	35.635	3.12	548	33	281	35.635	1.79	346.62	32.99
282	32.98	2.29	503.16	33.33	282	35.803	3.84	551	33.1	282	35.803	1.97	348.59	33.1
283	34.45	2.87	506.03	33.54	283	36.139	4.03	555	33.3	283	36.139	2.02	350.61	33.29
284	33.95	2.70	508.72	33.98	284	36.979	4.54	560	33.7	284	36.979	2.14	352.75	33.72
285	34.67	2.43	511.15	33.21	285	35.635	3.93	564	33	285	35.635	1.9	354.65	32.99
286	33.26	2.45	513.60	33.09	286	35.467	3.01	567	32.9	286	35.467	1.67	356.32	32.89
287	32.54	2.04	515.64	32.71	287	34.963	3.29	570	32.6	287	34.963	1.75	358.07	32.55
288	34.6	3.40	519.04	32.57	288	34.795	2.64	573	32.4	288	34.795	1.56	359.63	32.43
289	33.05	2.98	522.02	31.11	289	33.283	1.87	575	31.2	289	33.283	1.33	360.96	31.19
290	32.18	3.21	525.23	32.71	290	34.963	2.35	577	32.6	290	34.963	1.54	362.5	32.55
291	32.51	3.74	528.97	33.68	291	37	2.86	580	33.7	291	37	1.73	364.23	33.73
292	31.03	3.44	532.41	33.73	292	36.5	2.94	583	33.5	292	36.5	1.71	365.94	33.49
293	30.89	2.47	534.88	33.98	293	35	2.8	586	32.6	293	35	1.67	367.61	32.57
294	31.43	2.10	536.99	32.28	294	35	2.8	588	32.6	294	35	1.67	369.28	32.57
295	32.69	2.99	539.98	33.27	295	35	2.47	591	32.6	295	35	1.57	370.85	32.57
296	33.44	2.54	542.52	32.21	296	35	2.62	594	32.6	296	35	1.62	372.47	32.57
297	33.23	1.53	544.05	29.02	297	32	2.51	596	29.9	297	32	1.58	374.05	29.92
298	32.15	1.91	545.96	30.63	298	33	3.26	599	30.9	298	33	1.81	375.86	30.92
299	31.36	1.60	547.56	28.30	299	29.4	1.39	601	25.4	299	29.4	1.18	377.04	25.35
300	31.07	1.85	549.41	32.13	300	33.5	3.43	604	31.4	300	33.5	1.85	378.89	31.38
301	32.33	2.86	552.27	33.49	301	34.5	3.04	607	32.2	301	34.5	1.74	380.63	32.21
302	33.19	2.73	555.00	32.64	302	36.5	2.77	610	33.5	302	36.5	1.67	382.3	33.49
303	33.19	2.07	557.06	31.64	303	37.5	3.25	613	33.9	303	37.5	1.8	384.1	33.94
304	33.44	3.84	560.90	33.15	304	37.5	3.26	616	33.9	304	37.5	1.81	385.91	33.94
305	30.96	3.42	564.32	33.60	305	34	2.29	619	31.8					
306	30.82	1.50	565.81	27.45	306	30.5	1.65	620	28.2					
307	30.49	1.24	567.06	24.85	307	27.5	0.87	621	23.9					
308	30.89	1.43	568.49	25.70	308	29.5	1.53	623	26.9					
309	31.28	2.19	570.68	28.85	309	31.5	2.28	625	29.4					
310	31.54	2.68	573.35	31.05	310	33.5	2.66	628	31.4					
311	31.03	2.85	576.20	32.80	311	37.5	3.26	631	33.9					
312	30.24	3.49	579.69	33.15	312	37.5	3.77	635	33.9					
313	31.21	3.59	583.28	34.05	313	36	5.38	640	33.2					
314	30.31	3.15	586.42	32.25	314	35.5	5.03	645	32.9					
315	32.8	3.78	590.20	32.30	315	35.2	4.93	650	32.7					

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
316	32.54	3.26	593.46	31.55	316	32	3.3	653	29.9					
317	32.94	2.97	596.43	30.04	317	33.8	4.5	658	31.6					
318	31.72	3.21	599.64	31.73	318	36	4.57	662	33.2					
319	29.41	3.02	602.66	32.55	319	36.3	3.75	666	33.4					
320	29.2	2.47	605.13	32.06	320	34.8	3.89	670	32.4					
321	29.63	3.65	608.78	32.66	321	36	4.06	674	33.2					
322	29.66	3.00	611.78	31.31	322	33.3	3.12	677	31.2					
323	29.05	3.77	615.55	32.16	323	35	4.12	681	32.6					
324	28.55	3.28	618.83	30.81	324	32	2.73	684	29.9					
325	28.87	4.49	623.31	33.56	325	37.8	4.06	688	34.1					
326	31.93	4.96	628.27	33.16	326	38	2.88	691	34.1					
327	30.1	5.26	633.53	32.71	327	37.1	4.6	696	33.8					
328	29.84	4.56	638.10	30.96	328	31	2.64	698	28.8					
329	28.84	4.52	642.61	31.91	329	36.5	2.71	701	33.5					
330	29.56	3.77	646.39	31.91	330	36.5	4.31	705	33.5					
331	30.89	3.61	650.00	33.91	331	29	1.83	707	26.2					
332	31.18	3.39	653.39	32.96	332	27	1.02	708	23					
333	32.08	2.71	656.09	30.07	333	27.9	0.98	709	24.6					
334	31.57	2.21	658.30	28.87	334	30	1.57	711	27.5					
335	32.33	2.48	660.78	29.47	335	31	1.81	713	28.8					
336	29.7	1.13	661.91	21.85	336	27.5	0.99	714	23.9					
337	29.05	1.09	663.00	21.85	337	27.5	0.86	714	23.9					
338	29.2	2.29	665.28	28.15	338	31	2.3	717	28.8					
339	32.83	1.53	666.81	22.88	339	26.8	1.08	718	24.1					
340	31.5	1.32	668.14	22.88	340	27.9	1.02	719	24.6					
341	30.35	1.23	669.37	22.88	341	28	1.2	720	24.7					
342	29.99	1.32	670.69	22.88	342	28	1.32	721	24.7					
343	28.4	1.35	672.04	22.88	343	27.6	1.12	722	24.5					
344	27.14	1.27	673.32	22.88	344	28	1.29	724	24.7					
345	27.14	1.13	674.45	22.88	345	27.8	1.27	725	24.6					
346	26.96	1.03	675.48	22.88	346	28.5	1.44	726	24.9					
347	29.59	1.17	676.65	22.88	347	28	1.48	728	24.7					
348	27.83	1.05	677.70	22.88	348	26.9	1.26	729	24.1					
349	27.97	1.02	678.72	22.88	349	27.6	1.36	731	24.5					
350	28.37	1.01	679.73	22.88	350	29.6	1.72	732	25.5					

Appendix $G_{(i)}$: Climatic Parameters that Influenced Loss of water from the Makoye Reservoir through Evaporation

2015					2016					2017				
Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp	Julian Day	Radiation MJ $m^{-2}d^{-1}$	Evapo. (m3/day)	Cum. Evapo.	Daily Mean Temp
351	27.36	1.03	680.76	22.88	351	28	1.7	734	24.7					
352	27.76	1.07	681.82	22.88	352	27.6	2.02	736	24.5					
353	27.04	0.90	682.72	22.88	353	28	1.84	738	24.7					
354	29.41	1.10	683.83	22.88	354	28	1.52	739	24.7					
355	28.94	1.30	685.13	22.88	355	29.5	1.91	741	25.4					
356	27.5	1.26	686.39	22.88	356	28	1.91	743	24.7					
357	27.07	1.20	687.59	22.88	357	28	2.17	745	24.7					
358	26.5	1.42	689.02	22.88	358	27.6	2.16	747	24.5					
359	29.02	1.41	690.42	22.88	359	28	2.28	750	24.7					
360	29.7	1.27	691.69	22.88	360	28	2.16	752	24.7					
361	29.45	1.28	692.97	22.88	361	27.5	2.12	754	24.4					
362	27.76	1.22	694.19	22.88	362	28	1.91	756	24.7					
363	26.82	1.24	695.44	22.88	363	27.5	1.61	758	24.4					
364	26.68	1.20	696.64	22.88	364	28	1.86	759	24.7					
365	27.65	1.16	697.80	22.88	365	28	2.07	761	24.7					
					366	27	1.8	763	24.2					

Annual and 3-year averages for Basin Radiation and Evaporation from the Reservoir

Period	Radiation	Annual Average Evaporation m^3/year	Annual Total Evaporation
2015	917.6716667	58.14966511	697.7959813
2016	926.2405	63.60530568	763.2636682
2017	774.4064167	38.5871867	385.871867
3-Year mean (2015-2017)	**872.7728611**	**160.3421575**	**615.6438388**

Appendix $G_{(ii)}$: Monthly Mean Temperatures and monthly Water losses through Evaporation from the Makoye Reservoir, 2015-2017

Mean Monthly Temperature	Total monthly Loss m^3/month
26.54	79.99
26.39	67.03
26.73	68.52
24.74	47.15
25.48	45.29
21.67	27.90
22.73	24.04
26.49	51.33
31.38	67.88
32.51	81.77
31.36	97.40
23.19	39.49
26.87	59.53
27.45	73.94
28.53	77.51
26.18	53.35
26.54	58.15
23.74	32.00
24.50	30.10
27.50	49.85
31.53	94.04
32.32	90.21
30.72	93.83
24.69	50.75
24.63	39.88
23.49	33.31
26.80	44.05
26.97	37.69
24.08	34.60
21.76	26.76
22.87	27.42
27.28	37.62
31.43	52.11
32.37	52.44

Appendix H: Socio-geohydrological perspectives on the Makoye Reservoirs Bathymetry and Sedimentation

i: Availability of water in the Makoye Reservoir

Water availability in the Catchment	Number of household respondents	Percentage (%)
Readily available	7	5
Moderately Available	25	18
Not readily available	108	77
Total	**140**	**100**

Source: Field Interviews, 2017

ii: Water Stressful Periods within the Makoye Reservoir Catchment

Responses	Number of household respondents	Percentage (%)
July to February	14	10
August to February	24	17
September to December	102	73
Total	**140**	**100**

Source: Field Interviews, 2017

iii: Some socio-geohydrological concerns raised by residents in the Makoye Reservoir catchment

Concerns from Key Informants	Frequency of responses	Percentage of responses (%)
The reservoir's depth has drastically reduced	8	5
The cows do not receive adequate amount of water per day during dry seasons	55	32
Water scarcity is forcing people especially women and children to go fetch water from distant places	34	20
People's bad attitude and carelessness has contributed to sedimentation of the reservoir because they plough near the reservoir	10	6
Animals get stack in mud when the reservoir dries and sometimes they die	4	2
Animals are suffering and some get sick and die	6	4
Dipping of our animals is now being prolonged than before because there is poor water supply	26	15
There is a lot of soil (sediment) that enters into the reservoir	16	9
The reservoir cannot supply enough water for animals in the catchment and surrounding areas	7	4
There is no awareness on how to care for the reservoir, that is why it is drying quickly	4	2
TOTAL	**170**	**100**

Appendix I: Location of sample points for Sediment Depths and Elevations on the Makoye Reservoir

No	X	Y	Sediment depth(m)	Elevation(m)
1	574591.79	8203927.76	-0.1	1108.36
2	574609.38	8203968.58	-0.1	1107.953
3	574620.2	8203985.29	-0.84	1108.1
4	574636.02	8203988.67	-1.1	1106.552
5	574642.09	8204005.42	-1.2	1106.363
6	574648.49	8204013.82	-1.1	1107.36
7	574655.95	8204022.02	-1.2	1107.03
8	574661.56	8204029.8	-1.2	1107.08
9	574672.56	8204046.35	-1.1	1106.521
10	574686.82	8204060.69	-0.9	1105.892
11	574702.74	8204073.71	-0.9	1107.15
12	574716.4	8204088.48	-0.85	1105.778
13	574723.74	8204098.96	-0.5	1106.918
14	574731.05	8204106.79	-0.8	1106.952
15	574737.67	8204113.59	-0.67	1107.486
16	574744.56	8204121.7	-0.58	1106.657
17	574751.18	8204128.12	-0.34	1108.114
18	574757.38	8204135.75	-0.2	1107.704
19	574607.3	8203938.98	-0.3	1106.791
20	574621.34	8203995.11	-0.9	1106.764
21	574636.34	8203971.82	-1.15	1106.612
22	574647.64	8203986.24	-1.4	1106.886
23	574664.7	8204002.27	-1.26	1106.446
24	574679.17	8204020.93	-1.15	1105.928
25	574690.19	8204036.63	-1.4	1106.625
26	574701.68	8204048.9	-1.6	1107.023
27	574716.06	8204060.7	-1.02	1106.491
28	574731.04	8204073.96	-0.78	1107.086
29	574745.78	8204089.51	-0.65	1106.785
30	574759.46	8204103.95	-0.86	1105.926
31	574768.21	8204120.14	-0.76	1104.74
32	574775.75	8204136.78	-0.1	1105.3
33	574619.31	8203921.76	-0.46	1107.379
34	574627.82	8203932.41	-0.46	1107.565
35	574638.17	8203943.89	-0.72	1106.38
36	574650.48	8203959.32	-0.5	1106.341
37	574663.46	8203974.35	-0.9	1106.165
38	574690.55	8204004.69	-2.3	1105.39
39	574702.75	8204020.87	-1.4	1105.988
40	574715.17	8204035.32	-1.12	1105.735
41	574728.14	8204050.36	-0.65	1105.908
42	574740.58	8204065.25	-0.67	1106.89

43	574753.52	8204080.57	-0.86	1105.904
44	574766.41	8204096.03	-1.04	1105.998
45	574780.16	8204111.51	-0.7	1106.669
46	574792.81	8204126.53	-0.55	1107.321
47	574797.7	8204132.02	-0.8	1107.52
48	574652.79	8203930.62	-0.76	1106.763
49	574665.63	8203946.05	-1.2	1106.445
50	574678.48	8203961.07	-0.98	1106.871
51	574691.47	8203976.18	-0.96	1106.92
52	574704.39	8203991.4	-0.9	1106.812
53	574717.43	8204006.71	-0.9	1107.377
54	574730.9	8204022.91	-1.28	1,106
55	574743	8204037.48	-0.76	1106.562
56	574755.32	8204052.33	-1.38	1106.573
57	574781.65	8204083.23	-0.86	1106.836
58	574808.1	8204113.43	-0.58	1106.473
59	574642.55	8203888.03	-0.58	1107.401
60	574645.67	8203889.63	-0.1	1107.299
61	574656.3	8203903.66	-0.45	1106.749
62	574668.66	8203919.37	-0.32	1106.58
63	574681.35	8203934.11	-0.64	1106.267
64	574694.13	8203949.31	-0.56	1106.283
65	574706.78	8203964	-0.8	1106.35
66	574719.6	8203979.84	-1.1	1106.49
67	574733.17	8203995.57	-1.24	1106.339
68	574759.41	8204025.7	-1.2	1106.486
69	574756.56	8204024.46	-0.92	1106.327
70	574796.4	8204070.04	-1	1106.596
71	574796.4	8204070.04	-0.4	1106.721
72	574796.4	8204070.04	-0.92	1107.115
73	574830.42	8204116.17	-0.9	1107.472
74	574669.68	8203888.7	-0.05	1107.101
75	574709.65	8203934.14	-0.2	1108.464
76	574788.39	8203898.33	-0.5	1106.406
77	574799.47	8203898.88	-0.7	1106.042
78	574817.25	8203894.86	-0.42	1107.335
79	574798.37	8203881.95	-0.4	1106.693
80	574796.51	8203854.9	-1.2	1107.282
81	574816.87	8203868.76	-0.75	1107.206
82	574825.41	8203873.45	-0.65	1106.999
83	574820.13	8203855.79	-0.4	1107.542
84	574843.15	8203844.94	-0.4	1107.965
85	574788.39	8203898.33	-0.5	1106.406

86	574799.47	8203898.88	-0.7	1106.042
87	574817.25	8203894.86	-0.42	1107.335
88	574798.37	8203881.95	-0.4	1106.693
89	574796.51	8203854.9	-1.2	1107.282
90	574816.87	8203868.76	-0.75	1107.206
91	574825.41	8203873.45	-0.65	1106.999
92	574820.13	8203855.79	-0.4	1107.542
93	574843.15	8203844.94	-0.4	1107.965
94	574874.79	8204087.65	-0.4	1107.099
95	574856.86	8204068.69	-0.3	1106.605
96	574852.34	8204055.9	-0.3	1107.809
97	574844.87	8204058.3	-0.25	1109.309
98	574868.39	8204075.52	-0.3	1108.007
99	574879.42	8204080.98	-0.2	1107.795
100	574882.56	8204092.68	-0.25	1107.361
101	574681.36	8203903.17	-0.1	1107.099
102	574730.48	8203956.62	-0.5	1106.605
103	574746.37	8203949.4	-0.54	1107.809
104	574744.93	8203975.4	-0.8	1106.309
105	574847.5	8204111.2	-0.25	1106.221
106	574821.49	8204083.75	-1	1107.177
107	574778.15	8204049.08	-1.3	1106.388
108	574770.93	8204062.08	-1.3	1108.097
109	574768.04	8203998.52	-1.2	1107.89
110	574743.48	8203973.96	-1.25	1106.18
111	574697.25	8203891.61	-0.57	1107.627
112	574856.17	8204102.53	-0.2	1107.612
113	574705.92	8203903.17	-0.48	1106.311
114	574833.05	8204082.31	-1.18	1107.176
115	574825.83	8204076.53	-0.1	1106.566
116	574744.93	8203986.96	-0.45	1107.327
117	574799.82	8204038.97	-0.55	1108.032
118	574753.59	8203950.84	-0.8	1106.24
119	574779.6	8204015.87	-0.7	1107.024
120	574769.49	8203981.18	-1.2	1107.063
121	574801.27	8204002.85	-0.8	1107.536
122	574733.37	8203868.5	-0.8	1109.309
123	574701.59	8203887.28	-0.3	1109.461
124	574730.48	8203910.39	-0.5	1111.955
125	574824.38	8204040.41	-0.3	1111.769
126	574811.38	8204008.63	-0.3	1111.102
127	574739.15	8203917.62	-0.98	1108.007
128	574755.27	8203838.7	-1.3	1108.186

129	574704.48	8203878.61	-0.3	1109.882
130	574736.26	8203842.49	-0.3	1108.327
131	574711.7	8203880.05	-0.35	1109.998
132	574703.65	8203858.91	-0.3	1106.521
133	574830.43	8204017.61	-0.3	1106.2
134	574702.28	8203863.47	-0.3	1106.813
135	574816.75	8204001.19	-0.4	1107.361
136	574739.22	8203903.14	-0.5	1106.661
137	574826.33	8204023.53	-0.2	1108.213
138	574771.6	8203953.3	-1.3	1108.072
139	574809.91	8203992.98	-0.7	1106.776
140	574786.19	8203961.97	-1.4	1108.341
141	574784.37	8203949.66	-1.35	1105.864
142	574771.67	8203934.66	-1	1106.761
143	574835.36	8204013.09	-0.35	1107.469
144	574787.57	8203991.27	-1.15	1106.17
145	574735.7	8203935.84	-0.5	1106.452
146	574761.64	8203936.43	-1.25	1106.221
147	574743.36	8203848.56	-1	1106.177
148	574742.18	8203862.12	-1.2	1106.388
149	574802.93	8203984.2	-1.1	1106.097
150	574835.94	8203999.53	-0.3	1106.89
151	574818.26	8203988.91	-0.58	1106.18
152	574840.08	8203994.81	-0.3	1106.521
153	574844.8	8203988.91	-0.3	1106.2
154	574847.15	8203978.89	-0.3	1106.813
155	574832.41	8203987.74	-0.4	1107.361
156	574829.46	8203984.2	-0.5	1106.661
157	574874.28	8203895.15	-0.2	1108.213
158	574763.41	8203847.97	-1.3	1108.072
159	574807.64	8203876.28	-0.7	1106.776
160	574783.79	8203917.31	-1.4	1108.341
161	574771.08	8203835.59	-1.35	1105.864
162	574799.44	8203958.77	-0.84	1107.355
163	574721.38	8203855.09	-0.35	1107.067
164	574764.28	8203916.46	-0.9	1108.915
165	574791.69	8203932.55	-0.8	1108.146
166	574746.41	8203884.29	-0.5	1108.716
167	574758.68	8203815.76	-0.9	1108.04
168	574783.95	8203828.87	-1.25	1106.221
169	574737.99	8203830.46	-1	1106.177
170	574745.07	8203831.55	-1.2	1106.388
171	574776.11	8203816.3	-1.1	1106.097

172	574764.28	8203911.7	-0.58	1106.18
173	574761.37	8203876.65	-0.4	1107.099
174	574855.13	8203876.65	-0.3	1106.605
175	574866.85	8203870.53	-0.3	1107.809
176	574878.06	8203862.28	-0.25	1109.309
177	574866.85	8203906.61	-0.3	1106.89
178	574843.92	8203861.77	-0.5	1108.126
179	574844.94	8203965.72	-0.3	1108.007
180	574615.64	8203904.57	-0.2	1107.795
181	574625.83	8203892.85	-0.25	1107.361
182	574783.98	8203799.17	-1.5	1108.007
183	574792.23	8203778.85	-1.5	1108.007
184	574797.31	8203757.47	-1.5	1108.007
185	574793.5	8203686.77	-1.5	1108.007
186	574821.23	8203657.78	-1.5	1108.007
187	574805.78	8203626.66	-1.5	1108.007
188	574787.58	8203607.61	-1.5	1108.007
189	574752.86	8203564.43	-1.5	1108.007
190	574766.83	8203536.7	-1.5	1108.007
191	574795.75	8203723.86	-1.5	1108.007
192	574766.22	8203594.32	-1.5	1108.007
193	574822.61	8203971.87	-0.5	1106.605
194	574812.98	8203935.28	-0.5	1106.605
195	574841.87	8203897.72	-0.5	1106.605

Appendix J: Real Time Daily Sedimentation in the Makoye Reservoir During The 2015/2016 And 2016/2017 Warm-Wet Seasons

Date	Sediment depth (m/day)	Daily Means	Cumulative Sediment depth (m/day)	Sediment volume (m^3/day)	Sediment load (t/day)	Cumulative volume of sediment (m^3/day)	Cumulative load of sediment (t/day)
4/4/2016	0.00282	0.000118	0.00282	184.49	380.0494	184.49	380.0494
4/5/2016	0.00008	0.000003	0.0029	5.24	10.7944	189.73	390.8438
4/6/2016	0.0001	0.000004	0.003	6.55	13.493	196.28	404.3368
4/7/2016	0.00012	0.000005	0.00312	7.86	16.1916	204.14	420.5284
4/8/2016	0.00009	0.000004	0.00321	5.89	12.1334	210.04	432.6824
4/9/2016	0.00015	0.000006	0.00336	9.83	20.2498	219.86	452.9116
4/10/2016	0.00012	0.000005	0.00348	7.86	16.1916	227.72	469.1032
4/11/2016	0.00009	0.000004	0.00357	5.9	12.154	233.62	481.2572
4/12/2016	0.00009	0.000004	0.00366	5.9	12.154	239.51	493.3906
4/13/2016	0.000075	0.000003	0.003735	4.94	10.1764	244.45	503.567
4/14/2016	0.0002	0.000008	0.003935	13.08	26.9448	257.53	530.5118
4/15/2016	0.00069	0.000029	0.004625	45.24	93.1944	302.78	623.7268
4/16/2016	0.000453	0.000019	0.005078	29.7	61.182	332.48	684.9088
4/17/2016	0.000005	0	0.005083	0.33	0.6798	332.8	685.568
11/28/2016	0.00003	0.000001	0.005113	1.97	4.0582	334.77	689.6262
11/29/2016	0.000009	0	0.005122	0.59	1.2154	335.36	690.8416
11/30/2016	0.000006	0	0.005128	0.39	0.8034	335.75	691.645
12/1/2016	0.0001	0.000004	0.005228	6.56	13.5136	342.31	705.1586
12/2/2016	0.000293	0.000012	0.005521	19.22	39.5932	361.53	744.7518
12/3/2016	0	0	0.005521	0	0	361.53	744.7518
12/4/2016	0.000001	0	0.005522	0.07	0.1442	361.6	744.896
12/5/2016	0.000001	0	0.005523	0.07	0.1442	361.67	745.0402
12/6/2016	0	0	0.005523	0	0	361.67	745.0402
12/7/2016	0	0	0.005523	0	0	361.67	745.0402
12/8/2016	0	0	0.005523	0	0	361.67	745.0402
12/9/2016	0	0	0.005523	0	0	361.67	745.0402
12/10/2016	0	0	0.005523	0	0	361.67	745.0402
12/11/2016	0	0	0.005523	0	0	361.67	745.0402
12/12/2016	0	0	0.005523	0	0	361.67	745.0402
12/13/2016	0	0	0.005523	0	0	361.67	745.0402
12/14/2016	0	0	0.005523	0	0	361.67	745.0402
12/15/2016	0	0	0.005523	0	0	361.67	745.0402
12/16/2016	0	0	0.005523	0	0	361.67	745.0402
12/17/2016	0	0	0.005523	0	0	361.67	745.0402
12/18/2016	0	0	0.005523	0	0	361.67	745.0402
12/19/2016	0	0	0.005523	0	0	361.67	745.0402
12/20/2016	0	0	0.005523	0	0	361.67	745.0402
12/21/2016	0.000211	0.000009	0.005734	13.84	28.5104	375.51	773.5506
12/22/2016	0.000082	0.000003	0.005816	5.38	11.0828	380.89	784.6334
12/23/2016	0.000168	0.000007	0.005984	11.02	22.7012	391.91	807.3346
12/24/2016	0.000272	0.000011	0.006256	17.85	36.771	409.76	844.1056
12/25/2016	0.000684	0.000029	0.00694	44.9	92.494	454.66	936.5996
12/26/2016	0.00185	0.000077	0.00879	121.53	250.3518	576.18	1186.9308
12/27/2016	0.005064	0.000211	0.013854	333.37	686.7422	909.55	1873.673
12/28/2016	0.00261	0.000109	0.016464	172.24	354.8144	1081.79	2228.4874
12/29/2016	0.000036	0.000002	0.0165	2.38	4.9028	1084.17	2233.3902
12/30/2016	0.000368	0.000015	0.016868	24.31	50.0786	1108.48	2283.4688
12/31/2016	0.000018	0.000001	0.016886	1.19	2.4514	1109.66	2285.8996
1/1/2017	0	0	0.016886	0	0	1109.66	2285.8996
1/2/2017	0.000087	0.000004	0.016973	5.75	11.845	1115.41	2297.7446

1/3/2017	0.0003	0.000013	0.017273	19.82	40.8292	1135.23	2338.5738
1/4/2017	0	0	0.017273	0	0	1135.23	2338.5738
1/5/2017	0	0	0.017273	0	0	1135.23	2338.5738
1/6/2017	0	0	0.017273	0	0	1135.23	2338.5738
1/7/2017	0.000072	0.000003	0.017345	4.76	9.8056	1139.99	2348.3794
1/8/2017	0.000016	0.000001	0.017361	1.06	2.1836	1141.05	2350.563
1/9/2017	0	0	0.017361	0	0	1141.05	2350.563
1/10/2017	0	0	0.017361	0	0	1141.05	2350.563
1/11/2017	0	0	0.017361	0	0	1141.05	2350.563
1/12/2017	0	0	0.017361	0	0	1141.05	2350.563
1/13/2017	0	0	0.017361	0	0	1141.05	2350.563
1/14/2017	0	0	0.017361	0	0	1141.05	2350.563
1/15/2017	0	0	0.017361	0	0	1141.05	2350.563
1/16/2017	0	0	0.017361	0	0	1141.05	2350.563
1/17/2017	0.00006	0.000003	0.017421	3.97	8.1782	1145.01	2358.7206
1/18/2017	0	0	0.017421	0	0	1145.01	2358.7206
1/19/2017	0	0	0.017421	0	0	1145.01	2358.7206
1/20/2017	0	0	0.017421	0	0	1145.01	2358.7206
1/21/2017	0	0	0.017421	0	0	1145.01	2358.7206
1/22/2017	0	0	0.017421	0	0	1145.01	2358.7206
1/23/2017	0.000325	0.000014	0.017746	21.48	44.2488	1166.49	2402.9694
1/24/2017	0.000042	0.000002	0.017788	2.78	5.7268	1169.27	2408.6962
1/25/2017	0	0	0.017788	0	0	1169.27	2408.6962
1/26/2017	0	0	0.017788	0	0	1169.27	2408.6962
1/27/2017	0	0	0.017788	0	0	1169.27	2408.6962
1/28/2017	0	0	0.017788	0	0	1169.27	2408.6962
1/29/2017	0.000184	0.000008	0.017972	12.16	25.0496	1181.43	2433.7458
1/30/2017	0.000687	0.000029	0.018659	45.43	93.5858	1226.86	2527.3316
1/31/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/1/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/2/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/3/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/4/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/5/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/6/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/7/2017	0	0	0.018659	0	0	1226.86	2527.3316
2/8/2017	0.00001	0	0.018669	0.66	1.3596	1227.52	2528.6912
2/9/2017	0.000426	0.000018	0.019095	28.18	58.0508	1255.7	2586.742
2/10/2017	0.00011	0.000005	0.019205	7.28	14.9968	1262.98	2601.7388
2/11/2017	0.00007	0.000003	0.019275	4.63	9.5378	1267.61	2611.2766
2/12/2017	0.0001	0.000004	0.019375	6.6	13.596	1274.21	2624.8726
2/13/2017	0.000377	0.000016	0.019752	24.95	51.397	1299.16	2676.2696
2/14/2017	0.00064	0.000027	0.020392	42.36	87.2616	1341.52	2763.5312
2/15/2017	0.000374	0.000016	0.020766	24.76	51.0056	1366.29	2814.5574
2/16/2017	0.001488	0.000062	0.022254	98.59	203.0954	1464.87	3017.6322
2/17/2017	0.000226	0.000009	0.02248	29.58	60.9348	1479.85	3048.491

SV=(20661(Depth)^2-29262*(Depth)+5905)* *Sediment Load = SV*2.06*

Appendix K: Full HRU Report for the SWAT Simulation of Water flows at Chimbumbu Gauging Station

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SWAT model simulation Date: 12/21/2017 12:00:00 AM Time: 00:00:00

MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 0 / 0 / 0 [percent]

Number of HRUs: 148

Number of Subbasins: 29

Area [ha] Area[acres]

Watershed
90396.0000 223373.0358

Area [ha] Area[acres] percentWat.Area

LANDUSE:

Agricultural Land-Row Crops --> AGRR
30273.7500 74807.9499 33.49

Forest-Deciduous --> FRSD
13608.0000 33626.0484 15.05

Forest-Mixed --> FRST
607.5000 1501.1629 0.67

Range-Brush --> RNGB
29382.7500 72606.2444 32.50

Range-Grasses --> RNGE
16524.0000 40831.6302 18.28

SOILS:

Chromic Luvisols-Lc54
66825.0000 165127.9163 73.92

Orthic Ferralsols-Fo77
23571.0000 58245.1196 26.08

SLOPE:

0-20 90396.0000 223373.0358 100.00

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN# 1 5589.0000 13810.6985 6.18

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1822.5000 4503.4886 2.02 32.61

Forest-Deciduous --> FRSD
567.0000 1401.0854 0.63 10.14

Forest-Mixed --> FRST
101.2500 250.1938 0.11 1.81

Range-Brush --> RNGB
1660.5000 4103.1785 1.84 29.71

Range-Grasses --> RNGE
1437.7500 3552.7521 1.59 25.72

SOILS:

Chromic Luvisols-Lc54
5589.0000 13810.6985 6.18 100.00

SLOPE:0-20 5589.0000 13810.6985
6.18 100.00

HRUs

1 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1822.5000 4503.4886 2.02 32.61 1

2 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 567.0000 1401.0854 0.63 10.14 2

3 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20 101.2500 250.1938 0.11 1.81 3

4 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 1660.5000 4103.1785 1.84 29.71 4

5 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 1437.7500 3552.7521 1.59 25.72 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 2
344.2500 850.6590 0.38

LANDUSE:

Agricultural Land-Row Crops --> AGRR
60.7500 150.1163 0.07 17.65

Forest-Deciduous --> FRSD
182.2500 450.3489 0.20 52.94

Range-Brush --> RNGB
101.2500 250.1938 0.11 29.41

SOILS:

Chromic Luvisols-Lc54
344.2500 850.6590 0.38 100.00

SLOPE:

0-20
344.2500 850.6590 0.38 100.00

HRUs

6 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 60.7500 150.1163 0.07 17.65 1

7 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 182.2500 450.3489 0.20 52.94 2

8 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 101.2500 250.1938 0.11 29.41 3

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN #3 2733.7500 6755.2329 3.02

LANDUSE:

Agricultural Land-Row Crops --> AGRR	546.7500	1351.0466	0.60	20.00
Forest-Deciduous --> FRSD	243.0000	600.4652	0.27	8.89
Forest-Mixed --> FRST	40.5000	100.0775	0.04	1.48
Range-Brush --> RNGB	891.0000	2201.7056	0.99	32.59
Range-Grasses --> RNGE	1012.5000	2501.9381	1.12	37.04

SOILS:

Chromic Luvisols-Lc54	2733.7500	6755.2329	3.02	100.00

SLOPE:

0-20	2733.7500	6755.2329	3.02	100.00

HRUs

9 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 546.7500 1351.0466 0.60 20.00 1

10 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 243.0000 600.4652 0.27 8.89 2

11 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20 40.5000 100.0775 0.04 1.48 3

12 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 891.0000 2201.7056 0.99 32.59 4

13 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 1012.5000 2501.9381 1.12 37.04 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN# 4 3017.2500 7455.7756 3.34

LANDUSE:

Agricultural Land-Row Crops --> AGRR
324.0000 800.6202 0.36 10.74

Forest-Deciduous --> FRSD
526.5000 1301.0078 0.58 17.45

Range-Brush --> RNGB
1599.7500 3953.0622 1.77 53.02

Range-Grasses --> RNGE
567.0000 1401.0854 0.63 18.79

SOILS:

Chromic Luvisols-Lc54
3017.2500 7455.7756 3.34 100.00

SLOPE:

0-20
3017.2500 7455.7756 3.34 100.00

HRUs

14 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 324.0000 800.6202 0.36 10.74 1

15 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 526.5000 1301.0078 0.58 17.45 2

16 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 1599.7500 3953.0622 1.77 53.02 3

17 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 567.0000 1401.0854 0.63 18.79 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 5
1073.2500 2652.0544 1.19

LANDUSE:

Agricultural Land-Row Crops --> AGRR
222.7500 550.4264 0.25 20.75

Forest-Deciduous --> FRSD
182.2500 450.3489 0.20 16.98

Range-Brush --> RNGB
425.2500 1050.8140 0.47 39.62

Range-Grasses --> RNGE
243.0000 600.4652 0.27 22.64

SOILS:

Chromic Luvisols-Lc54
1073.2500 2652.0544 1.19 100.00

SLOPE:

0-20
1073.2500 2652.0544 1.19 100.00

HRUs

18 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 222.7500 550.4264 0.25 20.75 1

19 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 182.2500 450.3489 0.20 16.98 2

20 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 425.2500 1050.8140 0.47 39.62 3

21 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 243.0000 600.4652 0.27 22.64 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 6
5325.7500 13160.1945 5.89

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1518.7500 3752.9072 1.68 28.52

Forest-Deciduous --> FRSD
1336.5000 3302.5583 1.48 25.10

Forest-Mixed --> FRST
40.5000 100.0775 0.04 0.76

Range-Brush --> RNGB
1498.5000 3702.8684 1.66 28.14

Range-Grasses --> RNGE
931.5000 2301.7831 1.03 17.49

SOILS:

Chromic Luvisols-Lc54
5325.7500 13160.1945 5.89 100.00

SLOPE:

0-20 5325.7500 13160.1945 5.89
100.00

HRUs

22 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1518.7500 3752.9072 1.68
28.52 1

23 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
1336.5000 3302.5583 1.48 25.10 2

24 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 0.76 3

25 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
1498.5000 3702.8684 1.66 28.14 4

26 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
931.5000 2301.7831 1.03 17.49 5

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 7
2754.0000 6805.2717 3.05

LANDUSE:

Agricultural Land-Row Crops --> AGRR
891.0000 2201.7056 0.99 32.35

Forest-Deciduous --> FRSD
303.7500 750.5814 0.34 11.03

Forest-Mixed --> FRST
40.5000 100.0775 0.04 1.47

Range-Brush --> RNGB
992.2500 2451.8994 1.10 36.03

Range-Grasses --> RNGE
526.5000 1301.0078 0.58 19.12

SOILS: Chromic Luvisols-Lc54 2754.0000
6805.2717 3.05 100.00

SLOPE:

0-20
2754.0000 6805.2717 3.05 100.00

HRUs

27 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 891.0000 2201.7056 0.99 32.35 1

28 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
303.7500 750.5814 0.34 11.03 2

29 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 1.47 3

30 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
992.2500 2451.8994 1.10 36.03 4

31 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
526.5000 1301.0078 0.58 19.12 5

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 8
2085.7500 5153.9925 2.31

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1275.7500 3152.4420 1.41 61.17

Forest-Deciduous --> FRSD
101.2500 250.1938 0.11 4.85

Range-Brush --> RNGB
283.5000 700.5427 0.31 13.59

Range-Grasses --> RNGE
425.2500 1050.8140 0.47 20.39

SOILS:

Chromic Luvisols-Lc54
2085.7500 5153.9925 2.31 100.00

SLOPE:

0-20
2085.7500 5153.9925 2.31 100.00

HRUs

32 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1275.7500 3152.4420 1.41 61.17 1

33 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
101.2500 250.1938 0.11 4.85 2

34 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
283.5000 700.5427 0.31 13.59 3

35 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
425.2500 1050.8140 0.47 20.39 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 9
10732.5000 26520.5441 11.87

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1842.7500 4553.5274 2.04 17.17

Forest-Deciduous --> FRSD
3361.5000 8306.4346 3.72 31.32

Forest-Mixed --> FRST
121.5000 300.2326 0.13 1.13

Range-Brush --> RNGB
4272.7500 10558.1789 4.73 39.81

Range-Grasses --> RNGE
1134.0000 2802.1707 1.25 10.57

SOILS:

Chromic Luvisols-Lc54
5001.7500 12359.5743 5.53 46.60

Orthic Ferralsols-Fo77
5730.7500 14160.9698 6.34 53.40

SLOPE:

0-20
10732.5000 26520.5441 11.87 100.00

HRUs

36 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 972.0000 2401.8606 1.08 9.06 1

37 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 870.7500 2151.6668 0.96 8.11 2

38 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
1458.0000 3602.7909 1.61 13.58 3

39 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
1903.5000 4703.6437 2.11 17.74 4

40 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
81.0000 200.1551 0.09 0.75 5

41 Forest-Mixed --> FRST/Orthic Ferralsols-Fo77/0-20
40.5000 100.0775 0.04 0.38 6

42 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
1660.5000 4103.1785 1.84 15.47 7

43 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
2612.2500 6455.0004 2.89 24.34 8

44 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
830.2500 2051.5893 0.92 7.74 9

45Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
303.7500 750.5814 0.34 2.83 10

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 10
4799.2500 11859.1867 5.31

LANDUSE:

Agricultural Land-Row Crops --> AGRR
2430.0000 6004.6515 2.69 50.63

Forest-Deciduous --> FRSD
162.0000 400.3101 0.18 3.38

Forest-Mixed --> FRST
20.2500 50.0388 0.02 0.42

Range-Brush --> RNGB
891.0000 2201.7056 0.99 18.57

Range-Grasses --> RNGE
1296.0000 3202.4808 1.43 27.00

SOILS:

Chromic Luvisols-Lc54
4799.2500 11859.1867 5.31 100.00

SLOPE:

0-20
4799.2500 11859.1867 5.31 100.00

HRUs

46 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 2430.0000 6004.6515 2.69 50.63 1

47 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
162.0000 400.3101 0.18 3.38 2

48 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
20.2500 50.0388 0.02 0.42 3

49 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
891.0000 2201.7056 0.99 18.57 4

50 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
1296.0000 3202.4808 1.43 27.00 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 11
3685.5000 9107.0548 4.08

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1458.0000 3602.7909 1.61 39.56

Forest-Deciduous --> FRSD
465.7500 1150.8915 0.52 12.64

Forest-Mixed --> FRST
40.5000 100.0775 0.04 1.10

Range-Brush --> RNGB
1215.0000 3002.3258 1.34 32.97

Range-Grasses --> RNGE
506.2500 1250.9691 0.56 13.74

SOILS:

Orthic Ferralsols-Fo77
3543.7500 8756.7834 3.92 96.15

Chromic Luvisols-Lc54
141.7500 350.2713 0.16 3.85

SLOPE:

0-20
3685.5000 9107.0548 4.08 100.00

HRUs

51 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 1458.0000 3602.7909 1.61 39.56 1

52 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
121.5000 300.2326 0.13 3.30 2

53 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
344.2500 850.6590 0.38 9.34 3

54 Forest-Mixed --> FRST/Orthic Ferralsols-Fo77/0-20
40.5000 100.0775 0.04 1.10 4

55 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
20.2500 50.0388 0.02 0.55 5

56 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
1194.7500 2952.2870 1.32 32.42 6

57Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
506.2500 1250.9691 0.56 13.74 7

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 12
2673.0000 6605.1167 2.96

LANDUSE:

Agricultural Land-Row Crops --> AGRR
769.5000 1901.4730 0.85 28.79

Forest-Deciduous --> FRSD
648.0000 1601.2404 0.72 24.24

Forest-Mixed --> FRST
20.2500 50.0388 0.02 0.76

Range-Brush --> RNGB
931.5000 2301.7831 1.03 34.85

Range-Grasses --> RNGE
303.7500 750.5814 0.34 11.36

SOILS:

Chromic Luvisols-Lc54
2673.0000 6605.1167 2.96 100.00

SLOPE:

0-20
2673.0000 6605.1167 2.96 100.00

HRUs

58 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 769.5000 1901.4730 0.85 28.79 1

59 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 648.0000 1601.2404 0.72 24.24 2

60 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20 20.2500 50.0388 0.02 0.76 3

61 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 931.5000 2301.7831 1.03 34.85 4

62 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 303.7500 750.5814 0.34 11.36 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 13
2511.0000 6204.8066 2.78

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1235.2500 3052.3645 1.37 49.19

Forest-Deciduous --> FRSD
81.0000 200.1551 0.09 3.23

Range-Brush --> RNGB
486.0000 1200.9303 0.54 19.35

Range-Grasses --> RNGE
708.7500 1751.3567 0.78 28.23

SOILS:

Chromic Luvisols-Lc54
1316.2500 3252.5196 1.46 52.42

Orthic Ferralsols-Fo77
1194.7500 2952.2870 1.32 47.58

SLOPE:

0-20
2511.0000 6204.8066 2.78 100.00

HRUs

63 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 465.7500 1150.8915 0.52 18.55 1

64 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 769.5000 1901.4730 0.85 30.65 2

65 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 81.0000 200.1551 0.09 3.23 3

66 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 283.5000 700.5427 0.31 11.29 4

67 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20 202.5000 500.3876 0.22 8.06 5

68 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 486.0000 1200.9303 0.54 19.35 6

69Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20 222.7500 550.4264 0.25 8.87 7

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 14
4151.2500 10257.9463 4.59

LANDUSE:

Agricultural Land-Row Crops --> AGRR
587.2500 1451.1241 0.65 14.15

Forest-Deciduous --> FRSD
1316.2500 3252.5196 1.46 31.71

Range-Brush --> RNGB
1437.7500 3552.7521 1.59 34.63

Range-Grasses --> RNGE
810.0000 2001.5505 0.90 19.51

SOILS:

Orthic Ferralsols-Fo77
4151.2500 10257.9463 4.59 100.00

SLOPE:

0-20
4151.2500 10257.9463 4.59 100.00

HRUs

70 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 587.2500 1451.1241 0.65 14.15 1

71 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
1316.2500 3252.5196 1.46 31.71 2

72 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
1437.7500 3552.7521 1.59 34.63 3

73Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
810.0000 2001.5505 0.90 19.51 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 15
3746.2500 9257.1711 4.14

LANDUSE:

Agricultural Land-Row Crops --> AGRR
40.5000 100.0775 0.04 1.08

Forest-Deciduous --> FRSD
2247.7500 5554.3026 2.49 60.00

Range-Brush --> RNGB
1194.7500 2952.2870 1.32 31.89

Range-Grasses --> RNGE
263.2500 650.5039 0.29 7.03

SOILS:

Chromic Luvisols-Lc54
506.2500 1250.9691 0.56 13.51

Orthic Ferralsols-Fo77
3240.0000 8006.2020 3.58 86.49

SLOPE:

0-20
3746.2500 9257.1711 4.14 100.00

HRUs

74 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 40.5000 100.0775 0.04 1.08 1

75 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
121.5000 300.2326 0.13 3.24 2

76 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
2126.2500 5254.0701 2.35 56.76 3

77 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
162.0000 400.3101 0.18 4.32 4

78 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
1032.7500 2551.9769 1.14 27.57 5

79 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
182.2500 450.3489 0.20 4.86 6

80Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
81.0000 200.1551 0.09 2.16 7

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 16
243.0000 600.4652 0.27

LANDUSE:

Forest-Deciduous --> FRSD
20.2500 50.0388 0.02 8.33

Range-Brush --> RNGB
182.2500 450.3489 0.20 75.00

Range-Grasses --> RNGE
40.5000 100.0775 0.04 16.67

SOILS:

Orthic Ferralsols-Fo77
243.0000 600.4652 0.27 100.00

SLOPE:

0-20
243.0000 600.4652 0.27 100.00

HRUs

81 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
20.2500 50.0388 0.02 8.33 1

82 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
182.2500 450.3489 0.20 75.00 2

83Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
40.5000 100.0775 0.04 16.67 3

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 17
2754.0000 6805.2717 3.05

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1741.5000 4303.3336 1.93 63.24

Forest-Deciduous --> FRSD
60.7500 150.1163 0.07 2.21

Range-Brush --> RNGB
607.5000 1501.1629 0.67 22.06

Range-Grasses --> RNGE
344.2500 850.6590 0.38 12.50

SOILS:

Chromic Luvisols-Lc54
2754.0000 6805.2717 3.05 100.00

SLOPE:

0-20
2754.0000 6805.2717 3.05 100.00

HRUs

84 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1741.5000 4303.3336 1.93 63.24 1

85 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
60.7500 150.1163 0.07 2.21 2

86 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
607.5000 1501.1629 0.67 22.06 3

87 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
344.2500 850.6590 0.38 12.50 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 18
526.5000 1301.0078 0.58

LANDUSE:

Agricultural Land-Row Crops --> AGRR
162.0000 400.3101 0.18 30.77

Forest-Deciduous --> FRSD
20.2500 50.0388 0.02 3.85

Range-Brush --> RNGB
303.7500 750.5814 0.34 57.69

Range-Grasses --> RNGE
40.5000 100.0775 0.04 7.69

SOILS:

Chromic Luvisols-Lc54
141.7500 350.2713 0.16 26.92

Orthic Ferralsols-Fo77
384.7500 950.7365 0.43 73.08

SLOPE:

0-20
526.5000 1301.0078 0.58 100.00

HRUs

88 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 101.2500 250.1938 0.11 19.23 1

89 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 60.7500 150.1163 0.07 11.54 2

90 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
20.2500 50.0388 0.02 3.85 3

91 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
303.7500 750.5814 0.34 57.69 4

92 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 7.69 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 19
2956.5000 7305.6593 3.27

LANDUSE:

Agricultural Land-Row Crops --> AGRR
465.7500 1150.8915 0.52 15.75

Forest-Deciduous --> FRSD
364.5000 900.6977 0.40 12.33

Forest-Mixed --> FRST
20.2500 50.0388 0.02 0.68

Range-Brush --> RNGB
1701.0000 4203.2561 1.88 57.53

Range-Grasses --> RNGE
405.0000 1000.7753 0.45 13.70

SOILS:

Chromic Luvisols-Lc54
2956.5000 7305.6593 3.27 100.00

SLOPE:

0-20
2956.5000 7305.6593 3.27 100.00

HRUs

93 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 465.7500 1150.8915 0.52 15.75 1

94 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
364.5000 900.6977 0.40 12.33 2

95 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
20.2500 50.0388 0.02 0.68 3

96 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
1701.0000 4203.2561 1.88 57.53 4

97 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
405.0000 1000.7753 0.45 13.70 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 20
2409.7500 5954.6127 2.67

LANDUSE:

Agricultural Land-Row Crops --> AGRR
850.5000 2101.6280 0.94 35.29

Forest-Deciduous --> FRSD
344.2500 850.6590 0.38 14.29

Forest-Mixed --> FRST
40.5000 100.0775 0.04 1.68

Range-Brush --> RNGB
627.7500 1551.2016 0.69 26.05

Range-Grasses --> RNGE
546.7500 1351.0466 0.60 22.69

SOILS:

Chromic Luvisols-Lc54
2126.2500 5254.0701 2.35 88.24

Orthic Ferralsols-Fo77
283.5000 700.5427 0.31 11.76

SLOPE:

0-20
2409.7500 5954.6127 2.67 100.00

HRUs

98 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 749.2500 1851.4342 0.83 31.09 1

99 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 101.2500 250.1938 0.11 4.20 2

100 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
324.0000 800.6202 0.36 13.45 3

101 Forest-Deciduous --> FRSD/Orthic Ferralsols-Fo77/0-20
20.2500 50.0388 0.02 0.84 4

102 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 1.68 5

103 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
587.2500 1451.1241 0.65 24.37 6

104 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20
40.5000 100.0775 0.04 1.68 7

105Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
425.2500 1050.8140 0.47 17.65 8

106 Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20
121.5000 300.2326 0.13 5.04 9

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 21
263.2500 650.5039 0.29

LANDUSE:

Agricultural Land-Row Crops --> AGRR
81.0000 200.1551 0.09 30.77

Forest-Deciduous --> FRSD
60.7500 150.1163 0.07 23.08

Range-Brush --> RNGB
40.5000 100.0775 0.04 15.38

Range-Grasses --> RNGE
81.0000 200.1551 0.09 30.77

SOILS:

Chromic Luvisols-Lc54
263.2500 650.5039 0.29 100.00

SLOPE:

0-20
263.2500 650.5039 0.29 100.00

HRUs

107 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 81.0000 200.1551 0.09
30.77 1

108 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
60.7500 150.1163 0.07 23.08 2

109 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 15.38 3

110Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
81.0000 200.1551 0.09 30.77 4

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 22
405.0000 1000.7753 0.45

LANDUSE:

Agricultural Land-Row Crops --> AGRR
40.5000 100.0775 0.04 10.00

Forest-Mixed --> FRST
40.5000 100.0775 0.04 10.00

Range-Brush --> RNGB
263.2500 650.5039 0.29 65.00

Range-Grasses --> RNGE
60.7500 150.1163 0.07 15.00

SOILS:

Chromic Luvisols-Lc54
405.0000 1000.7753 0.45 100.00

SLOPE:

0-20
405.0000 1000.7753 0.45 100.00

HRUs

111 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 40.5000 100.0775 0.04
10.00 1

112 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 10.00 2

113 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
263.2500 650.5039 0.29 65.00 3

114Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
60.7500 150.1163 0.07 15.00 4

Area [ha] Area[acres] percentWat.Area
percentSub.Area

SUBBASIN # 23
5953.5000 14711.3962 6.59

LANDUSE:

Agricultural Land-Row Crops --> AGRR
2936.2500 7255.6206 3.25 49.32

Forest-Mixed --> FRST
20.2500 50.0388 0.02 0.34

Range-Brush --> RNGB
1113.7500 2752.1319 1.23 18.71

Range-Grasses --> RNGE
1883.2500 4653.6049 2.08 31.63

SOILS:

Chromic Luvisols-Lc54
1215.0000 3002.3258 1.34 20.41

Orthic Ferralsols-Fo77
4738.5000 11709.0704 5.24 79.59

SLOPE:

0-20
5953.5000 14711.3962 6.59 100.00

HRUs

115 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 607.5000 1501.1629 0.67 10.20 1

116 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 2328.7500 5754.4577 2.58 39.12 2

117Forest-Mixed --> FRST/Orthic Ferralsols-Fo77/0-20 20.2500 50.0388 0.02 0.34 3

118 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 263.2500 650.5039 0.29 4.42 4

119 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20 850.5000 2101.6280 0.94 14.29 5

120Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 344.2500 850.6590 0.38 5.78 6

121 Range-Grasses --> RNGE/Orthic Ferralsols-Fo77/0-20 1539.0000 3802.9460 1.70 25.85 7

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 24
243.0000 600.4652 0.27

LANDUSE:

Agricultural Land-Row Crops --> AGRR
141.7500 350.2713 0.16 58.33

Range-Brush --> RNGB
81.0000 200.1551 0.09 33.33

Range-Grasses --> RNGE
20.2500 50.0388 0.02 8.33

SOILS:

Chromic Luvisols-Lc54
243.0000 600.4652 0.27 100.00

SLOPE:

0-20
243.0000 600.4652 0.27 100.00

HRUs

122 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 141.7500 350.2713 0.16 58.33 1

123 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 81.0000 200.1551 0.09 33.33 2

124Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 20.2500 50.0388 0.02 8.33 3

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 25
6682.5000 16512.7916 7.39

LANDUSE:

Agricultural Land-Row Crops --> AGRR
3746.2500 9257.1711 4.14 56.06

Forest-Deciduous --> FRSD
40.5000 100.0775 0.04 0.61

Range-Brush --> RNGB
1113.7500 2752.1319 1.23 16.67

Range-Grasses --> RNGE
1782.0000 4403.4111 1.97 26.67

SOILS:

Chromic Luvisols-Lc54
6621.7500 16362.6753 7.33 99.09

Orthic Ferralsols-Fo77
60.7500 150.1163 0.07 0.91

SLOPE:

0-20
6682.5000 16512.7916 7.39 100.00

HRUs

125 Agricultural Land-Row Crops-->AGRR/Chromic Luvisols-Lc54/0-20 3705.7500 9157.0935 4.10 55.45 1

126 Agricultural Land-Row Crops --> AGRR/Orthic Ferralsols-Fo77/0-20 40.5000 100.0775 0.04 0.61 2

127 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 40.5000 100.0775 0.04 0.61 3

128 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 1093.5000 2702.0932 1.21 16.36 4

129 Range-Brush --> RNGB/Orthic Ferralsols-Fo77/0-20 20.2500 50.0388 0.02 0.30 5

130 Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 1782.0000 4403.4111 1.97 26.67 6

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 26
3361.5000 8306.4346 3.72

LANDUSE:

Agricultural Land-Row Crops --> AGRR
648.0000 1601.2404 0.72 19.28

Forest-Deciduous --> FRSD
243.0000 600.4652 0.27 7.23

Forest-Mixed --> FRST
20.2500 50.0388 0.02 0.60

Range-Brush --> RNGB
2085.7500 5153.9925 2.31 62.05

Range-Grasses --> RNGE
364.5000 900.6977 0.40 10.84

SOILS:

Chromic Luvisols-Lc54
3361.5000 8306.4346 3.72 100.00

SLOPE:

0-20
3361.5000 8306.4346 3.72 100.00

HRUs

131 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 648.0000 1601.2404 0.72 19.28 1

132 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 243.0000 600.4652 0.27 7.23 2

133 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20 20.2500 50.0388 0.02 0.60 3

134 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 2085.7500 5153.9925 2.31 62.05 4

135Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 364.5000 900.6977 0.40 10.84 5

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 27
2916.0000 7205.5818 3.23

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1579.5000 3903.0235 1.75 54.17

Forest-Deciduous --> FRSD
20.2500 50.0388 0.02 0.69

Range-Brush --> RNGB
972.0000 2401.8606 1.08 33.33

Range-Grasses --> RNGE
344.2500 850.6590 0.38 11.81

SOILS:

Chromic Luvisols-Lc54
2916.0000 7205.5818 3.23 100.00

SLOPE:

0-20
2916.0000 7205.5818 3.23 100.00

HRUs

136 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1579.5000 3903.0235 1.75 54.17 1

137 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 20.2500 50.0388 0.02 0.69 2

138 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 972.0000 2401.8606 1.08 33.33 3

139Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 344.2500 850.6590 0.38 11.81 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 28
2349.0000 5804.4965 2.60

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1275.7500 3152.4420 1.41 54.31

Forest-Deciduous --> FRSD
40.5000 100.0775 0.04 1.72

Range-Brush --> RNGB
850.5000 2101.6280 0.94 36.21

Range-Grasses --> RNGE
182.2500 450.3489 0.20 7.76

SOILS:

Chromic Luvisols-Lc54

2349.0000 5804.4965 2.60 100.00

SLOPE:

0-20
2349.0000 5804.4965 2.60 100.00

HRUs

140 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1275.7500 3152.4420 1.41 54.31 1

141 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20
40.5000 100.0775 0.04 1.72 2

142 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20
850.5000 2101.6280 0.94 36.21 3

143Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20
182.2500 450.3489 0.20 7.76 4

Area [ha] Area[acres] percentWat.Area percentSub.Area

SUBBASIN # 29
4110.7500 10157.8688 4.55

LANDUSE:

Agricultural Land-Row Crops --> AGRR
1579.5000 3903.0235 1.75 38.42

Forest-Deciduous --> FRSD
668.2500 1651.2792 0.74 16.26

Forest-Mixed --> FRST
40.5000 100.0775 0.04 0.99

Range-Brush --> RNGB
1559.2500 3852.9847 1.72 37.93

Range-Grasses --> RNGE
263.2500 650.5039 0.29 6.40

SOILS:

Chromic Luvisols-Lc54
4110.7500 10157.8688 4.55 100.00

SLOPE:0-20 4110.7500 10157.8688 4.55 100.00

HRUs

144 Agricultural Land-Row Crops --> AGRR/Chromic Luvisols-Lc54/0-20 1579.5000 3903.0235 1.75 38.42 1

145 Forest-Deciduous --> FRSD/Chromic Luvisols-Lc54/0-20 668.2500 1651.2792 0.74 16.26 2

146 Forest-Mixed --> FRST/Chromic Luvisols-Lc54/0-20 40.5000 100.0775 0.04 0.99 3

147 Range-Brush --> RNGB/Chromic Luvisols-Lc54/0-20 1559.2500 3852.9847 1.72 37.93 4

148Range-Grasses --> RNGE/Chromic Luvisols-Lc54/0-20 263.2500 650.5039 0.29 6.40 5

Appendix L: Makoye reservoir's basin Daily Rainfall and Simulated Sediment Data for the simulation period 2014-2017

Date	Rainfall	Simulated Sediment (tons/day)
1/1/2014	19.45	25.30
1/2/2014	39.22	13.60
1/3/2014	2.26	76.10
1/4/2014	8.76	0.00
1/5/2014	4.25	394.00
1/6/2014	8.05	0.00
1/7/2014	16.92	139.00
1/8/2014	2.75	10.30
1/9/2014	5.06	0.00
1/10/2014	0.08	28.30
1/11/2014	10.24	0.00
1/12/2014	6.35	204.00
1/13/2014	14.64	39.80
1/14/2014	17.2	9.00
1/15/2014	26.29	7.00
1/16/2014	61.32	39.70
1/17/2014	30.4	106.00
1/18/2014	17.23	38.90
1/19/2014	33.8	22.90
1/20/2014	53.79	51.70
1/21/2014	25.17	70.70
1/22/2014	26.77	35.70
1/23/2014	26.93	49.50
1/24/2014	22.21	38.60
1/25/2014	29.3	18.60
1/26/2014	35.17	33.50
1/27/2014	36.76	66.80
1/28/2014	16.43	72.00
1/29/2014	17.68	10.90
1/30/2014	55.04	21.90
1/31/2014	22.28	153.00
2/1/2014	7.13	16.70
2/2/2014	15.08	202.00
2/3/2014	16.26	109.00
2/4/2014	21.66	13.00
2/5/2014	4.29	26.60
2/6/2014	1.42	0.00
2/7/2014	2.14	0.00
2/8/2014	9.12	0.00
2/9/2014	5.14	81.90
2/10/2014	8.93	13.80
2/11/2014	16.21	184.00

2/12/2014	6.93	12.80
2/13/2014	6.68	10.70
2/14/2014	4.91	80.10
2/15/2014	17.38	20.00
2/16/2014	15.06	15.70
2/17/2014	11.98	84.00
2/18/2014	2.76	5.78
2/19/2014	6.31	0.00
2/20/2014	24.9	72.00
2/21/2014	52.23	25.00
2/22/2014	1.81	154.00
2/23/2014	18.63	0.00
2/24/2014	15.52	27.00
2/25/2014	5.86	88.00
2/26/2014	10.77	58.70
2/27/2014	4.79	487.00
2/28/2014	15.14	0.00
3/1/2014	28.2	12.30
3/2/2014	17.3	41.70
3/3/2014	27.57	14.40
3/4/2014	14.87	34.40
3/5/2014	1.23	12.30
3/6/2014	6.68	0.00
3/7/2014	8.76	133.00
3/8/2014	10.36	166.00
3/9/2014	4.68	430.00
3/10/2014	5.62	0.00
3/11/2014	6.58	35.70
3/12/2014	3.33	47.60
3/13/2014	0.14	0.00
3/14/2014	0	0.00
3/15/2014	0	0.00
3/16/2014	8.34	0.00
3/17/2014	8.93	41.60
3/18/2014	12.64	111.00
3/19/2014	7.42	320.00
3/20/2014	5.72	73.90
3/21/2014	4.79	41.10
3/22/2014	4.7	10.10
3/23/2014	4.61	7.94
3/24/2014	0	5.02
3/25/2014	0.04	0.00
3/26/2014	4.97	0.00
3/27/2014	0.01	0.79
3/28/2014	0.66	0.00

3/29/2014	2.63	0.00
3/30/2014	0.58	0.00
3/31/2014	10.62	0.00
4/1/2014	8.48	56.80
4/2/2014	3.96	41.70
4/3/2014	0.51	0.00
4/4/2014	0.33	0.00
4/5/2014	0.47	0.00
4/6/2014	0.05	0.00
4/7/2014	1.89	0.00
4/8/2014	1.45	0.00
4/9/2014	0.17	0.00
4/10/2014	0	0.00
4/11/2014	0.01	0.00
4/12/2014	0.07	0.00
4/13/2014	0	0.00
4/14/2014	0	0.00
4/15/2014	6.93	0.00
4/16/2014	8	0.00
4/17/2014	0.77	0.00
4/18/2014	6.47	0.00
4/19/2014	0	0.00
4/20/2014	0.23	0.00
4/21/2014	0	0.00
4/22/2014	0	0.00
4/23/2014	0	0.00
4/24/2014	0	0.00
4/25/2014	0	0.00
4/26/2014	0.09	0.00
4/27/2014	0.48	0.00
4/28/2014	1.54	0.00
4/29/2014	2.07	0.00
10/9/2014	6.37	0.00
10/10/2014	0	0.00
10/11/2014	0	0.00
10/12/2014	0	0.00
10/13/2014	0	0.00
10/14/2014	0	0.00
10/15/2014	0.45	0.00
10/16/2014	5.15	0.00
10/17/2014	0	0.00
10/18/2014	0	0.00
10/19/2014	12.24	0.00
10/20/2014	0.82	0.00
10/21/2014	0.51	0.00

10/22/2014	0	0.00
10/23/2014	0	0.00
10/24/2014	2.98	0.00
10/25/2014	10.19	0.00
10/26/2014	0	0.00
10/27/2014	0	0.00
10/28/2014	2.69	0.00
10/29/2014	0	0.00
10/30/2014	0	0.00
10/31/2014	0	0.00
11/1/2014	0	0.00
11/2/2014	0	0.00
11/3/2014	0	0.00
11/4/2014	0.01	0.00
11/5/2014	0	0.00
11/6/2014	0	0.00
11/7/2014	1.98	0.00
11/8/2014	0.19	0.00
11/9/2014	0	0.00
11/10/2014	0	0.00
11/11/2014	0	0.00
11/12/2014	0.11	0.00
11/13/2014	0.27	0.00
11/14/2014	1.11	0.00
11/15/2014	0	0.00
11/16/2014	0.03	0.00
11/17/2014	0	0.00
11/18/2014	0	0.00
11/19/2014	31.07	0.00
11/20/2014	6.56	0.00
11/21/2014	6.64	0.00
11/22/2014	5.99	0.00
11/23/2014	12.76	0.00
11/24/2014	1.35	0.00
11/25/2014	0	0.00
11/26/2014	0	0.00
11/27/2014	8.54	0.00
11/28/2014	3.96	0.00
11/29/2014	0.27	0.00
11/30/2014	18.08	0.00
12/1/2014	0.76	0.00
12/2/2014	26.9	0.00
12/3/2014	20.31	7.64
12/4/2014	0	15.60
12/5/2014	0	0.00

12/6/2014	0	0.00
12/7/2014	0.55	0.00
12/8/2014	0.11	0.00
12/9/2014	0.44	0.00
12/10/2014	0.02	0.00
12/11/2014	3.82	0.00
12/12/2014	0.03	0.00
12/13/2014	1.11	0.00
12/14/2014	0	0.00
12/15/2014	0	0.00
12/16/2014	0	0.00
12/17/2014	0	0.00
12/18/2014	0	0.00
12/19/2014	0	0.00
12/20/2014	0.02	0.00
12/21/2014	0	0.00
12/22/2014	0	0.00
12/23/2014	0	0.00
12/24/2014	0	0.00
12/25/2014	0	0.00
12/26/2014	0	0.00
12/27/2014	0	0.00
12/28/2014	0	0.00
12/29/2014	0	0.00
12/30/2014	0	0.00
12/31/2014	14.99	0.00
1/1/2015	0.01	0.24
1/2/2015	7.56	0.00
1/3/2015	0	0.00
1/4/2015	4.12	0.00
1/5/2015	3.62	0.00
1/6/2015	0.09	0.00
1/7/2015	0	0.00
1/8/2015	0	0.00
1/9/2015	0	0.20
1/10/2015	0	0.00
1/11/2015	0	0.00
1/12/2015	0	0.00
1/13/2015	0	0.00
1/14/2015	0	0.00
1/15/2015	0	0.00
1/16/2015	0	0.00
1/17/2015	0	0.00
1/18/2015	0	0.20
1/19/2015	0	0.00

1/20/2015	0	0.00
1/21/2015	0	0.00
1/22/2015	0	0.00
1/23/2015	0	0.00
1/24/2015	0	0.00
1/25/2015	0	0.00
1/26/2015	0	0.00
1/27/2015	0	0.00
1/28/2015	0	0.00
1/29/2015	0	0.00
1/30/2015	0	0.00
1/31/2015	1.25	0.00
2/1/2015	1.82	0.00
2/2/2015	0	0.00
2/3/2015	0	0.00
2/4/2015	0	0.00
2/5/2015	0.07	0.00
2/6/2015	8.7	0.00
2/7/2015	0.21	0.00
2/8/2015	10.31	0.00
2/9/2015	0	0.00
2/10/2015	0.35	0.00
2/11/2015	0	0.00
2/12/2015	0	0.00
2/13/2015	0	0.00
2/14/2015	0	0.00
2/15/2015	1.97	0.00
2/16/2015	0	0.00
2/17/2015	0	0.00
2/18/2015	0	0.00
2/19/2015	0	0.00
2/20/2015	0	0.00
2/21/2015	0	0.00
2/22/2015	0	0.00
2/23/2015	0.58	0.00
2/24/2015	2.91	0.00
2/25/2015	0.1	0.00
2/26/2015	0	0.00
2/27/2015	0.02	0.00
2/28/2015	0.91	0.00
3/1/2015	0.02	0.00
3/2/2015	3.52	0.00
3/3/2015	9.09	0.00
3/4/2015	0	0.00
3/5/2015	0.12	0.00

3/6/2015	0	0.00
3/7/2015	0.01	0.00
3/8/2015	0	0.00
3/9/2015	0	0.00
3/10/2015	0	0.00
3/11/2015	0.15	0.00
3/12/2015	3.43	0.00
3/13/2015	0	0.00
3/14/2015	0	0.00
3/15/2015	0	0.00
3/16/2015	0	0.00
3/17/2015	0	0.00
3/18/2015	0	0.00
3/19/2015	0	0.00
3/20/2015	0	0.00
3/21/2015	0	0.00
3/22/2015	0	0.00
3/23/2015	0	0.00
3/24/2015	0.02	0.00
3/25/2015	0	0.00
3/26/2015	0	0.00
3/27/2015	0	0.00
3/28/2015	0	0.00
3/29/2015	0	0.00
3/30/2015	0	0.00
3/31/2015	0.59	0.00
4/1/2015	0.4	0.00
4/2/2015	4.25	0.00
4/3/2015	2.01	0.00
4/4/2015	0.18	0.00
4/5/2015	0	0.00
4/6/2015	0	0.00
4/7/2015	0	0.00
4/8/2015	0	0.00
4/9/2015	0	0.00
4/10/2015	0	0.00
4/11/2015	0.47	0.00
4/12/2015	0	0.00
4/13/2015	1.67	0.00
10/7/2015	1.49	0.00
10/8/2015	0	0.00
10/9/2015	0	0.00
10/10/2015	12.24	0.00
10/11/2015	0.82	0.00
10/12/2015	0.51	0.00

10/13/2015	0	0.00
10/14/2015	0	0.00
10/15/2015	0	0.00
10/16/2015	0	0.00
10/17/2015	0	0.00
10/18/2015	0	0.00
10/19/2015	2.69	0.00
10/20/2015	0	0.00
10/21/2015	0	0.00
10/22/2015	0	0.00
10/23/2015	0	0.00
10/24/2015	0	0.00
10/25/2015	0	0.00
10/26/2015	0	0.00
10/27/2015	0	0.00
10/28/2015	0	0.00
10/29/2015	1.98	0.00
10/30/2015	0.46	0.00
10/31/2015	0	0.00
11/1/2015	0	0.00
11/2/2015	0	0.00
11/3/2015	0.11	0.00
11/4/2015	1.33	0.00
11/5/2015	0	0.00
11/6/2015	0	0.00
11/7/2015	0.03	0.00
11/8/2015	0	0.00
11/9/2015	0	0.00
11/10/2015	31.07	0.00
11/11/2015	6.56	0.00
11/12/2015	6.64	0.00
11/13/2015	0	0.00
11/14/2015	0	0.00
11/15/2015	0	0.00
11/16/2015	0	0.00
11/17/2015	0	0.00
11/18/2015	0	0.00
11/19/2015	0	0.00
11/20/2015	0	0.00
11/21/2015	0	0.00
11/22/2015	0	0.00
11/23/2015	0	0.00
11/24/2015	0	0.00
11/25/2015	0	0.00
11/26/2015	0	0.00

11/27/2015	0	0.00
11/28/2015	0	0.00
11/29/2015	0	0.00
11/30/2015	0	0.00
12/1/2015	0	0.00
12/2/2015	25	0.00
12/3/2015	11	0.00
12/4/2015	20	0.00
12/5/2015	0	0.00
12/6/2015	0	0.00
12/7/2015	0	0.00
12/8/2015	0	0.00
12/9/2015	0	0.00
12/10/2015	0	0.00
12/11/2015	0	0.00
12/12/2015	0	0.00
12/13/2015	0	0.00
12/14/2015	0	0.00
12/15/2015	0	0.00
12/16/2015	0	0.00
12/17/2015	0	0.00
12/18/2015	0	0.00
12/19/2015	0	0.00
12/20/2015	28	0.00
12/21/2015	15	0.00
12/22/2015	30	0.00
12/23/2015	0	0.00
12/24/2015	0	0.00
12/25/2015	35	0.00
12/26/2015	0	0.00
12/27/2015	0	0.00
12/28/2015	0	0.00
12/29/2015	0	0.00
12/30/2015	10	0.00
12/31/2015	0	0.00
1/1/2016	0	0.00
1/2/2016	30	0.00
1/3/2016	16	0.00
1/4/2016	10	0.00
1/5/2016	0	0.00
1/6/2016	25	0.00
1/7/2016	0	0.00
1/8/2016	35	0.00
1/9/2016	0	0.00
1/10/2016	0	0.00

1/11/2016	30	0.00
1/12/2016	0	0.00
1/13/2016	0	0.00
1/14/2016	0	0.00
1/15/2016	0	0.00
1/16/2016	46	0.00
1/17/2016	19	0.00
1/18/2016	11	0.00
1/19/2016	1	0.00
1/20/2016	0	0.00
1/21/2016	0	0.00
1/22/2016	40	0.00
1/23/2016	0	0.00
1/24/2016	0	0.00
1/25/2016	0	0.00
1/26/2016	0	0.00
1/27/2016	0	0.00
1/28/2016	0	0.00
1/29/2016	3	0.00
1/30/2016	0	0.00
1/31/2016	0	0.00
2/1/2016	0	0.00
2/2/2016	1	0.00
2/3/2016	0	0.00
2/4/2016	0	0.00
2/5/2016	63	0.00
2/6/2016	25	0.00
2/7/2016	0.5	0.00
2/8/2016	0	0.00
2/9/2016	21.5	0.00
2/10/2016	60	0.00
2/11/2016	11	0.00
2/12/2016	87	0.00
2/13/2016	0	0.00
2/14/2016	2	0.00
2/15/2016	5	0.00
2/16/2016	0	0.00
2/17/2016	0	0.00
2/18/2016	0	0.00
2/19/2016	0	0.00
2/20/2016	0	0.00
2/21/2016	25	0.00
2/22/2016	0.5	0.00
2/23/2016	12	0.00
2/24/2016	0	0.00

2/25/2016	0	0.00
2/26/2016	0.01	0.00
2/27/2016	0.04	0.00
2/28/2016	0.05	0.00
2/29/2016	0	0.00
3/1/2016	0	0.00
3/2/2016	0	0.00
3/3/2016	0	0.00
3/4/2016	0	0.00
3/5/2016	0	0.00
3/6/2016	0	393.00
3/7/2016	0	21.40
3/8/2016	0	24.10
3/9/2016	0	29.30
3/10/2016	0	64.60
3/11/2016	0	18.30
3/12/2016	0	5.42
3/13/2016	0	1.56
3/14/2016	0	0.51
3/15/2016	0	19.00
3/16/2016	0	61.00
3/17/2016	0	70.80
3/18/2016	0	50.90
3/19/2016	0	0.45
11/25/2016	32	0.00
11/26/2016	32.5	0.00
11/27/2016	0.5	0.00
11/28/2016	2	0.00
11/29/2016	0	2.71
11/30/2016	0.5	1.18
12/1/2016	0	0.40
12/2/2016	0	8.01
12/3/2016	0.5	20.00
12/4/2016	1.5	0.00
12/5/2016	0	0.00
12/6/2016	0	0.00
12/7/2016	0	0.00
12/8/2016	0	0.00
12/9/2016	0	0.00
12/10/2016	0	0.00
12/11/2016	49	0.00
12/12/2016	10	0.82
12/13/2016	29	0.00
12/14/2016	27	0.00
12/15/2016	0	0.00

12/16/2016	6	0.00
12/17/2016	3	0.00
12/18/2016	9	0.46
12/19/2016	10	0.73
12/20/2016	0	2.01
12/21/2016	0	0.57
12/22/2016	0	10.10
12/23/2016	0	7.04
12/24/2016	0	15.00
12/25/2016	52	20.00
12/26/2016	0	74.10
12/27/2016	2.5	248.00
12/28/2016	15	414.00
12/29/2016	1.3	314.00
12/30/2016	80	3.87
12/31/2016	0	67.70
1/1/2017	43	2.90
1/2/2017	6	2.90
1/3/2017	6.5	6.85
1/4/2017	1.2	20.80
1/5/2017	0	5.79
1/6/2017	0	1.75
1/7/2017	15	0.50
1/8/2017	0	5.78
1/9/2017	5	1.60
1/10/2017	0	0.49
1/11/2017	5.5	0.14
1/12/2017	18	0.08
1/13/2017	0	0.02
1/14/2017	0	0.01
1/15/2017	8	0.02
1/16/2017	21	0.12
1/17/2017	6	17.50
1/18/2017	4	5.99
1/19/2017	0.5	1.91
1/20/2017	39	0.79
1/21/2017	55	2.50
1/22/2017	0.5	0.40
1/23/2017	5	0.50
1/24/2017	0.2	31.70
1/25/2017	1	9.59
1/26/2017	40	0.33
1/27/2017	30	2.00
1/28/2017	10	1.46
1/29/2017	57	0.49
1/30/2017	0	37.60

1/31/2017	0	107.00
2/1/2017	0.2	0.00
2/2/2017	0.6	0.00
2/3/2017	3	0.45
2/4/2017	0	0.10
2/5/2017	29	0.00
2/6/2017	4.5	0.00
2/7/2017	4	0.00
2/8/2017	3	0.12
2/9/2017	65	3.08
2/10/2017	0	49.80
2/11/2017	0	18.20
2/12/2017	0	6.02
2/13/2017	0	12.40
2/14/2017	0	55.50
2/15/2017	43	53.20
2/16/2017	0	2.23
2/17/2017	0	114.00
2/18/2017	0	36.60

Appendix M: Laboratory Analysed Soils and Sediment raw data from the Makoye Reservoir basin

The University of Zambia
Department of Soil Science
Service Laboratory

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Tel 295421
E-mail: soil@unza.zm

ATTN:Mr. M. Muchanga

Soil Analysis Results - October, 2017

Lab	Sample Id	pH	K	Na	Ca	Mg	P	S	Sampling Points	
			Ammonium Acetate				Bray-1	Na-Acetate		
no.	Id	$CaCl_2$	cmol/kg				mg/kg		X	Y
20171708	Agric Plot; Sample (5); Magoye	7.50	0.84	1.21	10.74	10.88	1.42	4.22	574582.81	8203583.1
20171709	Layer 2 (20 cm); Magoye Dam - Bed; Monze	5.49	2.55	1.00	16.71	12.88	1.00	59.49	574692.62	8204022.8
20171710	Core Sediment; Layer 1(10 cm); Magoye; Dam-Bed; Monze	5.58	43.87	25.00	16.58	3.15	1.42	77.64	574692.62	8204022.8
20171711	Magoye; Layer 3 (30 cm); Dam-Bed; Monze	5.40	37.08	0.27	17.16	3.14	1.10	34.60	574889.96	8204069.4
20171712	Sediment Trap; Magoye; Dam; Monze	6.64	1.10	0.08	16.54	11.71	1.47	33.76	574692.62	8204022.8
20171713	Sediment; Layer 5 (50 cm); Magoye Dam-Bed; Monze	5.14	39.54	1.18	15.64	63.13	1.42	32.49	574692.62	8204022.8
20171714	Layer 4 (40 cm); Magoye Dam-Bed; Monze	3.88	1.81	1.25	9.35	11.75	1.05	111.81	574772.83	8203534.8
20171743	Trap B; Magoye	6.85	0.63	0.90	6.10	11.92	0.53	32.37	574730.48	8202070.6
20171744	Point 15; Magoye	7.60	0.36	17.07	6.34	12.67	0.42	165.29	575016.54	8203928.1
20171745	Point 19; Magoye	4.63	0.65	0.37	1.09	4.83	0.58	33.06		

Lab	Sample Id	Cu	Fe	Pb	Cd	Cl^-	NH_4	NO_3	Sampling Points	
		DTPA				Water etract	Potassium Chloride			
no.	Id	mg/kg							X	Y
20171708	Agric Plot; Sample (5); Magoye	4.56	22.22	0.77	0.00	81.65	9.33	149.33	574582.81	8203583.1
20171709	Layer 2 (20 cm); Magoye Dam - Bed; Monze	3.56	36.16	0.03	0.00	99.40	14.00	56.00	574692.62	8204022.8
20171710	Core Sediment; Layer 1(10 cm); Magoye; Dam-Bed; Monze	2.88	41.16	0.08	0.00	99.40	23.33	32.67	574692.62	8204022.8
20171711	Magoye; Layer 3 (30 cm); Dam-Bed; Monze	4.44	32.14	0.01	0.00	106.50	23.33	42.00	574889.96	8204069.4
20171712	Sediment Trap; Magoye; Dam; Monze	1.76	18.68	0.44	0.00	74.55	32.67	70.00	574692.62	8204022.8
20171713	Sediment; Layer 5 (50 cm); Magoye Dam-Bed; Monze	3.02	36.96	0.06	0.00	81.65	18.67	56.00	574692.62	8204022.8
20171714	Layer 4 (40 cm); Magoye Dam-Bed; Monze	1.48	36.42	0.02	0.00	120.70	79.33	172.67	574772.83	8203534.8
20171743	Trap B; Magoye	3.26	8.98	0.16	0.00	81.65	32.67	116.67	574730.48	8202070.6
20171744	Point 15; Magoye	6.94	2.02	0.57	0.00	127.80	56.00	102.67	575016.54	8203928.1
20171745	Point 19; Magoye	3.26	14.08	0.07	0.00	56.80	32.67	56.00		

C. NACHALWE
Acting Chief Scientist
12/01/2018

Head, Soil Science

Appendix N: Water quality results for Makoye Reservoir during the 2015/16 warm-wet season

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY

P.O Box 32379, Lusaka
Direct Telefax: 260-1-290962

PHYSICAL/CHEMICAL EXAMINATION OF WATER

Attn : Dr. Sichingabula
UNZA
Lusaka
Sampled by : Client
Report date : 05.05.2016

Laboratory Results

Parameter	Makoye Channel	Makoye Channel	Makoye Channel	Makoye Channel	Makoye Channel	Makoye Channel
Sampling date	02.02.2016	05.02.2016	14.02.2016	22.02.2016	28.02.2016	29.02.2016
pH	6.90	6.82	6.77	7.03	7.12	7.39
Turbidity (NTU)	1,839	4,386	2,941	620	1,149	729
Alkalinity (as mg $CaCO_3$/l)	52	38	36	58	62	80
Conductivity (μs/cm)	84	103	78	152	167	187
Total Dissolved Solids (mg/l)	42	52	39	76	84	93
Phoshorous (mg/l)	0.51	0.18	0.17	0.13	0.09	0.45
Total Suspended Solids (mg/l)	2,105	6,050	3,520	360	2,100	1,250
Iron (mg/l)	8.35	4.41	3.18	3.26	4.45	6.51
Ammonia (as NH_4-Nmg/l)	0.47	0.17	0.49	0.32	0.26	0.29
Sulphates (mg/l)	7.44	4.02	3.16	7.94	7.36	9.08
Nitrates (as NO_3–Nmg/l)	5.97	2.71	0.63	0.82	3.85	0.45
Total phosphates (mg/l)	1.17	0.42	0.39	0.31	0.20	1.03
Magnesium (mg/l)	5.04	3.60	3.84	5.52	5.76	8.88
Calcium (mg/l)	12.4	10.0	8.8	14.8	16.0	18.0
Fluorides (mg/l)	0.07	0.13	0.06	0.13	0.06	0.08
Copper (mg/l)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Sodium (mg/l)	11.88	19.80	1055	13.24	17.16	16.50
Lead (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA, 1998".

Sampling point	
X	**Y**
574774.1	8203586

J. Kabika
Co-ordinator- Environmental Engineering Laboratory

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY

P.O Box 32379, Lusaka
Direct Telefax: 260-1-290962

PHYSICAL/CHEMICAL EXAMINATION OF WATER

Attn : Dr. Sichingabula
UNZA
Lusaka
Sampled by : Client
Report date : 05.05.2016

Laboratory Results

Parameter	Makoye 01	Makoye 02	Makoye 03	Makoye 6	Makoye 7	Makoye 8
Sampling date	04.03.2016	04.03.2016	04.03.2016	04.03.2016	04.03.2016	04.03.2016
pH	7.02	7.22	7.00	6.92	7.07	7.23
Turbidity (NTU)	2,252	1,868	1,174	1,265	1,807	1,927
Alkalinity (as mg $CaCO_3$/l)	102	86	48	44	72	52
Conductivity (µs/cm)	86	112	84	84	85	80
Total Dissolved Solids (mg/l)	44	56	42	42	42	40
Phoshorous (mg/l)	0.05	0.42	0.06	0.02	<0.01	0.07
Total Suspended Solids (mg/l)	3,850	2,240	1,800	2,040	3,050	2,950
Iron (mg/l)	5.57	7.41	6.76	0.32	491	3.88
Ammonia (as NH_4-Nmg/l)	0.18	0.14	0.04	0.35	0.21	0.18
Sulphates (mg/l)	9.77	5.35	11.35	15.71	7.13	11.13
Nitrates (as NO_3 –Nmg/l)	5.87	4.52	3.04	3.68	2.47	1.52
Total phosphates (mg/l)	0.12	0.97	0.12	0.04	<0.01	0.16
Magnesium (mg/l)	8.64	11.04	6.72	3.84	10.3	3.84
Calcium (mg/l)	27.2	16.8	8.0	12.0	12.4	15.2
Fluorides (mg/l)	0.08	0.12	0.07	0.07	0.08	0.07
Copper (mg/l)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Sodium (mg/l)	9.90	14.52	9.90	13.20	15.18	13.86
Lead (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA, 1998".

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Co-ordinator- Environmental Engineering Laboratory

UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
05 MAY 2016
DEPT OF CIVIL ENGINEERING
P O. BOX 32379, LUSAKA

Sampling Points Across the Makoye Reservoir

NO	Res (reservoir sampling points)										Spillway (Nsw)	Channel (throwback)
	1	2	3	6	7	8	9	10	11	12		
X	574803	574855	574736.7	574591.9	574695.2	574641.1	574750.7	574880.2	574823.7	574723.1	574790.97	574774
Y	8203961	8203855	8203847	8203949	8204062	8203922	8204138	8204082	8204131	8203973	8204127.3	8204127

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY

P.O Box 32379, Lusaka
Direct Telefax: 260-1-290962

PHYSICAL/CHEMICAL EXAMINATION OF WATER

Attn : Dr. Sichingabula
UNZA
Lusaka

Sampled by : Client

Report date : 05.05.2016

Laboratory Results

Parameter	Makoye Channel	Makoye Channel	Makoye Overflow spillway	Makoye Channel	Makoye Channel	Makoye spillway
Sampling date	30.01.2016	01.03.2016	03.04.2016	04.03.2016	06.03.2016	06.03.2016
pH	7.37	7.08	7.45	6.91	7.27	7.07
Turbidity (NTU)	1,823	2,186	758	4,250	1,201	1,686
Alkalinity (as mg $CaCO_3$/l)	52	34	48	50	40	70
Conductivity (µs/cm)	143	82	173	72	85	100
Total Dissolved Solids (mg/l)	72	41	71	36	43	50
Phoshorous (mg/l)	0.12	<0.01	<0.01	0.19	0.20	0.01
Total Suspended Solids (mg/l)	2,051	4,021	1,051	9,050	1,600	2,560
Iron (mg/l)	3.14	5.16	5.81	5.57	7.40	6.76
Ammonia (as NH_4-Nmg/l)	0.12	0.09	0.13	0.21	0.98	0.67
Sulphates (mg/l)	12.68	9.94	11.52	3.28	6.21	4.89
Nitrates (as NO_3–Nmg/l)	1.90	3.74	4.69	1.12	6.34	13.96
Total phosphates (mg/l)	0.27	<0.01	<0.01	0.44	0.46	0.02
Magnesium (mg/l)	5.76	3.84	5.28	5.52	4.08	9.60
Calcium (mg/l)	12.0	8.0	11.2	11.6	10.0	12.8
Fluorides (mg/l)	0.14	0.11	0.14	0.06	0.08	0.12
Copper (mg/l)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Sodium (mg/l)	16.50	15.84	19.14	11.22	13.20	9.24
Lead (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA. 1998".

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SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
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P.O Box 32379, Lusaka
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PHYSICAL/CHEMICAL EXAMINATION OF WATER

Attn : Dr. Sichingabula
UNZA
Lusaka

Sampled by : Client

Report date : 05.05.2016

Laboratory Results

Parameter	**Makoye 9**	**Makoye 10**	**Makoye 11**	**Makoye 12**	**Makoye Dam highest overflow 87 mm single event**	**Makoye Channel**
Sampling date	03.03.2016	03.03.2016	03.03.2016	03.03.2016	-	01.03.2016
pH	7..00	7.24	7.41	7.45	7.38	7.08
Turbidity (NTU)	2,130	1,794	2,254	673	1,867	2,186
Alkalinity (as mg $CaCO_3$/l)	53	74	44	74	42	34
Conductivity (μs/cm)	82	136	85	180	71	82
Total Dissolved Solids (mg/l)	41	68	43	90	35	41
Phoshorous (mg/l)	0.20	<0.01	0.85	0.09	0.72	<0.01
Total Suspended Solids (mg/l)	3,100	2,100	4,120	280	2,560	4,021
Iron (mg/l)	5.81	4.97	4.70	5.17	3.19	5.16
Ammonia (as NH_4-Nmg/l)	0.38	0.32	0.19	0.22	0.17	0.09
Sulphates (mg/l)	29.28	48.80	77.87	76.41	65.49	9.94
Nitrates (as NO_3–Nmg/l)	12.76	1.70	2.81	2.74	5.97	3.74
Total phosphates (mg/l)	0.47	0.01	1.95	0.22	1.64	<0.01
Magnesium (mg/l)	5.52	9.36	5.76	9.36	4.56	3.84
Calcium (mg/l)	12.58	14.8	8.8	13.2	10.0	8.0
Fluorides (mg/l)	0.07	0.14	0.12	0.14	0.06	0.11
Copper (mg/l)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Sodium (mg/l)	12.54	14.52	15.18	15.84	15.14	15.84
Lead (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA, 1998".

J. Kabika
Co-ordinator- Environmental Engineering Laboratory

UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
05 MAY 2016
DEPT OF CIVIL ENGINEERING
P O. BOX 32379, LUSAKA

Appendix O: Water quality results for Makoye Reservoir during the 2016/2017 warm-wet season, 2017 cool-dry season and 2017 warm wet season

Address: **Mr. Manoah Muchanga**
Geography And Environmental Studies
UNZA
Lusaka

Report date: **03.04.2018**

School Of Engineering
Department Of Civil & Environmenta Engineering
Environmental Engineering Laboratory

Laboratory Results

Parameter		pH	TDS (mg/l)	TSS (mg/l)	Tub (NTU)	Ca^{2+} (mg/l)	Fe^{3+} (mg/l)	Alk (mg/l)	EC (µS/cm)	SO_4^{2-} (mg/l)	P (mg/l)	T. PO_4^{3-} (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	NO^3-N (mg/l)	NH^4-N (mg/l)	Na^+ (mg/l)	Mg^{2+} (mg/l)	Cu^{2+} (mg/l)	F^- (mg/l)	Pb (mg/l)	Cd (mg/l)
Parameter																						
ID	Date																					
Res	28.11.16	6.68	45	184	1998	14.4	6.36	42	90	87.86	2.94	3.99	3.17	15.0	3.81	2.49	9.83	1.44	<0.003	0.09	<0.01	<0.0002
Cha	13.12.16	6.38	27	23	949	4.8	5.97	42	53	91.77	2.88	3.74	3.59	17.0	3.94	2.72	11.22	7.20	<0.003	0.04	<0.01	<0.0002
Nsw	13.12.16	6.79	48	35	367	5.6	6.13	52	96	79.13	2.96	3.56	4.01	19.0	3.98	2.52	12.54	9.12	<0.003	0.09	<0.01	<0.0002
Res	13.12.16	6.52	53	8	242	9.6	6.21	48	106	56.84	1.88	2.98	3.17	15.0	3.02	1.51	9.90	5.76	<0.003	0.12	<0.01	<0.0002
Cha	12.12.16	7.22	81	100	1173	21.6	5.97	76	163	66.53	1.74	2.88	3.38	16.0	3.88	2.42	10.56	5.28	<0.003	0.14	<0.01	<0.0002
Res	12.12.16	7.69	118	103	807	32.0	5.35	100	235	63.80	1.72	2.89	2.74	13.0	4.23	2.49	8.58	4.80	<0.003	0.15	<0.01	<0.0002
Cha	25.12.16	6.28	43	611	4085	4.8	5.14	32	85	36.70	1.59	2.74	3.80	18.0	5.86	2.30	11.88	4.80	<0.003	0.12	<0.01	<0.0002
Res	25.12.16	6.42	57	23	576	8.8	4.96	42	113	41.32	2.94	3.18	3.59	17.0	4.32	2.07	11.22	4.80	<0.003	0.12	<0.01	<0.0002
Nsw	25.12.16	6.44	56	116	489	4.0	4.00	50	112	30.34	1.99	2.62	3.16	15.0	4.09	2.67	9.90	9.60	<0.003	0.12	<0.01	<0.0002
Cha	26.11.16	6.44	50	60	603	6.4	4.50	32	99	27.79	3.04	4.02	3.02	15.0	3.84	2.96	9.83	3.84	<0.003	0.08	<0.01	<0.0002
Cha.	28.12.16	6.47	28	62	1347	8.8	4.03	24	55	22.16	3.18	4.00	2.96	15.0	4.11	1.82	8.91	0.48	<0.003	0,04	<0.01	<0.0002
Res	28.12.16	6.44	47	5	711	6.4	4.88	30	94	24.40	2.84	3.79	3.94	11.0	11.22	1.99	7.26	3.36	<0.003	0.12	<0.01	<0.0002
Nsw	28.12.16	6.82	48	433	957	4.8	4.78	36	95	42.86	2.71	3.89	2.53	12.0	5.94	2.55	7.92	5.76	<0.003	0.12	<0.01	<0.0002
Cha	30.12.16	6.40	28	212	2963	3.2	6.13	18	59	24.70	2.22	3.33	2.96	14.0	6.02	1.89	9.24	2.40	<0.003	0.11	<0.01	<0.0002
Res	30.12.16	7.07	38	514	1766	4.0	6.07	28	76	33.82	2.62	3.71	2.74	13.0	5.33	1.55	8.58	4.32	<0.003	0.12	<0.01	<0.0002
Nsw	30.12.16	6.24	38	287	2880	6.4	5.61	24	77	25.01	3.01	4.06	3.16	15.0	4.32	2.31	10.11	1.92	<0.003	0.10	<0.01	<0.0002
Res	30.10.17	7.46	332	1	523	24.8	2.57	194	669	33.55	6.82	9.11	5.70	27.0	5.01	2.58	17.31	31.68	<0.003	0.17	<0.01	<0.0002
Throwback	30.10.17	7.76	331	100	561	22.4	2.27	192	658	49.18	5.94	7.87	6.97	33.0	4.96	2.62	22.77	32.64	<0.003	0.18	<0.01	<0.0002
Cha	01.01.17	6.68	45	344	1363	6.4	5.08	34	89	58.02	6.83	8.42	3.59	17.0	6.12	2.62	12.33	4.32	<0.003	0.12	<0.01	<0.0002
Res	01.01.17	6.53	37	108	962	4.8	5.57	46	73	34.62	6.79	8.79	1.69	8.0	4.83	1.78	5.24	8.16	<0.003	0.11	<0.01	<0.0002

Nsw	01.01.17	6.73	38	82	1721	16.0	4.96	46	73	64.34	5.91	6.70	2.96	14.0	4.77	1.64	9.32	2.40	<0.003	0.12	<0.01	<0.0002
Res	07.01.17	7.10	59	138	797	10.4	5.02	50	119	30.39	1.96	2.93	2.74	13.0	4.64	1.60	8.56	5.76	<0.003	0.13	<0.01	<0.0002
Cha	07.01.17	6.88	71	38	573	12.0	4.36	60	142	44.80	2.43	3.17	2.74	13.0	2.24	1.46	7.24	7.20	<0.003	0.12	<0.01	<0.0002
Nsw	07.01.17	6.98	58	81	901	9.6	4.91	40	116	60.62	3.02	6.04	2.32	11.0	<0.01	1.77	2.84	3.84	<0.003	0.13	<0.01	<0.0002
Res	12.01.17	7.25	61	209	783	8.8	3.92	50	122	35.31	1.02	1.86	2.11	10.0	3.44	1.74	6.73	6.72	<0.003	0.13	<0.01	<0.0002
Cha	17.01.17	7.12	77	173	614	13.6	4.41	66	153	38.16	2.84	3.61	2.53	12.0	2.94	1.88	7.68	7.68	<0.003	0.14	<0.01	<0.0002
Nsw	17.01.17	6.89	61	73	817	13.6	4.91	56	126	25.52	5.88	7.94	2.59	17.0	3.01	1.62	5.11	5.28	<0.003	0.13	<0.01	<0.0002
Res	21.01.17	6.89	72	179	618	11.2	4.89	72	144	35.63	5.02	7.60	2.53	12.0	4.11	1.62	10.42	10.56	<0.003	0.14	<0.01	<0.0002
Nsw	21.01.17	7.20	80	242	674	10.4	5.08	66	160	36.27	5.19	7.50	2.74	13.0	5.02	1.55	9.19	9.60	<0.003	0.12	<0.01	<0.0002
Cha	22.01.17	6.38	27	98	1428	3.2	5.18	28	52	45.58	6.13	8.81	2.53	12.0	2.96	1.61	4.82	4.80	<0.003	0.09	<0.01	<0.0002
Res	22.01.17	6.71	59	308	783	8.8	5.81	41	115	45.35	5.96	8.91	2.96	14.0	2.33	1.69	5.74	5.76	<0.003	0.11	<0.01	<0.0002
Nsw	22.01.17	6.94	51	385	1210	6.4	4.94	56	114	54.57	5.17	6.64	3.17	15.0	4.02	1.63	9.64	9.60	<0.003	0.12	<0.01	<0.0002
Cha	24.01.17	6.65	44	337	1533	13.6	5.60	40	89	80.75	6.82	8.89	3.17	15.0	3.84	1.60	1.44	1.44	<0.003	0.05	<0.01	<0.0002
Res	24.01.17	6.68	48	637	993	10.4	5.67	34	97	86.59	5.33	8.68	2.74	13.0	4.36	1.63	1.92	1.92	<0.003	0.07	<0.01	<0.0002
Nsw	24.01.17	6.74	48	1393	893	8.0	5.11	40	86	61.40	0.19	0.79	2.53	12.0	2.94	1.68	4.82	4.80	<0.003	0.07	<0.01	<0.0002
Cha	26.01.17	6.36	29	413	99.3	11.2	6.19	36	57	38.65	1.16	2.01	2.11	10.0	10.36	1.88	6.67	1.92	<0.003	0.04	<0.01	<0.0002
Res	26.01.17	6.54	52	494	110	12.0	3.80	50	104	35.79	5.28	7.65	1.69	8.0	11.04	1.64	5.30	4.80	<0.003	0.04	<0.01	<0.0002
Nsw	26.01.17	6.86	50	778	616	15.2	5.02	48	101	41.76	5.13	6.15	1.90	9.0	9.83	1.65	5.92	2.40	<0.003	0.02	<0.01	<0.0002
Cha	27.01.17	6.75	56	737	291	14.4	5.14	44	111	37.56	4.96	5.81	1.69	8.0	8.19	1.67	5.28	1.92	<0.003	0.03	<0.01	<0.0002
Res	27.01.17	6.71	61	884	355	8.8	5.54	50	122	39.73	4.88	5.61	1.48	7.0	7.88	1.69	4.66	7.68	<0.003	0.04	<0.01	<0.0002
Nsw	27.01.17	6.68	50	535	773	13.6	4.48	48	99	46.42	3.84	4.97	1.90	9.0	5.36	1.67	5.91	3.36	<0.003	0.02	<0.01	<0.0002
Cha	28.01.17	6.65	58	566	317	11.2	4.38	52	116	33.13	5.02	7.72	2.11	10.0	7.02	1.71	6.62	5.76	<0.003	0.03	<0.01	<0.0002
Res	28.01.17	6.54	58	746	359	17.6	5.39	50	115	36.06	3.11	4.08	1.69	8.0	9.44	1.73	5.27	1.44	<0.003	0.02	<0.01	<0.0002
Nsw	28.01.17	6.78	51	894	828	18.2	5.45	50	103	34.88	6.63	9.01	2.11	10.0	12.32	1.72	6.61	1.92	<0.003	0.04	<0.01	<0.0002
Cha	30.01.17	6.45	28	414	86.3	11.2	5.56	30	56	23.58	4.99	5.63	1.69	8.0	8.36	1.74	5.32	0.96	<0.003	0.03	<0.01	<0.0002
Res	30.01.17	6.45	54	518	211	19.2	3.70	54	109	43.13	4.88	5.54	2.11	10.0	10.44	1.66	6.67	1.44	<0.003	0.04	<0.01	<0.0002
Nsw	30.01.17	6.55	52	330	46.8	12.8	5.64	50	105	36.97	4.93	5.43	2.32	11.0	9.36	1.61	7.26	4.32	<0.003	0.02	<0.01	<0.0002
Cha	05.02.17	7.01	86	417	318	16.8	5.41	70	173	44.41	5.36	7.46	1.90	9.0	8.31	1.73	5.98	6.72	<0.003	0.03	<0.01	<0.0002
Res	05.02.17	6.77	65	357	103	16.0	5.06	68	131	47.88	3.81	4.85	1.69	8.0	9.12	1.73	5.28	6.72	<0.003	0.02	<0.01	<0.0002
Nsw	05.02.17	6.77	64	785	206	12.0	4.91	58	129	47.37	5.29	7.13	1.90	9.0	7.33	1.73	5.93	6.72	<0.003	0.04	<0.01	<0.0002
Cha	09.02.17	6.33	25	874	286	4.8	5.15	32	49	37.08	6.04	8.11	2.74	13.0	6.96	1.81	5.56	4.80	<0.003	0.03	<0.01	<0.0002
Res	09.02.17	6.93	36	657	467	8.8	6.24	50	74	36.27	6.13	8.61	2.74	13.0	7.23	1.91	8.52	7.20	<0.003	0.02	<0.01	<0.0002
Nsw	09.02.17	7.34	37	409	460	9.6	5.93	36	74	45.69	4.16	6.69	2.96	14.0	8.61	1.58	9.24	3.84	<0.003	0.02	<0.01	<0.0002
Cha	16.02.17	7.05	52	320	230	26.4	5.16	100	273	36.94	5.02	7.19	2.53	12.0	2.96	1.65	7.89	11.52	<0.003	0.03	<0.01	<0.0002

Res	16.02.17	7.22	57	193	110	16.0	4.81	58	124	32.39	5.13	6.88	2.74	13.0	5.33	1.72	8.61	4.32	<0.003	0.14	<0.01	<0.0002
Nsw	16.02.17	7.45	140	220	194	26.4	5.09	116	279	89.13	<0.01	<0.01	2.32	11.0	<0.01	0.27	7.12	12.00	<0.003	0.13	<0.01	<0.0002
Res part1	17.07.17	7.49	194	2.2	2.24	40.0	0.82	134	388	23.99	<0.01	<0.01	2.96	14.0	<0.01	<0.01	9.33	8.16	<0.003	0.13	<0.01	<0.0002
Res part2	17.07.17	7.64	205	<1.0	1.73	37.6	<0.01	158	410	25.22	<0.01	<0.01	2.88	15.2	<0.01	<0.01	9.34	15.36	<0.003	0.15	<0.01	<0.0002
Res part3	17.07.17	7.67	186	4	2.37	28.0	2.07	148	373	23.74	<0.01	<0.01	2.53	12.0	<0.01	<0.01	7.82	18.72	<0.003	0.12	<0.01	<0.0002
Res part4	17.07.17	7.63	182	<1.0	2.59	25.6	<0.01	132	363	24.30	<0.01	<0.01	3.38	16.0	<0.01	<0.01	10.22	16.32	<0.003	0.14	<0.01	<0.0002
Res part5	17.07.17	7.63	182	<1.0	1.68	24.0	0.31	138	364	23.43	<0.01	<0.01	2.11	10.0	0.96	<0.01	6.66	20.64	<0.003	0.13	<0.01	<0.0002
Res part6	17.07.17	8.37	180	<1.0	1.05	26.4	<0.01	134	360	26.65	<0.01	<0.01	2.96	14.0	1.33	<0.01	9.23	16.32	<0.003	0.12	<0.01	<0.0002
Res part7	17.07.17	6.93	190	<1.0	0.72	27.2	<0.01	138	378	27.74	<0.01	<0.01	2.53	12.0	2.44	<0.01	7.92	17.28	<0.003	0.14	<0.01	<0.0002
Res part8	17.07.17	7.61	182	<1.0	3.74	30.4	<0.01	128	363	24.60	<0.01	<0.01	2.90	14.0	1.34	<0.01	9.42	18.92	<0.003	0.13	<0.01	<0.0002
Res part9	17.07.17	7.66	187	2.4	5.12	29.6	0.45	130	376	23.67	<0.01	<0.01	2.32	11.0	<0.01	<0.01	7.26	14.40	<0.003	0.14	<0.01	<0.0002
Res part10	17.07.17	7.58	186	3.9	10.7	29.6	0.93	134	368	23.08	<0.01	<0.01	2.96	14.0	1.36	<0.01	9.24	14.40	<0.003	0.03	<0.01	<0.0002
Res part11	17.07.17	7.44	187	<1.0	4.69	27.2	<0.01	132	372	22.87	<0.01	<0.01	1.90	9.0	2.42	<0.01	5.82	17.76	<0.003	0.01	<0.01	<0.0002
Res part12	17.07.17	7.66	182	2.6	3.11	28.0	0.31	142	363	22.52	<0.01	<0.01	2.32	11.0	<0.01	<0.01	7.19	17.28	<0.003	0.14	<0.01	<0.0002
Res part13	17.07.17	7.77	182	<1.0	1.02	30.4	0.35	140	368	22.77	<0.01	<0.01	2.77	12.0	<0.01	<0.01	7.30	15.36	<0.003	0.14	<0.01	<0.0002

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