ARDHI UNIVERSITY

ACCURACY ASSESSMENT OF SATELLITE ALTIMETRY DATA FOR WATER LEVEL MONITORING AND VOLUME ESTIMATION OF MTERA HYDROELECTRIC DAM

A Comparative Analysis with In-situ measurements

RUGABILANA AHMED H

BSc Geomatics

Dissertation

Ardhi University, Dar es Salaam

July, 2023

`

ACCURACY ASSESSMENT OF SATELLITE ALTIMETRY DATA FOR WATER LEVEL MONITORING AND VOLUME ESTIMATION OF MTERA HYDROELECTRIC DAM

A Comparative Analysis with In-situ measurements

RUGABILANA AHMED H

A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

`

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Accuracy assessment of satellite altimetry data for water level monitoring and volume estimation of Mtera Hydroelectric dam, a comparative analysis with in-situ measurements"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

…………………………………

Mr. Bakari Mchila

(Main Supervisor)

Date ………/………/…...……

`

DECLARATION AND COPYRIGHT

I, RUGABILANA AHMED H hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

………………………………..

RUGABILANA AHMED H

22757/T.2019

(Candidate)

`

ACKNOWLEDGEMENT

First and foremost, I am deeply grateful to Almighty God for the blessings, guidance, and strength provided throughout this journey.

I would like to +express my sincerest appreciation to my father, Hassan Rugabilana, whose unwavering support, encouragement, and wisdom have been the cornerstone of my academic pursuits. His invaluable insights and guidance have played a pivotal role in shaping this research.

I extend my deepest thanks to Mr. Bakari Mchila, my dedicated supervisor, for His exceptional guidance, expertise, and continuous encouragement. His valuable feedback and constructive criticism have immensely contributed to the quality and refinement of this research.

I am profoundly indebted to Dr. Saria and Mrs. Valerie Ayubu for their invaluable contributions, insightful suggestions, and expertise, which have significantly enhanced the analysis and findings of this study.

Special appreciation goes to the engineer Laou from TANESCO for his collaboration, support, and provision of essential data. His assistance has been crucial in conducting a comprehensive analysis and achieving meaningful results.

I would like to express my sincere gratitude to all the participants who generously shared their time and contributed to this research. Their involvement in providing in-situ measurements, participating in interviews, and engaging in insightful discussions has enriched the quality of this study.

Finally, I would like to acknowledge my family, friends, and colleagues for their unwavering support, understanding, and encouragement throughout this research endeavor. Their presence, encouragement, and belief in my abilities have been a constant source of motivation.

Words alone cannot express my gratitude to these individuals for their contributions, guidance, and support. Their collective efforts have made this research possible, and I am sincerely thankful for their invaluable contributions.

`

DEDICATION

I dedicate this dissertation to my beloved parents Mr. and Mrs. Hassan Rugabilana, my brother Amiri Rugabilana and Hussein Rugabilana, my sister Aisha Rugabilana and my friends and all relatives for their invaluable prayers, support, love, patience, encouragement and care throughout my studies. I really appreciate you for all you have done for me and may God bless you all

`

ABSTRACT

This dissertation research focuses on the "Accuracy Assessment of Satellite Altimetry Data for Water Level Monitoring and Volume Estimation at Mtera Dam." The study aims to evaluate the reliability and precision of satellite altimetry data by comparing it with in-situ measurements of maximum and minimum water levels at the Mtera Dam, Tanzania. Additionally, the research incorporates satellite images data to complement the analysis.

Study involved the collection of satellite altimetry data, from Jason-2 and Jason-3missions, and in-situ water level measurements obtained from Tanzania electricity company TANESCO. To enhance the analysis, additional data sources such as Landsat 8 imagery from the United States geological survey is integrated into the study. Modified normalized water index (MNDWI) was used for extraction of surface water areas, which then integrated by the maximum and minimum water levels obtained from the satellite altimetry data lead to the volume estimations of the dam.

The research employs statistical techniques such as bias, Mean Absolute Error (MAE), Root Mean Squared Error, Coefficient of Determination(R^2), and Pearson correlation coefficient to assess the accuracy of the data. The analysis covers a time series of seven years, from 2016 to 2022.

Results indicate that the satellite altimetry data provides promising water level and volume estimates, demonstrating a high correlation of 0.956 and (R^2)value 0.782 when compared to the in-situ measurements. The regression analysis further reveals a strong positive linear relationship between the two datasets, enabling accurate volume estimation based on satellite altimetry data.

The research results show a bias of almost 126.15 million cubic meters in volume estimation, indicating a systematic deviation between the satellite altimetry and in-situ measurements. Despite this bias, the study emphasizes the overall accuracy and potential applications of satellite altimetry data for water level monitoring and volume estimation.

Thus, the satellite altimetry data can be considered be used to monitor water level changes and volume estimation of Mtera Dam, since the results differences between the satellite altimetry's volume and water levels results compared to in-situ water level and volume results are relatively small.

Keywords: satellite-altimetry, water-level, monitoring, volume-estimation, in-situ data.

`

TABLE OF CONTENTS

CERTIFICATION ii
DECLARATION AND COPYRIGHT iii
ACKNOWLEDGEMENT iv
DEDICATION v
ABSTRACT vi
TABLE OF CONTENTS vii
LIST OF FIGURES x
LIST OF TABLES xi
ACRONOMYS AND ABBREVIATIONS xii
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background 1
1.2 Problem of Statement 3
1.3 Research Objectives 3
1.3.1 Main Objective 3
1.3.2 Specific Objectives 3
1.4 Significance of the Study 4
1.5 Beneficiaries 4
1.6 Research Questions 4
1.7 Description of the Study Area 4
1.7.1 Scope and Limitation of the Research 5
1.8 Organization of the Research 6
CHAPTER TWO 7
LITERATURE REVIEW 7
2.1 Overview 7
2.1.2 Hydroelectric Dams 7
2.2 Satellite Altimetry 7
2.2.1 Satellite missions 10
2.3 Digital Elevation Model 11

`

2.4 Time Series Analysis 12

2.5.1 Coefficient of Determination(R-squared) 13

2.6 Trend Analysis 13

2.7 Correlation Analysis 14

2.7.1 Spearman rank correlation 14

2.7.2 Kendall rank correlation 15

2.7.3 Pearson r correlation 15

2.8 Related Studies 15

CHAPTER THREE 18

METHODOLOGY 18

3.1 Overview 18

3.2 Data Collection 19

3.3 Software for Processing Data 20

3.4 Data Preprocessing 20

3.4.1. Removal of Outliers 20

3.4.2 Satellite Altimetry Data Preprocessing 20

3.4.3 Landsat Imagery Preprocessing 21

3.4.4 Geo-referencing and Resampling 21

3.4.5 Water Level Data Alignment. 21

3.4.6 Mtera dam visualization from Landsat8 images and DEM 21

3.5 Data Processing 22

3.5.1 Surface Area Calculation from Landsat Imagery 22

3.5.2 Water Level Extraction 23

3.5.3 Volume Estimation using Integral Formula 23

3.5.4 Accuracy Assessment of Volume Estimation 23

3.5.5 Data Analysis and Interpretation 24

3.6. Error analysis 24

3.6.1 Root Mean Squared Error 24

`

3.6.2 Regression Analysis 25

3.6.3 Correlation Analysis 25

3.6.4. Time Series Analysis 26

CHAPTER FOUR 27

RESULT, ANALYSIS AND DISCUSSION 27

4.0 Overview 27

4.1 Results 27

4.1.1 Data Preprocessing 27

4.1.2 Depth comparison results 30

4.1.3 Area results 31

4.1.4 Volume results 32

4.1.5 Volume Comparison 33

4.2. Analysis of the Results 34

4.2.1 Comparison of satellite altimetry data and in-situ water level data 34

4.2.2 Error analysis for the water volume 35

4.2.3 For the maximum and minimum water levels 36

4.2.4 Time Series Analysis 37

4.2.5 Temporal Trends of Water Levels 37

4.2.6 Temporal Trends of Dam area 39

4.2.7 Temporal Trends of water volume 39

4.2.8 Seasonal Analysis 40

4.2.9 Short-Term Fluctuations 40

4.3 Discussion of the Results 40

CHAPTER FIVE 43

CONCLUSION AND RECOMMANDATION 43

5.1 CONCLUSION 43

5.2 RECOMMENDATION 44

REFERENCES 45

`

LIST OF FIGURES

Figure 1.1; Study area map 6

Figure 2.1; DEM-TIN produced from contours with 10 m intervals (source https.www.remote sensing jounal.com) 16

Figure 3.1; Contour Map extracted from Alos parsal DEM and land8 image. 22

Figure 4.1; Annual highest and lowest insitu water levels comparison.................................. 29

Figure 4.2; Annual highest and lowest in-situ water levels comparison 30

Figure 4.3; Depth comparison between in-situ and satellite altimetry levels 31

Figure 4.4; Area comparison from satellite altimetry data 32

Figure 4.5; Volume comparison between satellite altimetry and in-situ water level results ... 34

Figure 4.6; Comparison of Highest water level at mtera dam 34

Figure 4.7; Comparison of Highest water level at mtera dam 35

`

LIST OF TABLES

Table 1.1; Scope of the research 5
Table 2.1; Satellite altimetry mission summary 11
Table 3.1; A methodology work flow 18
Table 3.2; Data collection and their sources. 19
Table 4.1; Monthly in-situ water level from Mtera hydroelectric dam 27
Table 4.2; Monthly In-situ water level from Mtera hydroelectric dam 28
Table 4.3; Annual in-situ maximum and minimum water levels. 28
Table 4.4; Annually maximum and minimum water levels from satellite altimetry 29
Table 4.5; Comparison between insitu and satellite altimetry maximum and minimum water levels 30
Table 4.6; Annual Mtera Hydroelectric dam water area 31
Table 4.7;Annual average Mtera Estimated water volume 32
Table 4.8; Annual average Mtera Estimated water volume 33
Table 4.9;Comparison between in-situ and satellite altimetry volume 33

`

ACRONOMYS AND ABBREVIATIONS

R^2	Coefficient of Determination
Bias	Mean Bias Error
DEM	Digital Elevation Model
DSM	Digital Surface Model
ENVISAT	Environmental Satellite
ESA	European Space Agency
ESA	European Space Agency
GCP	Ground Control Point
GDEM	Global Digital Elevation Model
GDR	Geophysical Data Records
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MAE	Mean Absolute Error
MBE	Mean Bias Error
MHW	Mean High Water
MODIS	Moderate Resolution Imaging Spectro-radiometer
MSL	Mean Sea Level
MSL	Mean Sea Level
RMS	Root Mean Square
RMSE	Root Mean Square Error
ROI	Region of Interest
SD	Standard Deviation
SRTM	Shuttle Radar Topography Mission
SSH	Sea Surface Height
SWOT	Satellite-derived Water Observation Technology
TOPEX/Poseidon	Ocean Topography Experiment/Poseidon Satellite
TWL	Total Water Level
USGS	United States Geological Survey
WSE	Water Surface Elevation
AWE	Above Water Elevation

`

VCI	Volume Change Index
WGS84	World Geodetic System 1984
MLW	Mean Low Water

`

CHAPTER ONE

INTRODUCTION

1.1 Background

Water level monitoring and volume estimation in reservoirs are crucial for effective water resource management, flood control, hydropower generation, and drought management. Accurate and timely information about water levels and reservoir volumes is essential for making informed decisions regarding water allocation, reservoir operation, and planning. Traditional in-situ measurement techniques, such as water level gauges and sensors, provide valuable data but are often limited in spatial coverage and can be expensive to implement. Satellite altimetry data, on the other hand, offers a remote sensing technique that has the potential to provide wide-scale and cost-effective monitoring of water bodies.

The Mtera Hydroelectric Dam, located in Tanzania, is a significant reservoir that supplies water for irrigation, domestic use, and hydropower generation. Currently water level in the Mtera dam is measured by using water level sensors known as staff gauges, these gauges are strategically placed at specific location, and staff gauges sensors is continuously measure water surface heights and transmits data to the central monitoring system by using special camera which capture the readings of the staff gauges. However, since the construction of the dam volume estimation and calculation within the dam is not available at all this is due to the lack of bathymetric, and low capital to conduct a constant and frequently advanced water levels and volume measurements methods.

By addressing this problem, the research aims to contribute to the field of hydrological studies and Electric resource management by providing valuable insights into the applicability and utility of satellite altimetry data. The findings of this research have the potential to influence water management strategies and enhance the understanding of water level dynamics and volume variations at Mtera Dam and other water bodies globally.

Satellite altimetry has emerged as a valuable tool for monitoring water levels in reservoirs. It involves the use of satellite sensors to measure the height of the water surface, which can then be converted into water volume estimations. However, before relying on satellite altimetry data for water management purposes, it is crucial to assess the accuracy and reliability of these measurements, particularly when compared to in-situ water level data. (Tourian, 2012)

Satellite data are found very useful in natural and artificially resource monitoring and management, since it provides a wide spatial extent and temporal coverage. Unlike traditional

`

field survey, mapping using remote sensing is not constrained by rough inaccessible terrains or geopolitical boundaries and it provides access to extensive historical data archives for respective studies. Remote sensing is up to date, cost effective, non-destructive and timely (Misra & Baraj, 2015). Satellite altimetry is a remote-sensing technique has been used to derive water-level data for approximately two decades (Sulistioadi YB, 2022). Remote sensing is a potential technique for hydrological monitoring and water resource management (Alsdorf et al, 2001)

Surface volume changes can be measured by satellites with two different approaches: whereas gravity missions such as the Gravity Recovery and Climate Experiment (GRACE) and its successor GRACE-FO observe total water storage changes with spatial resolutions of some hundred kilometers (Zaitchik et al, 2008) and another approach is a combination of satellite altimetry and optical imagery can be used to estimate surface water volume changes (Tim et al, 2019) Many hydrographic offices do not have the resources to conduct frequent hydrographic surveys using bathymetric method, especially in developing countries like Tanzania, due to the method demanding high cost, limited area, and time-consuming, so employing satellite altimetry to obtain water level monitoring and volume estimations help to solve this problem since its efficient and preferably costs effective methods of water level and volume estimation.

Several studies have projected the impacts of water level change, storage or volume changes and climate change in Africa (Mugabe , 2010) Climate change will have far-reaching, negative impacts on the availability of water resources, studies have also analyzed water level change in East Africa and specifically in Tanzania (Mwandosya, 1998) and at Ngerengere River used to be perennial in the late 1990s, but today it gets dry during the dry season, and this phenomenon is not only directly linked to decreased rainfall, but also increase in temperature (Irmak,S, 2018). The water level is the key component of these natural phenomena, which are mostly determined through their coastlines, which are recognized as the borderline between the land and the water body.

Accurate and regular monitoring of dams, lakes and reservoirs water level variations is crucial for fair and equitable water allocation to different sectors, ecosystem services, and for better understanding of climate change impacts (Li , 2018). Forecasting dam water level at any scale is an essential concern in water resource planning and catchment management, commercial navigation and domestic, agricultural, and industrial activities in many countries (Hwang & Wang, 2016).

`

Variables including incoming and outgoing water discharges, precipitation rate within the basin, groundwater harvesting, and evaporation are among the most determining factors affecting dam water level fluctuations (Muala, 2014). As the result of intensive human activities, climatic change and ecological factor lakes have changed remarkably. The dynamic changes of dam water level have to be monitored regularly and accurately as they can adversely affect the economic activities and developments taking place close to the lake shoreline.

Thus, this research study aims to assess the accuracy of satellite altimetry data by comparing it with in-situ water level data of the Mtera Hydroelectric Dam from 2016 to 2022. By integrating multiple data sources, including satellite altimetry data, in-situ measurements, digital elevation model (DEM) data, and Landsat images data for extraction of the dam water area, a comprehensive analysis will be conducted to evaluate the consistency between satellite altimetry data and in-situ measurements.

1.2 Problem of Statement

Traditional in-situ measurements have been the primary method for monitoring water levels at Mtera hydroelectric dam, but they can be limited in spatial coverage, lack of detailed bathymetry surveys, time-consuming, and highly operational cost. Satellite altimetry data presents a promising alternative for continuous water level monitoring and volume estimation. However, before implementing satellite altimetry on a wider scale, there is a crucial need to assess the accuracy and reliability of satellite altimetry data in comparison to in-situ measurements. Additionally, understanding the potential biases and limitations of satellite altimetry data is essential for its successful integration into Hydroelectric power resource management practices.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this research is to perform accuracy assessment of satellite altimetry data for water level and volume estimation at Mtera dam from 2016 to 2022.

1.3.2 Specific Objectives

i. Determine water levels from in-situ measurements and obtain highest and lowest water level per year.

ii. To determine water levels from satellite altimetry and compute the highest and lowest levels of water per year.

`

iii. To assess the closeness of satellite water levels and insitu water levels for comparison.
iv. To estimate volume of the dam from the satellite altimetry and insitu data and compare the results

1.4 Significance of the Study

i. Provide valuable insights into the impacts of water level changes of dams on the environment and local communities.
ii. By employing new satellite altimetry, the results obtained will improve operation of the Mtera dams in water level and volume measurements
iii. Provide insights for the management of hydroelectric power resources, water resources and infrastructure in the region by identifying patterns and trends in the changes in water storage in the Mtera dam.

1.5 Beneficiaries

Tanesco, the generated information could be used by Tanzania Electricity company for proper monitoring and operation of their daily electricity production more ever may use the obtained Results from the altimetry to generate an alternative means of producing electricity whenever the volume of the dam decline.

Hydrographic surveyor; Hydrographic surveyor could be used it as alternative bathymetry survey method in shallow water that could cover large area. Also generated information could be used by surveyor when conducting activities such as dredging and other engineering activities that takes place in the shallow water.

1.6 Research Questions

i. How accurate are the satellite-derived altimetry data, integrated with DEM, in estimating water levels at Mtera Hydroelectric Dam compared to in-situ measurements?
ii. Can a satellite altimetry be used for water level monitoring and volume estimation in the Mtera dam?
iii. What are the sources of discrepancies between the satellite altimetry data and in-situ measurements for water level monitoring and volume estimation?

1.7 Description of the Study Area

The research study focuses on the Mtera Hydroelectric Dam, located in the Great Ruaha River Basin, Tanzania. The dam is a key component of the country's water infrastructure, providing multiple benefits including hydropower generation, irrigation, and water supply for domestic and industrial use. The Mtera Reservoir, created by the dam, covers a vast area and serves as

`

an important water storage facility. It spans approximately from 630 to maximum 660 square kilometers and has a maximum storage capacity of 2.8 billion cubic meters.

The geographical coordinates of the study area are approximately 6°40' S latitude and 36°30' E longitude. It is situated in the Dodoma and Iringa regions of Tanzania, encompassing a diverse landscape that includes flat plains, hilly terrain, and the presence of nearby mountain ranges. The Great Ruaha River, which feeds the Mtera Reservoir, is the primary inflow source. It is a major tributary of the Rufiji River and is characterized by seasonal variations in water flow, influenced by rainfall patterns and the hydrological regime of the region.

The study area is subject to various climatic and environmental factors that impact water levels in the reservoir. These factors include rainfall variability, evaporation rates, inflow from upstream catchment areas, and human activities such as water abstraction for irrigation and hydropower generation. Understanding the dynamics of water levels in the Mtera Reservoir is essential for effective hydroelectric resource management and planning. The research study aims to assess the accuracy of satellite altimetry data by comparing it with in-situ water level data within this specific study area.

1.7.1 Scope and Limitation of the Research

This research mainly focused on Tanzania mainland at the Mtera hydroelectric dam as the study limited in using maximum and minimum water levels obtained from both insitu measurements and satellite altimetry data combined with Mtera spatial area to estimate volume changes, this research does not consider the bottom levels of the dam. Table 1.1 below describe scope of the research.

Table 1.1; Scope of the research

Name	Location	Location coordinates	Area
Mtera	Dodoma and Iringa	7°08′10.3″S, 35°59′12.6″E	660 sq.km

`

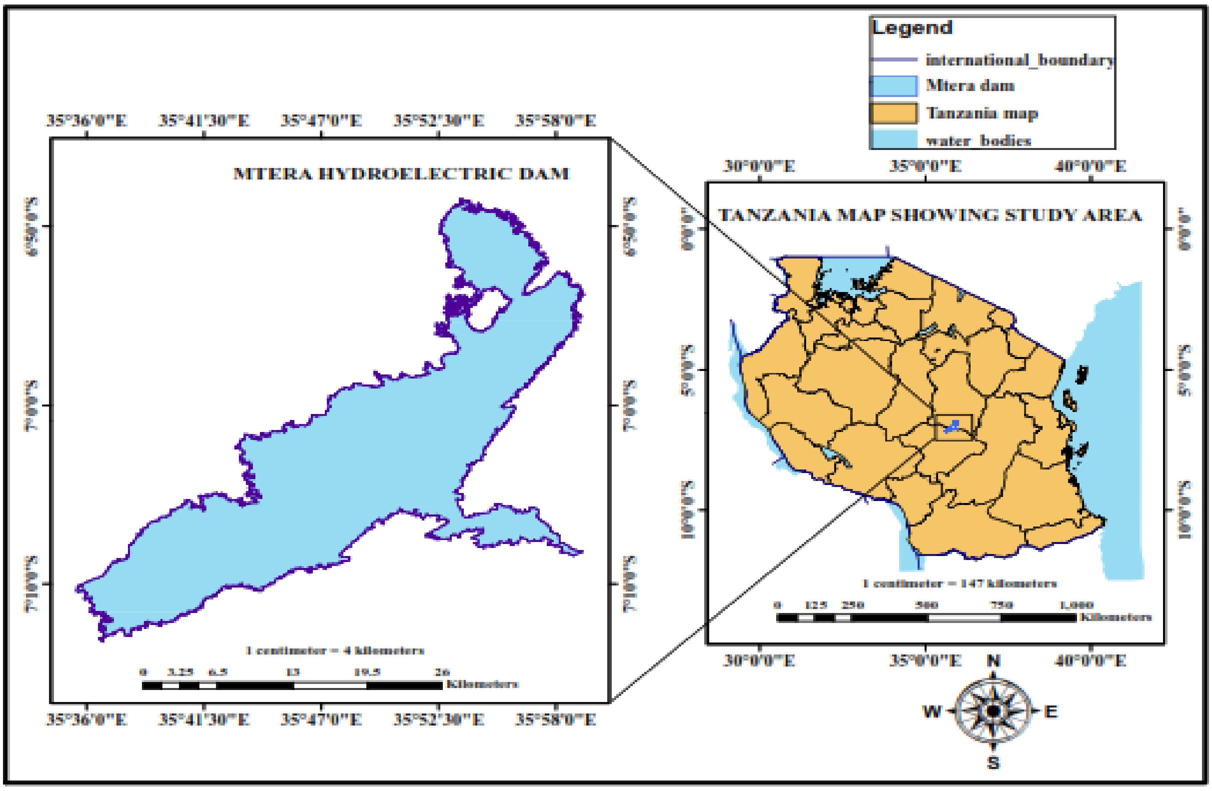


Figure 1.1; Study area map

1.8 Organization of the Research

This research comprises of five chapters, chapter one provides introduction, statement of the research problem, research objectives, descriptions of the study area, scope and limitations, the research outputs, significance of the research, beneficiaries, and the organization of the research. Chapter two comprises literature review, overview of satellite altimetry data and their missions and summary of previous related studies that has been done by different researchers on the dams. Chapter three covers all the methods and techniques used in order to achieve the main objective of the research. It explains how the data were collected, software's and techniques that were used in data processing. Chapter four comprises of results and Discussion of the results; it also explains the relevance of the findings and connect them to the research questions. Chapter five contains the conclusion and recommendations for the study. The conclusion summarizes the findings that answer the research questions, recommendation tells what next after this research has been done.

`

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter provides a review of the literature studies related to research work, it explains on the satellite altimetry technique based on water surface elevation, the chapter explains the principle mechanism of Satellite altimetry methods with their advantage and dis-advantage and why recent studies and researchers adopt to use Satellite altimetry in determination of water level changes and volume estimations.

2.1.2 Hydroelectric Dams

Hydroelectric dams are structures built to harness the potential energy of falling water to generate electricity. These dams have been widely used to produce electricity, especially in areas with high water flow rates. Mtera and Kidatu hydroelectric dams are two such structures located in Tanzania.Mtera Hydroelectric Dam is located on the Great Ruaha River in central Tanzania, while Kidatu Hydroelectric Dam is located on the Rufiji River in southern Tanzania. Both dams constructed in the 1970s and 1980s with the aim of generating electricity for the country's growing economy (Yawson , 2006). Mtera Hydroelectric Dam has a total installed capacity of 80 MW, with two turbines each generating 40 MW of power. The dam's reservoir has a capacity of 1.2 billion cubic meters to maximum 2.8 cubic meters and covers an area of about 630-660 square kilometers. The dam's construction was completed in 1981, and it has been supplying electricity to the national grid ever since. (Mwalyosi , 1986)

2.2 Satellite Altimetry

Satellite altimetry is a remote sensing technique for measuring height by estimating the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Altimetry measures the time required for pulse (released nadir to target) to travel from the satellite antenna to the earth's surface and back to the satellite receiver. The time required by microwave to illuminate a target and reflect back to the receiver antenna is used to calculate range. The speed of electromagnetic waves multiplied by half of the total times gives the range (height) from the satellite to water surface. An important quality of radar altimetry is its accuracy which it measures range. The limit of range resolution of radar system is as ability to distinguish in time the return pulse from point targets (Aronoff, 2005).

Since the launch of satellite embarking radar altimeters in the late 1970s, altimetrists have investigated the possibility of using these data for monitoring hydrological information of water

`

bodies such as Lake and rivers (Birkett et al ,2011). Due to the absence of continuously installation of gauge stations in most lakes and rivers and dams in Tanzania, it is a scientific and social challenge to develop a complementary water resource monitoring system with water level and discharge as the essential. Variables sources of observation to complement or replace in situ measured data that are lacking or unavailable. Therefore, satellite altimetry is the one of satellite technique which involves the determination of the dam levels.

A satellite altimeter measures the vertical range between the satellite and the water surface (Fu & Cazenove, 2001). It emits a short pulse of microwave radiation from the on-board radar antenna towards the water surface, part of the signal being reflected back to the satellite as shown in figure 2.1. By measuring the two-way travel time of the signal, the range can be determined (Medina *et al.* 2010). Thus, the water surface height is obtained by the difference between the satellite height above the known reference ellipsoid and the range of the satellite to the water surface. In spite of the simple principle of the range measurement from satellite altimetry, the technical challenges to get accurate measurements are substantial (Chelton et al , 2019).

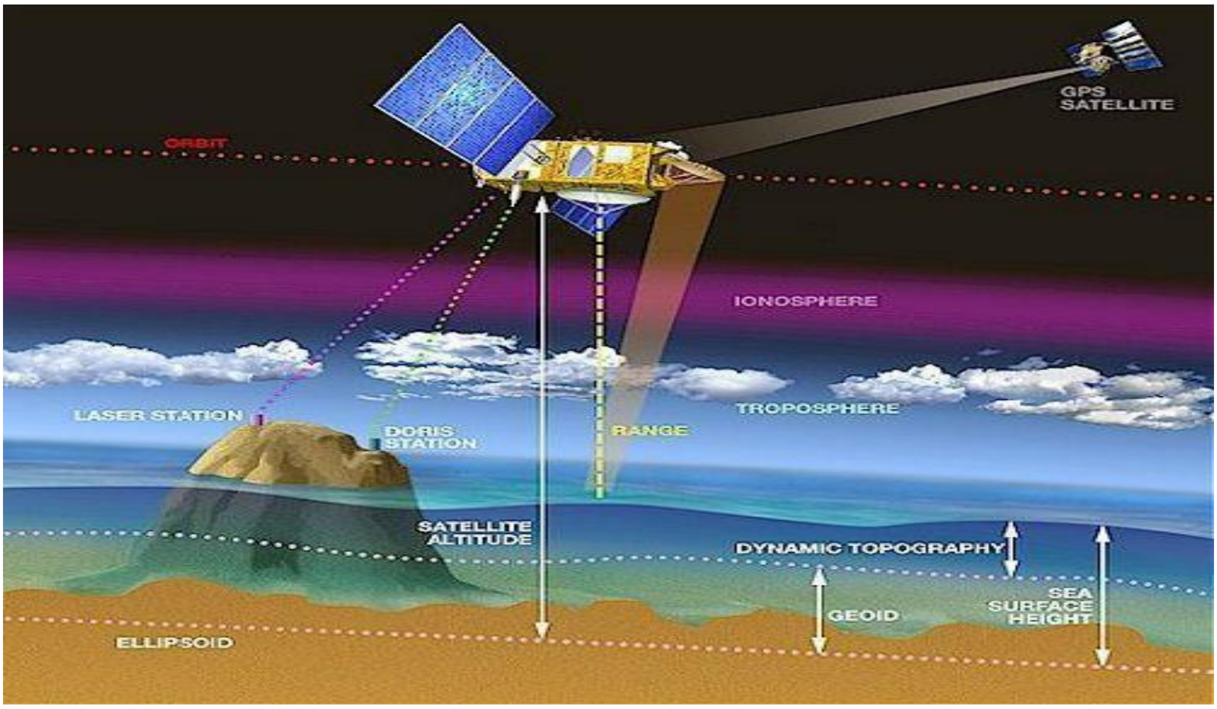


Figure 2.1; Satellite altimetry principle (https//doi.org/10.1112/.jp.ocaen)

Altimetry has capability to provide continuous water level data especially when difficulty of access arises due to harsh weather events. The revisit of the same area after a certain span of time (repeat period) help to generate time series data of rivers, lakes. Wetlands, inlands seas and floodplains. As maintaining data continuity through traditional gauging stations is

`

becoming increasingly difficult current altimetry missions provides a clue for monitoring large inland lakes globally (Adam, 2018) Once the systems are put in place, they could potentially provide data on multiple parameters such as temperature in addition to lake levels as means of data users to validate from the stations. Satellite altimetry obtain water level by performing the measurement of the surface and radar pulse from surface to satellite receiver. These measurements are combined with precise satellite location data yield surface water heights. The time required by microwave to illuminate a target and reflect back to the receiver antenna is used to calculate the range. The speed of the electromagnetic waves multiplied by half of the total times gives the range from the satellite to the water surface (Zhang , 2009). The approximation of the range R is computed as shown in equation 2.1.

$$R = \frac{ct}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.1$$

Where c represents the free space speed of the light and t is the two-way travel time

Taking the difference between radar altimeters height above the reference ellipsoid H and the range R obtained, the water surface height h can be determined as illustrated in equation 2.2.

$$\mathrm{h} = H - R \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.2$$

Where H is the orbit height of the satellite relative to the reference ellipsoid, h is the height of water surface relative to the reference ellipsoid (Topex/Poseidon). The electromagnetic waves on their way to the water surface as shown in equation 2.3 are decelerated by the atmosphere and ionosphere, thus corrections are applied to the range to compensate for delay effects. Specifically, for inland water bodies including lakes and reservoirs, classical corrections should include instrumental, ionosphere, wet and dry tropospheric, solid earth and pole tide corrections for radar altimetry (Birkett, 1995). Therefore, water surface height h can be written as

$$\mathrm{h} = H - R - corrections \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.3$$

The altimetry height is with respect to reference ellipsoid and it is the mean value within altimeter footprint. The ellipsoidal height can further be converted into orthometric height by removing a geoid height above the reference ellipsoid. The geoid height can be calculated from EGMs (Crétaux& Birkett, 2006), with a defined orbit, altimeter satellites provide the range measurements at intervals of several kilometers or tens of meters depending on the ground track spacing. Satellites overfly a given ground area with a regular repeat period thus, the time-series of surface height variations can be derived for a specific ground area along the satellite ground

`

track during the lifetime of the satellite mission. Although their primary objectives are ocean and ice studies, for more than 15 years satellite radar altimetry has been a successful technique for studying continental water bodies. In particular, the ability to remotely detect water surface level changes in lakes, rivers, dams and inland seas has been demonstrated. Altimetry satellites basically determine the distance from the satellite to a target surface by measuring the satellite-to-surface round-trip time of a radar pulse. The principle is that the altimeter emits a radar wave and analyses the return signal that bounces off the surface. Surface height is the difference between the satellite's position on orbit with respect to an arbitrary reference surface (the Earth's Centre or a rough approximation of the Earth's surface: the reference ellipsoid) and the satellite-to-surface range (calculated by measuring the time taken for the signal to make the round trip (Ghosh, 2017)

2.2.1 Satellite missions

Precise satellite altimetry, orbit determination and location missions have transformed the way we view Earth and its water bodies. Highly accurate altimetry measurements from Topex/Poseidon and Jason made by the Doris system give us the ability to observe sea surface height systematically. Since the launch of TOPEX/Poseidon satellites in 1992 followed by Jason-1 and Jason-2, the satellite altimetry missions have been calculating the surface water level on a continual basis since 1993 (Fernandes and Lázaro, 2017).

Within the earth observation program, the European Space Agency (ESA) launched the satellite; Environmental Satellite (ENVISAT) in 2002. Lake/reservoir surface water level products are generally derived from the long-term "repeat-track missions which fall into 2 groups having different temporal sampling such as 10-day Temporal sampling over a 21-year period, 1992 to the present day and 35-day temporal sampling over a 19yr period, 1994 to the present day (Handoko, 2017). ENVISAT consists of ERS-1 and ERS-2 mission flies on a helio-synchronous circular orbit with an inclination of 98.5° and a 35-day repeat period, potentially proving a world-wide dataset of water level time series.

Altimetry data are distributed by space agencies as GDRs (Geophysical Data Records), GDRs include satellite position and timing, radar measurements of the distance between the satellite and the reflecting surface called ranges, correction and flags as shown in table 2.1. Additional factors include the complexity of the terrain surrounding the lake or river, the ground tracking logic, and the algorithms used for processing echoes, all of which affects the rate how quickly the lake surface is acquired, uniquely identified and maintained (Handoko, 2018) The surface

`

roughness of the water and various atmospheric and geophysical influences such as water vapor, wind, rate of precipitation, presence of ice, tides, additionally play a role in product accuracy (Ricko et al, 2011).

Table 2.1; Satellite altimetry mission summary

Name	Country	Mission period	Orbit altitude km	Orbit inclination(km)	Equatorial Ground track (Km)	Period (days)	Accuracy (cm)
Sea-sat	USA	1978	800	108	800,160	17	5
Geo-sat	USA	1985-1990	800	108	164	17	4
ERS-1	Europe	1991-2000	785	98.5	80	35	3
ERS-2	Europe	1995-2011	785	98.5	80	35	3
ENVISAT	USA/France	2001-2013	785	98.5	80	35	3
T/P	USA/France	1992-2005	1336	66	315	10	2
Jason-1	USA/France	2001-2013	1336	66	315	10	2
Jason-2	USA/France	2008-2016	1336	66	315	10	2
Jason-3	USA/France	2016-presen Present	1336	66	315	10	2

2.3 Digital Elevation Model

Digital Elevation Model (DEM) is a digital representation of the surface topography of the Earth. DEMs are typical created by gathering elevation data from various sources such as LiDAR (Light Detection and Ranging), radar, or stereo satellite imagery, and then processing that data to create a gridded data set of elevation values. DEMs are widely used in a variety of applications such as environmental modeling, engineering design, and geographic information

`

systems (GIS). There are two types of DEMs that are commonly used: Digital Surface Model (DSM) and Digital Terrain Model (DTM).

A Digital Surface Model (DSM) represents the surface of the Earth including all of the features such as trees, buildings, and other structures. DSMs used in applications where the height of these features is important, such as urban planning, flood modeling, and 3D visualization. DSMs are created by combining elevation data from various sources and then adding the height of any features that are present on the surface.

On the other hand, a Digital Terrain Model (DTM) represents only the bare earth surface, without any man-made or natural features such as trees or buildings. DTMs commonly used in applications such as hydrological modeling, soil erosion modeling, and land-use planning. DTMs are created by removing any man-made or natural features from the DSM, leaving only the bare earth surface (David& wolock, 1994)

2.4 Time Series Analysis

Time series analysis is a statistical technique used to analyze data that is collected over time. It is used to identify patterns, trends, and relationships in data that can help predict future values.

In time series analysis, the data is typically represented as a sequence of values, which are recorded at regular intervals of time. The analysis involves examining the patterns in the data, including trends, seasonal patterns, and other cyclical effects. This is typically done by plotting the data over time and examining its characteristics. (ghashghaie et al, 2018)

2.5 Regression Analysis

Regression analysis is a quantitative research method which is used when the study involves modeling and analyzing several variables. Regression model describe the relationship between a dependent variable and one or more independent variable. The dependent variable is also called response variable and independent is called explanatory variables.

The basic form of regression models includes unknown parameters (β), independent variables (X), and the dependent variable (Y). Regression model, basically, specifies the relation of dependent variable (Y) to a function combination of independent variables (X) and unknown parameters (β) (Chiang, 2003).

Regression analysis used linear model equation as shown in equation 2.4 for the purpose of determining the trend that exist in the two data sets for the purpose of studying the change in

`

the water levels and volume changes. The basic linear regression equation is given as shown below

$y = \beta0 + \beta1*t$ ………………………………………….. 2.4

Where

y =represents the water level measurement, t =represents the time index,

β0= is the intercept, and β1 is the slope.

By estimating the values of β0 and β1, we can determine whether the water level measurements exhibit a significant increasing or decreasing trend.

2.5.1 Coefficient of Determination(R-squared)

This is the phrase used in regression analysis to describe how the data points fit along the regression equation's results line. According to (Asuero, 2006), more dots and lines are plotted when the coefficient is larger. The regression line should contain 80% of the points if the coefficient is 0.80. Values of 1 or 0 would mean, respectively.

The regression line reflects all of the data or none of the data. According to Statistics Solutions (https://www.statisticssolutions.com), a greater coefficient indicates a better goodness of fit for the observations.

2.6 Trend Analysis

To detect a general pattern of a relationship between related factors or variables and predict the future direction of this pattern, trend analysis is a time series analysis technique that compares the same item over a significantly long period of time (Sen, 2012). In order to effectively design and implement coping and adaptation options to the impacts of climate change, trend analysis is crucial for analyzing the spatial and temporal patterns in rainfall and temperature-related extremes.

Both parametric and non-parametric methods are available for trend analysis, with parametric methods relying on the premise that the distribution is what it is. Least squares linear regression is one technique that makes the assumption that the variables of interest have a fundamental distribution or normal distribution. According to Yue and Wang (2004), non-parametric methods do not rely on the presumption that data should have a normal distribution. Data from hydro meteorological time series are marked by a significant divergence from normally.

`

Because they offer more sensitivity than parametric methods for such data, non-parametric methods are favored for the detection of monotonic trends (Muthoni *et al*., 2018).

2.7 Correlation Analysis

Correlation analysis is the statistical tool used to study the closeness of the relationship between two or more variable. The variable is sad to be correlated when the movement of one variable is accompanied by the movement of another variable. (Jargons, 2021). In the correlation analysis, there are two types of variables- Dependent and Independent. The purpose of such analysis is to find out if any change in the independent variable results in the change in the dependent variable or not.

Also, Correlation refers to a bivariate analysis that measures the strength of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. A value of ± 1 indicates a perfect degree of association between the two variables. Correlation is used to determine the degree of association. There situations in which the x variable is not fixed or readily chosen by the experimenter, but instead is a random covariate to the y variable (Cengiz *et al.* 2003).

The direction of the relationship is indicated by the sign of the coefficient whether the correlation between the variables is positive or negative depends on its direction of change. The correlation is positive when both the variables move in the same direction, i.e., when one variable increases the other on an average also increases and if one variable decreases the other also decreases. The correlation is said to be negative when both the variables move in the opposite direction, i.e., when one variable increases the other decreases and vice versa. We measure four types of correlations: Kendall rank correlation, Spearman correlation, the Point-Bi-serial correlation and Pearson correlation, which are as follows (Stella, 2021)

2.7.1 Spearman rank correlation: It is a non-parametric test that is used to measure the degree of association between two variables. The test in this correlation does not have any assumption about the distribution of the data and is the appropriate correlation analysis when the two variables are measured on a scale that is at least ordinal. It expressed as the equation 2.5

$$\rho = \frac{6\sum di^2}{n(n^2-1)} \qquad \text{.....2.5}$$

Where by ρ is the Spearman rank correlation coefficient, di is the different between ranks corresponding in two variables and n is the number of values in each data (Shi & Conrad, 2009).

`

2.7.2 Kendall rank correlation: This correlation type is a non-parametric test that measures the strength of dependence between two variables. It expressed with the formula in equation 2.6 below.

$$\tau = \frac{nc - nd}{0.5n(n-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

Where by τ is the Kendall's rank correlation coefficient, (nc) number of concordant (ordered in the same way), and (nd) number of discordant (ordered in differently) (Douglas *et al.*, 2000)

2.7.3 Pearson r correlation: This is the most widely used correlation statistic to measure the degree of the relationship between linearly related variables. Normally, it uses continuous data, i.e., Data that is interval or ratio level. This correlation type assumes that both variables should be normally distributed.it presented in the

$$r = \frac{\sum_{i=1}^{n}(xi - x)(yi - \bar{y})}{\sqrt{\sum_{i=1}^{n}(xi - x)^2 \sum_{i=1}^{n}(yi - \bar{y})^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... 2.7$$

Where by r is the Pearson correlation coefficient, $\bar{x}$ is the mean of variable x and $\bar{y}$ is the mean of variable y.

2.8 Related Studies

Previous studies used various Remote sensing techniques including use of GRACE data, synthetic aperture radar (SAR) data, and satellite altimetry data to study and assess water level and storage changes at the dams. Lakes, Rivers and basins and some of these researches are;

Comparative assessment of remote sensing–based water dynamic in a dam lake using a combination of Sentinel-2 data and digital elevation mode. This study basically aims to determine the existing water volume and its temporal changes in **Bayramiç Dam Lake in western Turkey**. In this context, GIS methodologies including ANUDEM and TIN (as shown in figure below) models were tested comparatively. The bottom/ underwater topography produced from DEM and the water coastline extracted from NDWI derived from Sentinel 2A satellite images are the input parameters of the tested models. The analysis was carried out in approximately two hydrological periods covering the 2015–2016 and 2016–2017 water years, and in situ measurements were used as verification data.

`

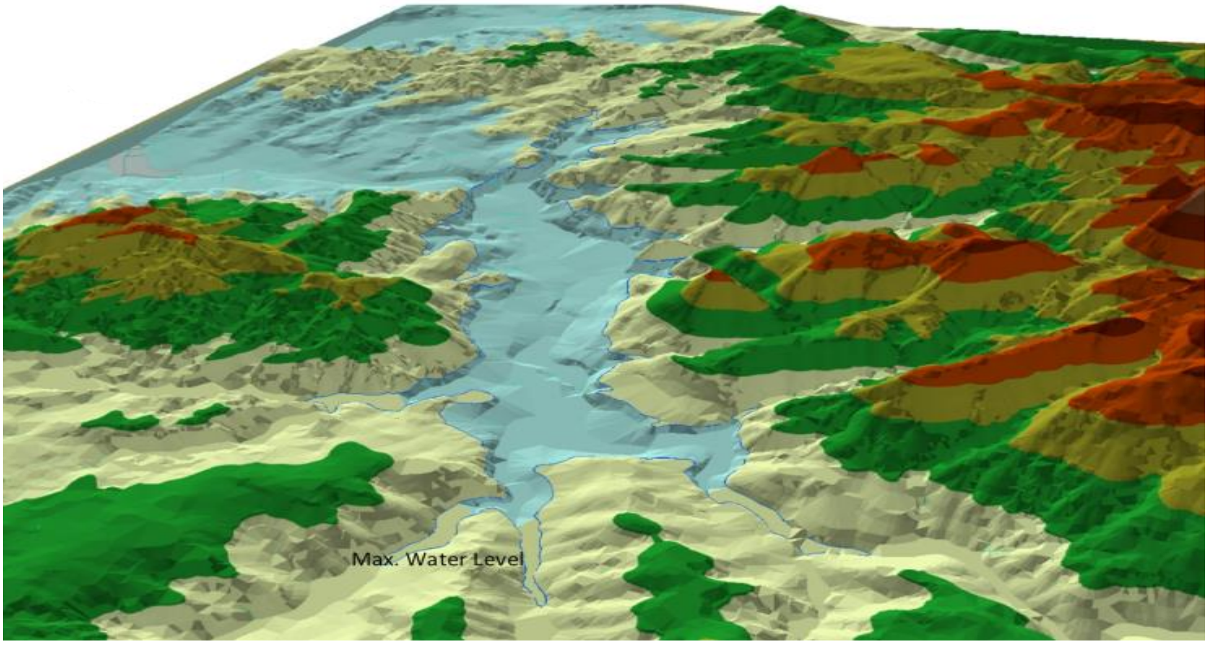


Figure 2.1; DEM-TIN produced from contours with 10 m intervals (source https.www.remote sensing jounal.com)

The results obtained the studied period, the dam water level varied between 124.35m and 144.62m, and the lake volume varied between 15.02 and 97.3 hm. Monthly total output due to surface evaporation, spillway, downstream release and water consumption for irrigation is greater than 0 and less than 24.608cubic meters. The water lost due surface evaporation from the lake reached up to 1.124 hm3 per month. The amount of water lost by evaporation from the open water surface in the two hydrological periods monitored was highest in July under the influence of the highest temperatures of the year (Cetinkaya , 2013).

(Fei , 2016)Conducted research on monitoring changes in the water volume of Hulun Lake by integrating satellite altimetry data and Landsat images between 1992 and 2010. Both researchers evaluated the feasibility of using monitoring the dynamics of the lake and reservoirs using remote sensing techniques (satellite altimetry and imagery), the results obtained were compared and validated with in situ measurements.

(Jiawei, 2022)Remotely sensed reservoir water storage dynamics (1984–2015) and the influence of climate variability and management at a global scale, in this study, we combined Landsat-derived surface water extents, satellite altimetry, and geo-statistical models to reconstruct monthly reservoir storage globally for 1984–2015, and examined long-term trends of global reservoir water storage and changes in reservoir resilience and vulnerability over the past three decades. There does not appear to be any systematic global decline in global reservoir

`

water availability, but found significantly decreasing trends in reservoir water volumes in southeastern Australia, southwestern USA, and eastern Brazil, creating the risk that storages fall to low capacity more often.

The above previous studies achieved to assess accuracy of satellite altimetry in water level in lakes sea and dams however they did not consider water level changes and volume at the same time also this did not counter using satellite altimetry for the minimal dam like Mtera thus this study aims to assess both water level and estimated volume changes in Mtera hydroelectric dam from 2016 to 2017 by using satellite altimetry and in-situ data combined with the Landsat8 images from the united states geological survey (USGS)

`

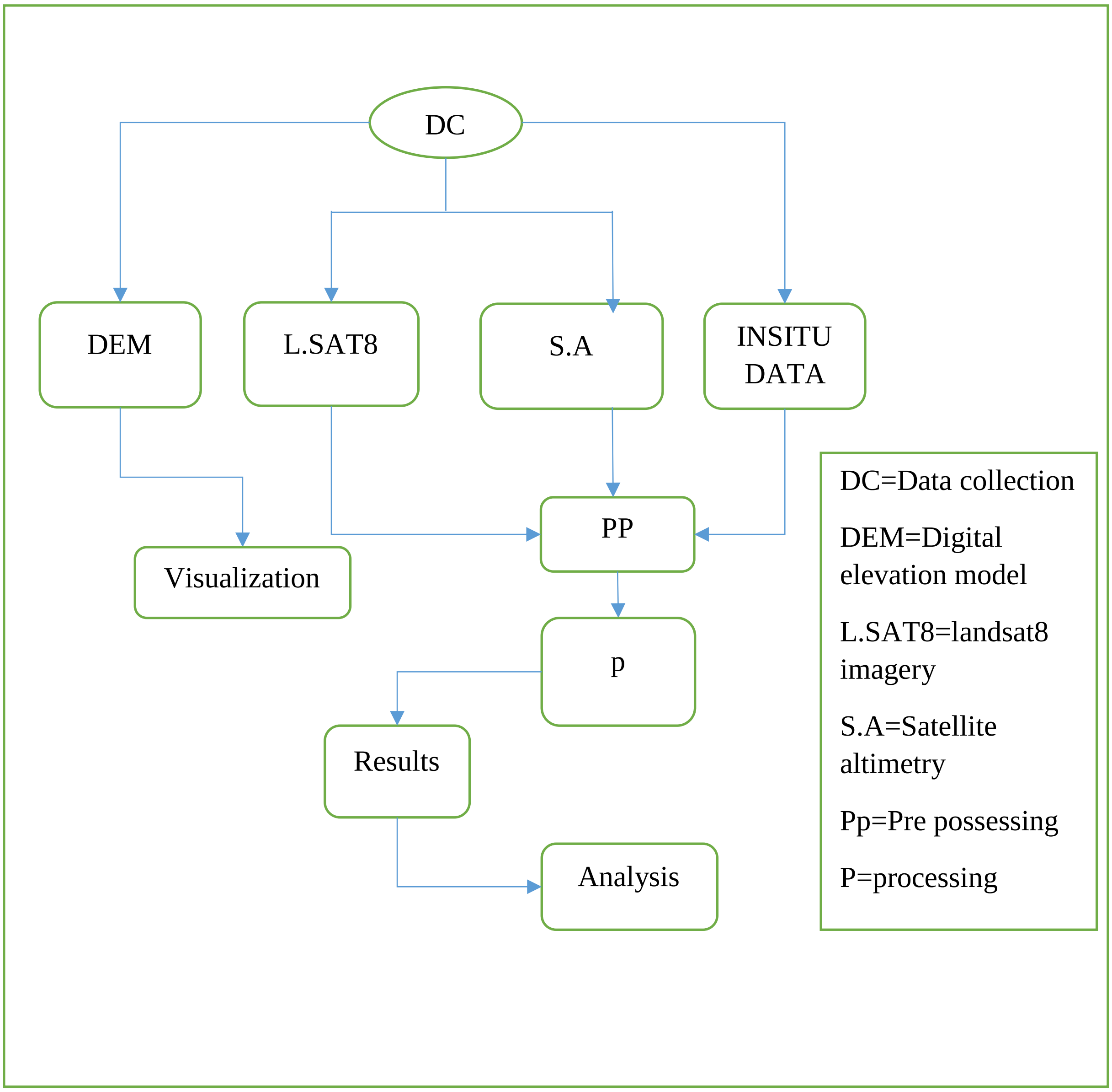
CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter outlines the methodology employed in the research to achieve the objectives of assessing the accuracy of satellite altimetry data for water level and volume estimation in the Mtera Hydroelectric Dam from 2016 to 2022. The chapter provides a detailed explanation of the data collection process, data preprocessing steps, mathematical calculations, and statistical analysis and techniques used in the study.

Table 3.1; A methodology work flow



`

3.2 Data Collection

The data collection process involved gathering four primary datasets: satellite altimetry data, in-situ water level measurements, and ancillary data as landsat8 satellite imagery data and Digital Elevation Model (DEM) data. The satellite altimetry data was directly downloaded from the DAHITI website, which provides water level measurements over the study area. Altimetry data to provide water level time series of inland waters and hydrological information on lakes, river, and reservoir. The estimation of water level time series in DAHITI is based on an extended outlier rejection and a Kalman filter approach, this approach is based on a rigorous combination of a variety of altimeter missions as derived from satellite. The daily in-situ water level measurements obtained from Tanzania electricity supply limited (TANESCO) which were collected using water level gauges installed at strategic locations in the Mtera Hydroelectric Dam, and were referenced from the mean sea level (MSL) these data were used to check the validity of the altimetry data and test how well the data will fit for use. DEM data Together with Land-sat8 images were downloaded and acquired from reputable sources such as the United States Geological Survey (USGS).

Table 3.2; Data collection and their sources.

DATASETS	FORMAT	SOURCES	YEAR	USES
Satellite Altimetry (multi mission) data	XYZ	Copernicus hub website DAHITI **(http://dahiti.dgfi.tum.tum.de/)**	2016-2022	Water level estimation
Historic in situ water level data	XYZ	Tanzania Electricity company limited (TANESCO)	2016-2022	Training and Validation
High resolution Alos-palsar Digital elevation model	Geo-tiff	Earthdata.nasa.gov.	2020	Topography visualization
Landsat 8 satellite image	Geo-tiff	United States Geological Survey (USGS)	2016-2022	Area calculation

`

3.3 Software for Processing Data

The software's which were used in data preprocessing, processing, water level and volume derivation and validation in order to attained objectives of the study are Arc map software, Microsoft excel and golden surfer; Arc Map Software. This software used to create advanced geospatial analysis in the study it deals in creation of detailed maps and conducting hydrological modeling which were used to derived the volume from maximum and minimum water levels integrated with the satellite imagery (Landsat8 images).

Microsoft excel; This software was used in organization and analyzation of data performing the mathematical and calculations, generating charts, graphs and tables. Golden Surpher. This software was used in grid data from Satellite altimetry data and the DEM data and perform mathematical operation involved in the study. Also, it used to design contours and creates 3D maps which were used to visualize topography surround Mtera dam. QGIS a powerful open-source GIS software which provide wide range of tools used for spatial analysis. Visualize data, and generate informative figures, charts and map.

3.4 Data Preprocessing

This part explains in detail on how the preprocessing that was carried out to calibrate the satellite altimetry data and satellite imagery data to make it possible to retrieve necessary information for accuracy assessment. Also, the in-situ water level data was required to be reduced in order to be used as training and validation data. Below were pre-processing procedures which were used in this study.

3.4.1. Removal of Outliers

The satellite altimetry data, Landsat8 image data were pre-processed to remove outliers and apply necessary corrections for factors such as atmospheric effects and tides. The in-situ water level measurements were calibrated and synchronized with the satellite altimetry data to remove inconsistencies and some missing data, one common method for outlier detection is the use of the Z-score. The Z-score measures the number of standard deviations a data point is from the mean. Data points with a Z-score above a certain threshold are considered outliers and can be removed (Aggarwal, 2014).

3.4.2 Satellite Altimetry Data Preprocessing

Quality Check; After gathering the satellite altimetry data covering the Mtera dam area for the study period, Assess the quality of the satellite altimetry data to identify and handle any outliers or missing values.

`

3.4.3 Landsat Imagery Preprocessing

Landsat8 images data collected from 2021 to 2022 were Landsat level 2 collection 2 data which is already corrected for radiometric, geometric and atmospheric correction However for the images below 2018 within our data were undergoes radiometric calibration corrects for sensor specific digital numbers (DN), geometric calibration for ensure accurate alignment of pixels into corresponding geographical location. Moreover, Atmospheric corrections applied to remove atmospheric interference and obtain surface reflectance values. This step is crucial to ensure consistency and accuracy in the spectral data. Cloud Masking: this was done by Identify and mask out cloud-covered pixels in the Landsat imagery to avoid any interference during analysis.

Mosaicking and Subsets; multiple Landsat images covering the study period, was undergoes mosaic into a single image to create a continuous and seamless dataset. Also, for the Landsat images cover a larger area than necessary, subset the data to include only the Mtera dam area for analysis. (Huisman & Rolf , 2009)

3.4.4 Geo-referencing and Resampling

The Landsat8 image and DEM data were georeferenced by Q-GIS software to match the spatial resolution and coordinate system of the satellite altimetry data, it’s a crucial step to align these data sets with the satellite altimetry data. Resampling is performed to adjust the spatial resolution of the Satellite image and DEM data to that of the satellite altimetry data. (Jensen, 2005).

3.4.5 Water Level Data Alignment.

Ensure that the time stamps of the Landsat imagery and satellite altimetry data are aligned correctly. This step is crucial for accurate comparison between water levels from both datasets at the same time steps.

3.4.6 Mtera dam visualization from Landsat8 images and DEM

The landsat8 images data were Overlaid onto the Alos-palsar DEM to extract the water surface area for visualization of the topography and extract contour at Mtera Hydroelectric dam as shown in the figure 3.1 below. This was done using Quantum-GIS and Golden surfer software, by utilizing techniques like raster calculation, contour extraction.

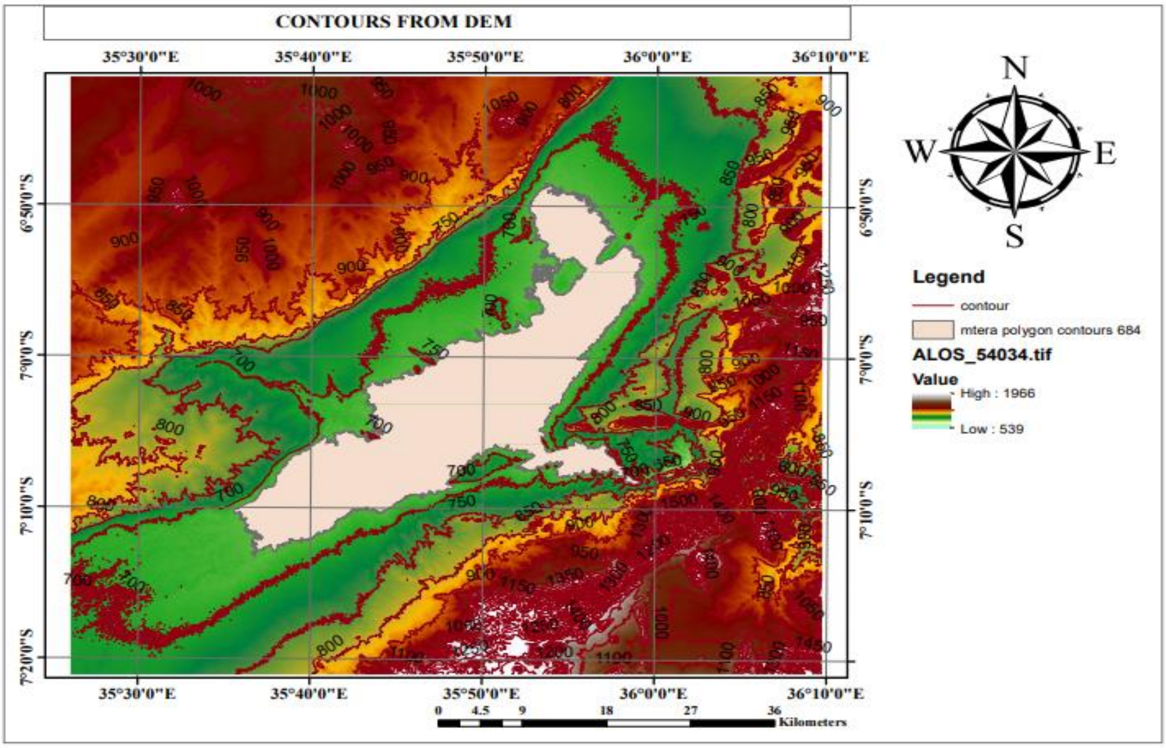


Figure 3.1; Contour Map extracted from Alos parsal DEM and land8 image.

3.5 Data Processing

This part described in detail on the process involved, mathematical equations and the software used in the processing of landsat8 satellite image, ALOS PALSAR Digital elevation model together with satellite altimetry data and in-situ data to obtain the results the process involved are as follows;

3.5.1 Surface Area Calculation from Landsat Imagery

Preprocess the Landsat images, including atmospheric correction and radiometric calibration, to convert them into surface reflectance values.

The area were calculated from the technique called modified normalized different water index(MNDWI)were it involves extraction of water pixels area from the landsat8 images and these pixels area derived from the blue bands, and the near infrared band and its formula is presented as follow (Feeters, 1996).

$$\text{NDWI}=\frac{Band3-band5}{band3+band5}$$

After determination of water pixels area then the Use zonal statistics in GIS software was used to calculate the water extent in the Landsat images for each time step. This will give the surface water area (A) at different time period of the study (Burrough et al, 2015)

`

3.5.2 Water Level Extraction

Extract water levels from the satellite altimetry data for each time step. These water levels represent the water level measurements for the dam and extract the corresponding in-situ water level measurements taken at the dam site for each time step. Then Determination of the minimum (h-min) and maximum (h-max) water levels from both datasets (satellite altimetry and in-situ measurements) for each time step means yearly during the study period from 2016 to 2022 was conducted so as to obtain surface elevation as Highest and lowest levels.

3.5.3 Volume Estimation using Integral Formula

Function that relates the surface area obtained from Landsat imagery to the lengths between the maximum and minimum water levels was generated. This function should be based on the geometry and shape of the dam. Analytical integration of the function over the lengths between the maximum and minimum water levels to calculate the volume of water stored in the dam for each time step was performed. The water volume at each step was obtained by multiplying the cross-sectional area by the reservoir length.

Estimation of the dam volume is done by analytical integration of the function relating the surface area (A) extracted from Landsat8 images and the lengths between maximum and minimum water levels (h) from both satellite altimetry and in-situ measurements. Mathematically relationship between water area and water levels is expressed in the equation 3.1 below.

$$A = (\mathrm{h}) \quad \ldots\ldots 3.1$$

For each time period, integrate the surface area function (A) over the range of water levels from (h-min) to (h-max) using the definite integral as shown in the below equation 3.2.

$$\mathrm{Vt} = \int_{h1}^{h2} A dh \quad \ldots\ldots 3.2$$

Where $h1$ and $L2$ are the minimum and maximum water levels. And A represents the raster surface area in Km^2

The result (Vt) for each time period will give the estimated volume of water from stored in the dam at that particular time. From maximum water level to minimum water level.

3.5.4 Accuracy Assessment of Volume Estimation

For each time period, compare the volume estimates obtained from satellite altimetry (V-satellite) with the volume estimates based on in-situ measurements (V-in-situ). then Calculation

`

of the differences between the two volume estimates (Differences = |V-satellite – V-in-situ|) to assess the accuracy of the volume estimation. Was performed.

More ever calculation of statistical metrics like Root Mean Square Error (RMSE) or Mean Absolute Error (MAE) for the volume estimates to quantify the overall accuracy was performed

3.5.5 Data Analysis and Interpretation

Analyzation of the results of the accuracy assessment for each time step to understand the accuracy of the volume estimation method and the agreement between satellite altimetry data and in-situ measurements. And then Identification of any discrepancies between volume estimates from the two datasets was performed.

3.6. Error analysis

The section described on the analysis which was performed based on several statistical approaches, correlation coefficient, correlation determination, root mean square errors between both datasets. It also explains on how the data were selected in performing validation for both satellite altimetry data and in-situ water level data from Mtera Hydroelectric dam, Satellite altimetry data and validation data from in-situ water level were random gridding at the same excel for validation. And was include the following;

3.6.1 Root Mean Squared Error

Root Mean Square Error (RMSE) is a commonly used metric to assess the accuracy of the satellite altimetry data. It measures the overall deviation between the satellite altimetry-derived water levels and the in-situ water level measurements at corresponding locations and time points.

The formula is expressed in equation (3.3)

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}((Zm - Zn))^2}{N}} \quad \text{…………………………………..………………….. 3.3}$$

Where,

Zm = the predicted levels/volume from satellite altimetry.

Zn = actual is the in-situ water level measurement.

N is the number of sample ((Montgomery, 2014)

`

3.6.2 Regression Analysis

Regression analysis helps determine the linear relationship between the satellite altimetry data and the in-situ water level measurements. It estimates regression coefficients, such as the slope and intercept, to quantify the relationship. The equation for a simple linear regression model is:

$$y = \beta 0 + \beta 1 * X \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.4$$

Where

y =is the in-situ water level measurement,

x =is the satellite altimetry water level,

β0= is the intercept, and β1= is the slope.

To determine the values of β0 and β1, we use a method called ordinary least squares (OLS) regression. The OLS method minimizes the sum of squared differences between the observed in-situ water level measurements and the predicted values based on the linear equation. (Kutner,M, 2005)

$$\beta 1 = \frac{\Sigma[(x - \bar{x})(y - \bar{y})]}{\Sigma(x - \bar{x})^2} \quad \text{and} \quad \beta 0 = \bar{y} - \beta 1 * \bar{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.5$$

3.6.3 Correlation Analysis

Measures the strength and direction of the relationship between the satellite altimetry data and the in-situ water level measurements. It calculates correlation coefficients, such as Pearson's correlation coefficient, to quantify the degree of association between the variables. The formula for Pearson's correlation coefficient (r) is:

$$r = \frac{\Sigma((x - \bar{x})(y - \bar{y})])}{\sqrt{(\Sigma(x - \bar{x})^2)} * \sqrt{(\Sigma(y - \bar{y})^2)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where

x and y are the respective data points,

x̄ and ȳ are the means of x and y, and Σ denotes the sum of the values.

The resulting correlation coefficient (r) ranges between -1 and 1, with values closer to -1 or 1 indicating a stronger correlation. A positive correlation coefficient indicates a positive relationship between the variables, while a negative correlation coefficient indicates a negative relationship. The magnitude of the coefficient indicates the strength of the relationship, with values closer to 1 or -1 indicating a stronger, (Dancey & Reidy, 2017).

`

3.6.4. Time Series Analysis

It's necessary to perform time series analysis to explore patterns, trends, and seasonality in the water level measurements. Time series analysis techniques include smoothing methods, trend analysis, seasonal decomposition, and forecasting. For this study we employ trend analysis and this involves use a simple linear regression model to determine the trend in water level measurements over time. The regression equation would be:

$$y = \beta 0 + \beta 1 * t \qquad (3.7)$$

Where

y =represents the water level measurement, t =represents the time index,

$\beta 0$= is the intercept, and $\beta 1$ is the slope.

By estimating the values of $\beta 0$ and $\beta 1$, we can determine whether the water level measurements exhibit a significant increasing or decreasing trend.

`

CHAPTER FOUR

RESULT, ANALYSIS AND DISCUSSION

4.0 Overview

This chapter presents all the results which were obtained from the methodology of this research and provide analysis of the obtained results as follows.

4.1 Results

4.1.1 Data Preprocessing

The obtained results from the data pre -processing are monthly and annually highest and lowest water levels for both daily historic water levels and satellite altimetry levels as shown from table 4.1 and 4.2, 4.3 and 4.4 below.

Table 4.1; Monthly in-situ water level from Mtera hydroelectric dam

ISITU HIGHESTAND LOWEST WATER LEVELS FROM (2020-2022) (m)								
	2016		2017		2018		2019	
Month	highest	lowest	highest	lowest	highest	lowest	highest	lowest
January	696.53	693.00	694.20	693.61	691.53	690.45	693.42	693.08
February	695.38	694.83	693.61	693.30	691.55	691.44	693.41	693.04
March	696.14	695.58	693.77	693.45	694.14	691.44	693.32	693.07
April	697.37	696.13	693.85	693.75	695.29	694.17	693.41	693.29
May	697.48	697.37	693.94	693.88	695.64	695.32	693.50	693.41
June	697.45	697.30	693.73	693.44	695.67	695.57	693.49	693.27
July	697.26	697.00	693.73	693.43	695.57	695.35	693.24	692.99
August	696.97	696.57	693.43	693.11	695.34	695.00	692.97	692.53
Septembe r	696.56	696.12	693.09	692.63	694.96	694.54	692.52	692.04
October	696.12	695.51	692.60	691.94	694.52	694.05	692.02	691.73
November	695.50	694.86	691.88	691.20	694.01	693.43	691.60	691.20
December	694.83	694.22	691.10	690.46	693.40	693.13	691.69	691.22

`

Table 4.2; Monthly In-situ water level from Mtera hydroelectric dam

ISITU HIGHEST AND LOWEST WATER LEVELS FROM (2020-2022) (m)						
	2020		2021		2022	
Month	highest	lowest	highest	lowest	highest	lowest
January	693.40	694.67	697.19	695.91	694.86	694.47
February	699.00	696.70	698.77	697.21	695.95	694.6
March	698.97	698.60	698.77	698.7	696.97	695.98
April	698.81	698.77	698.77	698.7	697.16	696.99
May	698.80	698.78	698.8	698.69	697.16	696.79
June	698.80	698.58	698.68	698.3	696.78	695.65
July	698.57	698.26	698.3	697.87	696.31	695.76
August	698.26	697.85	698.3	697.37	695.75	695.18
September	697.85	697.38	697.37	696.84	695.16	694.54
October	697.36	696.78	696.82	696.2	694.52	693.71
November	696.96	696.32	696.56	695.54	693.68	692.92
December	693.12	695.22	695.54	694.86	692.89	692.26

Table 4.3; Annual in-situ maximum and minimum water levels.

ANNUALLY HIGHEST AND LOWEST INSITU WATER LEVELS (m)			
Year	Highest/maximum levels(m)	Lowest/minimum levels(m)	Length Between(m)
2016	697.480	693.000	4.480
2017	694.200	690.460	3.740
2018	695.670	690.450	5.220
2019	693.500	691.200	2.300
2020	699.000	694.670	4.330
2021	698.800	694.860	3.940
2022	697.160	692.260	4.900

`

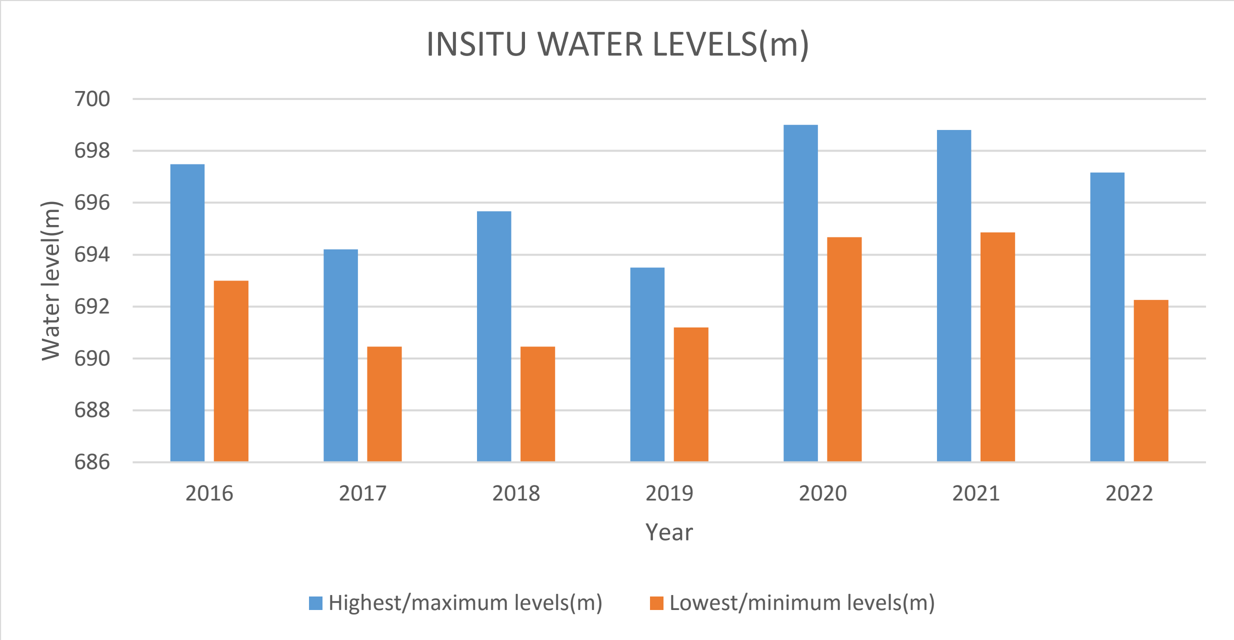


Figure 4.1; Annual highest and lowest insitu water levels comparison

Table 4.4; Annually maximum and minimum water levels from satellite altimetry

ANNUALLY HIGHEST AND LOWEST SATELLITE ALTIMETRY WATER LEVELS (m)			
Year	Highest/maximum levels(m)	Lowest/minimum levels(m)	Length between(m)
2016	700.133	696.181	3.952
2017	696.674	693.137	3.537
2018	698.371	693.972	4.399
2019	696.293	693.910	2.383
2020	701.562	697.369	4.193
2021	701.531	697.626	3.905
2022	699.848	695.174	4.674

`

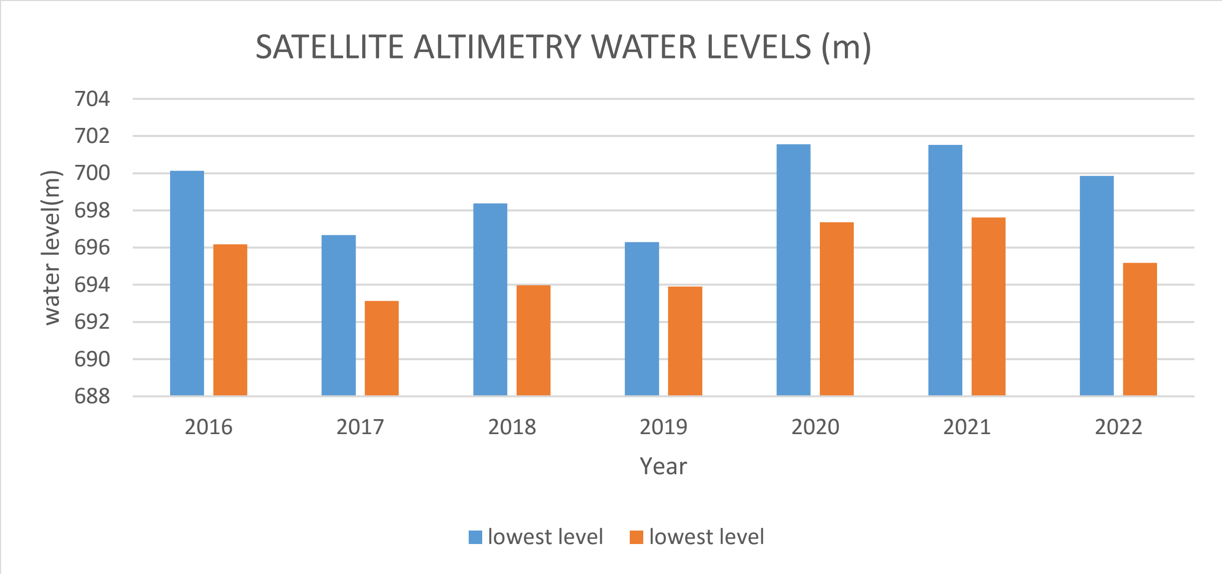


Figure 4.2; Annual highest and lowest in-situ water levels comparison

4.1.2 Depth comparison results

The results of depth or length from satellite altimetry data and in-situ water level data which were obtained from the maximum water level minus minimum water level are compared and presented in the table 4.5 and figure 4.3 below.

Table 4.5; Comparison between insitu and satellite altimetry maximum and minimum water levels

COMPARISON BETWEEN INSITU AND SATELLITE ALTIMETRY MAXIMUM AND MINIMUM WATER LEVELS (m)			
Year	In-situ (hmax-hmin) (m)	Sat-Altimetry (hmax-hmin) (m)	Differences (m)
2016	4.480	3.952	0.528
2017	3.740	3.537	0.203
2018	5.220	4.399	0.821
2019	2.300	2.383	-0.083
2020	4.330	4.193	0.104
2021	3.940	3.905	0.035
2022	4.900	4.674	0.226

`

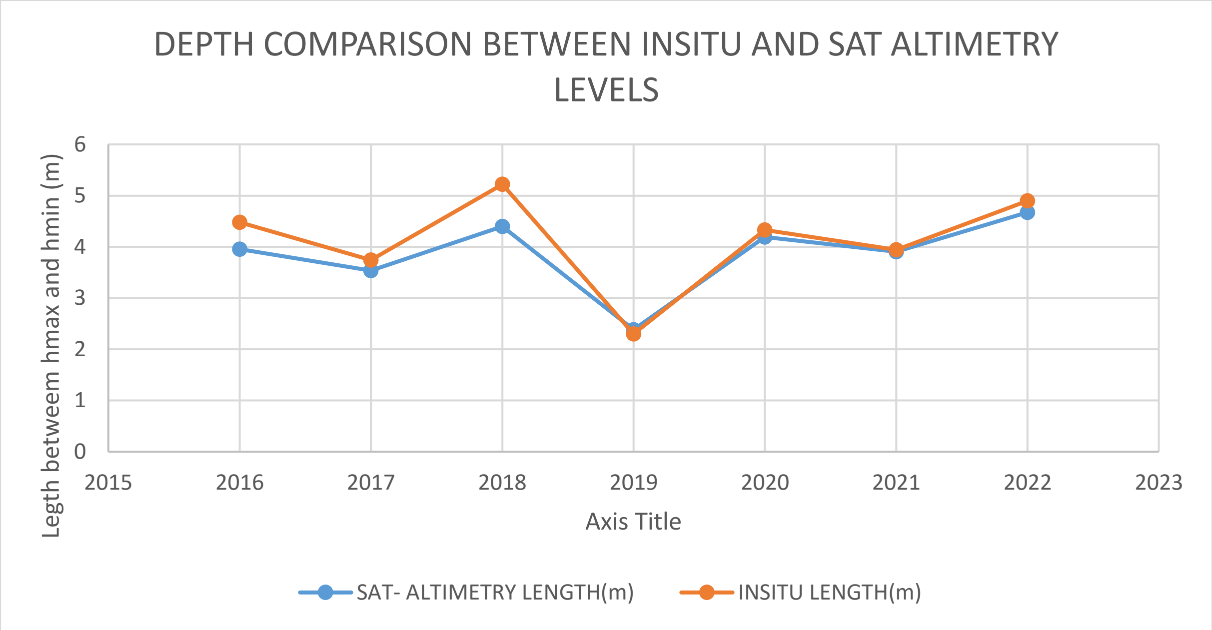


Figure 4.3; Depth comparison between in-situ and satellite altimetry levels

4.1.3 Area results

The area obtained from the landsat8 images and was calculated from the GIS techniques called raster area calculation from the ArcGIS software and the obtained area are presented as the below table 4.6.

Table 4.6; Annual Mtera Hydroelectric dam water area

ANNUALLY AREA OF MTERA HYDROELECTRIC DAM (m^2) OBTAINED FROM LANDSAT IMAGES		
Year	Area in (m^2)	Area in (km^2)
2016	506748000	506.748
2017	383892000	383.892
2018	393850000	393.85
2019	337452000	337.452
2020	612609000	612.609
2021	612373000	612.373
2022	530289000	530.289

`

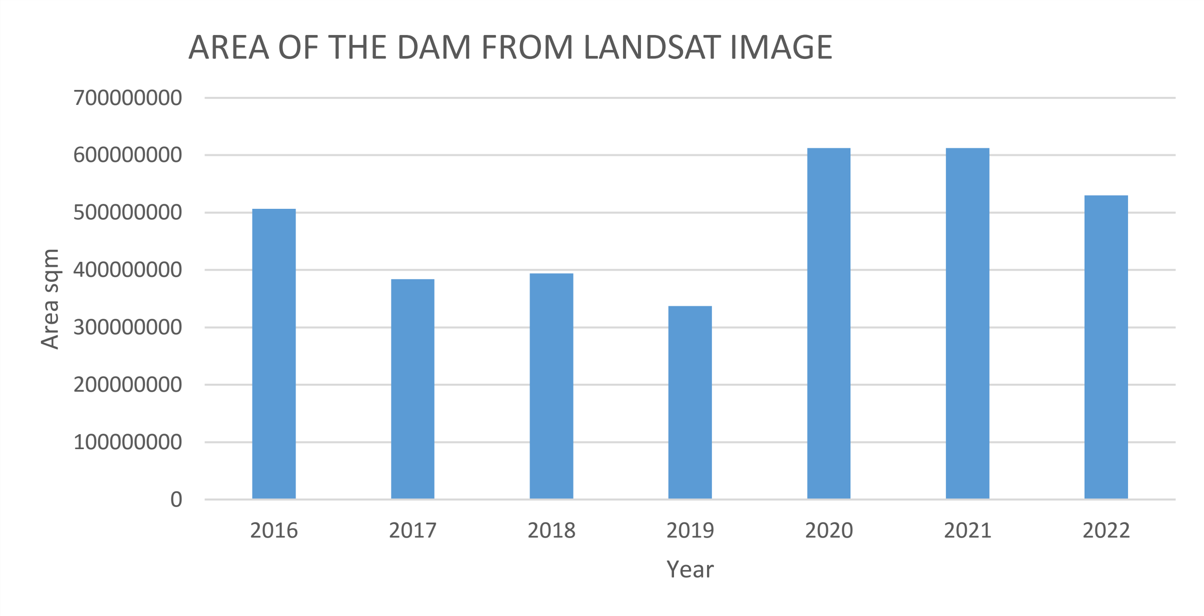


Figure 4.4; Area comparison from satellite altimetry data

4.1.4 Volume results

Volume obtained is surface volume from the lowest water levels to the highest water levels for both satellite altimetry and in-situ data then area which obtained from the Landsat image were integrated into these depths to obtain the surface volume of the dam and the results are shown in the table 4.7 and 4.8 below.

Table 4.7;Annual average Mtera Estimated water volume

ANNUALLY INSITU WATER VOLUME (m^3) BETWEEN HIGHEST AND LOWEST WATER LEVELS (m^2)					
Year	maximum levels(m)	minimum levels(m)	Depth between(m)	Area (m^2)	Volume (m^3)
2016	697.480	693.000	4.480	506748000	2,270,231,040
2017	694.200	690.460	3.740	383892000	1,435,756,080
2018	695.670	690.450	5.220	393850000	2,055,897,000
2019	693.500	691.200	2.300	337452000	776,139,600
2020	699.000	694.670	4.330	612609000	2,652,596,970
2021	698.800	694.860	3.940	612373000	2,412,749,620
2022	697.160	692.260	4.900	530289000	2,598,416,100

`

Table 4.8; Annual average Mtera Estimated water volume

ANNUALLY SATELLITE ALTIMETRY WATER VOLUME (m^3) BETWEEN HIGHEST AND LOWEST WATER LEVELS (m^2)					
Year	maximum levels(m)	minimum levels(m)	Depth between(m)	Area (m^2)	Volume (m^3)
2016	700.133	696.181	3.952	506748000	2,002,668,096
2017	696.674	693.137	3.537	383892000	1,357,826,004
2018	698.371	693.972	4.399	393850000	1,732,546,150
2019	696.293	693.910	2.383	337452000	804,148,116
2020	701.562	697.369	4.193	612609000	2,568,669,537
2021	701.531	697.626	3.905	612373000	2,391,316,565
2022	699.848	695.174	4.674	530289000	2,478,570,786

4.1.5 Volume Comparison

The obtained surface volume from in-situ data levels were compared with the Satellite altimetry data volume and the comparison yielded the following results as shown in the table 4.9 and figure 4. 5 below.

Table 4.9;Comparison between in-situ and satellite altimetry volume

COMPARISON BETWEEN INSITU AND SATELLITE ALTIMETRY VOLUME (m^3)			
Year	INSITU Volume (m^3)	SAT-ALTIMETRY Volume (m^3)	Differences (m)
2016	2,270,231,040	2,002,668,096	267,562,944
2017	1,435,756,080	1,357,826,004	77,930,076
2018	2,055,897,000	1,732,546,150	323,350,850
2019	776,139,600	804,148,116	-28,008,516
2020	2,652,596,970	2,568,669,537	83,927,433
2021	2,412,749,620	2,391,316,565	21,433,055
2022	2,598,416,100	2,478,570,786	119,845,314

`

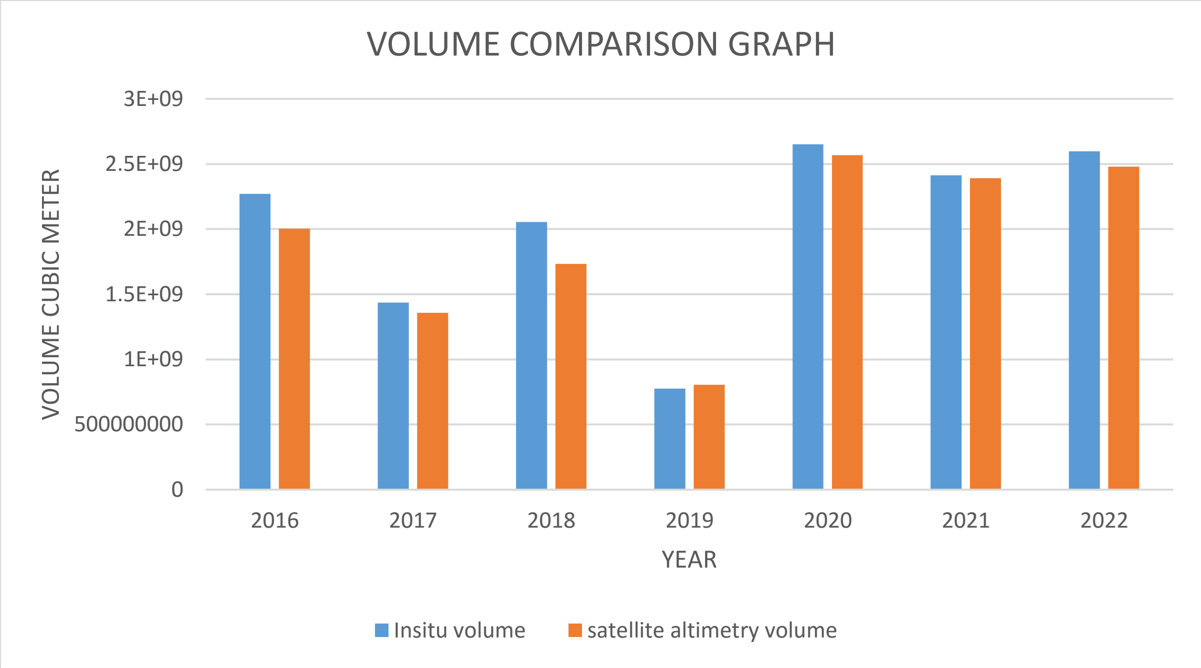


Figure 4.5; Volume comparison between satellite altimetry and in-situ water level results

4.2. Analysis of the Results

4.2.1 Comparison of satellite altimetry data and in-situ water level data

The comparison between satellite altimetry data and in-situ water level data aimed to assess the accuracy and reliability of the satellite-derived measurements in capturing the actual water levels at the Mtera Hydroelectric Dam.

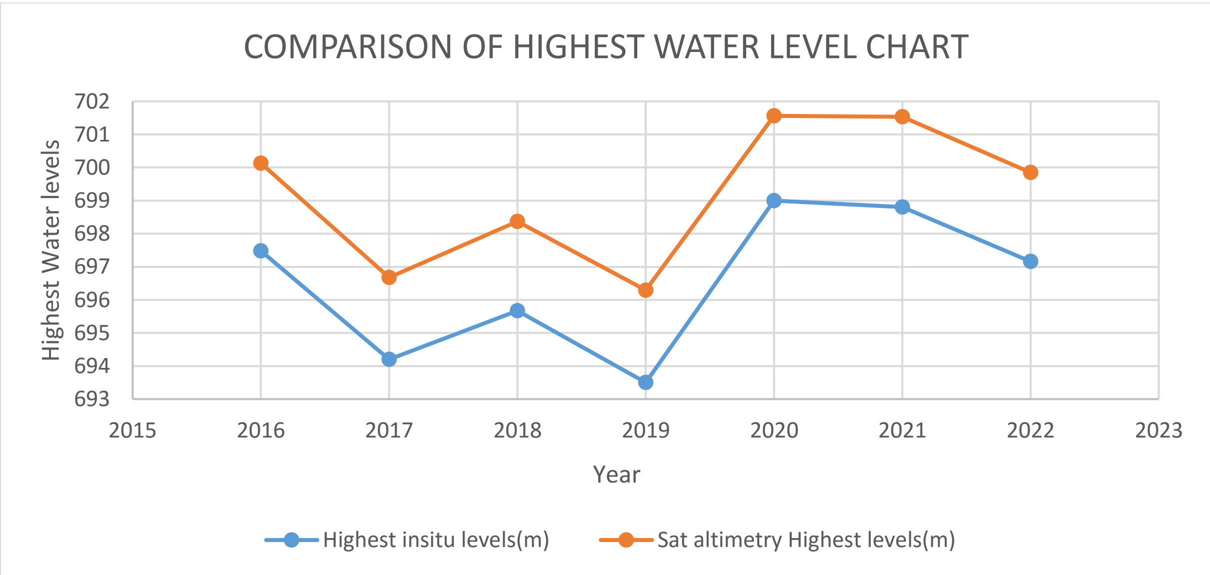


Figure 4.6; Comparison of Highest water level at mtera dam

`

Figure 4.4; Comparison of Highest water level at mtera dam.

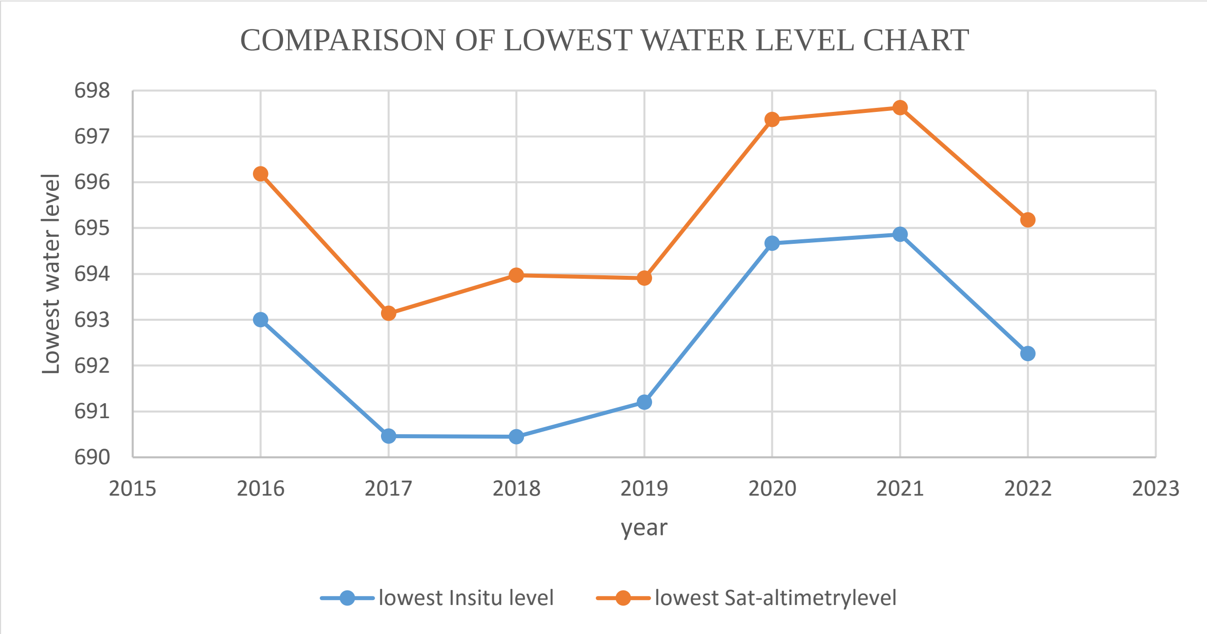


Figure 4.7; Comparison of Highest water level at mtera dam

4.2.2 Error analysis for the water volume

Bias: The bias between the Satellite Altimetry and In-situ volume estimates is 126.15 million cubic meters (m^3). This indicates an overall small deviation of the volume by the Satellite Altimetry measurements compared to the In-situ reference data.

Root Mean Square Error (RMSE**):** The RMSE value is 147.69 million m^3. The RMSE measures the average magnitude of the differences between the two datasets. A lower RMSE indicates a better fit between the Satellite Altimetry and In-situ data.

Correlation Coefficient: The correlation coefficient is approximately 0.956. A high correlation coefficient close to 1 suggests a strong positive linear relationship between the In-situ and Satellite Altimetry volume estimates. This indicates a good agreement between the two datasets and as one increases and the other tend to increase as well.

R-squared (Coefficient of Determination): The R-squared value is approximately 0.782. The R-squared value represents the proportion of the variance in the Satellite Altimetry volume estimates that can be explained by the variance in the In-situ reference data. A high R-squared value indicates that the Satellite Altimetry data can reasonably explain the variability in the In-situ measurements.

`

Regression Analysis**;** the regression analysis equation represents best fits that predicts in-situ volume (m^3) based on satellite altimetry volume (m^3).

- Slope (β1): 0.042
- Intercept (β0): 2,059,425,724.74
- Regression Equation: Y(m^3) = 2,059,425,724.74+ 0.042*X………………………...4.1

4.2.3 For the maximum and minimum water levels

Bias: The bias between the Satellite Altimetry and In-situ water level measurements is approximately 0.281 meters. This indicates a slight underestimation of the water level by the Satellite Altimetry compared to the In-situ reference data.

Mean Absolute error**; o**btained by find absolute difference between Insitu (hmax-hmin) (m) and Satellite Altimetry (hmax-hmin) (m) was calculated and found to be 0.5m

Root Mean Square Error (RMSE): The RMSE value is approximately 0.685 meters. The RMSE measures the average magnitude of the differences between the two water level datasets. A low RMSE indicates a good fit between the Satellite Altimetry and In-situ water level data.

Correlation Coefficient: The correlation coefficient is approximately 0.937. A high correlation coefficient close to 1 suggests a strong positive linear relationship between the In-situ and Satellite Altimetry water level measurements. This indicates a strong agreement between the two datasets.

Regression Analysis**:** This reveals that the satellite altimetry level has a positive effect on the in-situ level. For every unit increase in the satellite altimetry level, the in-situ level is estimated to increase by 0.9407 units. The intercept term represents the estimated in-situ level when the satellite altimetry level is zero

- Slope (β1): 7.658
- Intercept (β0): -27.930
- Regression Equation: Y = -27.930 + 7.658*X……………………………………4.2

Additional Analysis

- R-squared (R^2): 0.648 (64.8) % of the variability in the in-situ water volume can be explained by the satellite altimetry data)

`

The coefficient of determination (R^2) indicates that approximately 64.8% of the variability in the in-situ water levels (maximum and minimum) can be explained by the satellite altimetry data. This suggests that there are other factors contributing to the remaining variability.

In this case, with an R^2 of 0.648, the fit is strong, but also the remaining percent suggesting that there are other factors influencing the in-situ water level measurements apart from the satellite altimetry data. These are Additional factors: Since a significant portion of the variability is not explained by the satellite altimetry data, it is important to identify and consider other factors that may contribute to the variability in the in-situ water level measurements. These factors could include local environmental conditions, measurement errors, or other variables that influence water level. Calibration and adjustments: Consider performing calibration or adjustments to the satellite altimetry data to improve its alignment with the in-situ measurements. This could involve applying correction factors or employing statistical techniques to reduce systematic biases and align the datasets more closely.

Integration with other data sources: Explore the possibility of integrating the satellite altimetry data with other complementary datasets, such as weather data, river flow measurements, or hydrological models. By combining multiple data sources, you may obtain a more comprehensive and accurate understanding of the water level dynamics at the dam.

Continual monitoring and evaluation: Keep monitoring and evaluating the satellite altimetry data over time to assess its long-term performance and track any changes or improvements. Regular updates and re-assessments can help identify trends, patterns, and potential sources of discrepancies, enabling further refinement of the water level monitoring and estimation processes.

4.2.4 Time Series Analysis

4.2.5 Temporal Trends of Water Levels

The time series analysis revealed interesting temporal trends in the water levels of the Mtera Hydroelectric Dam. The satellite altimetry data and in-situ water level measurements were analyzed to identify any discernible trends and patterns as shown from figure 4.8 below.

`

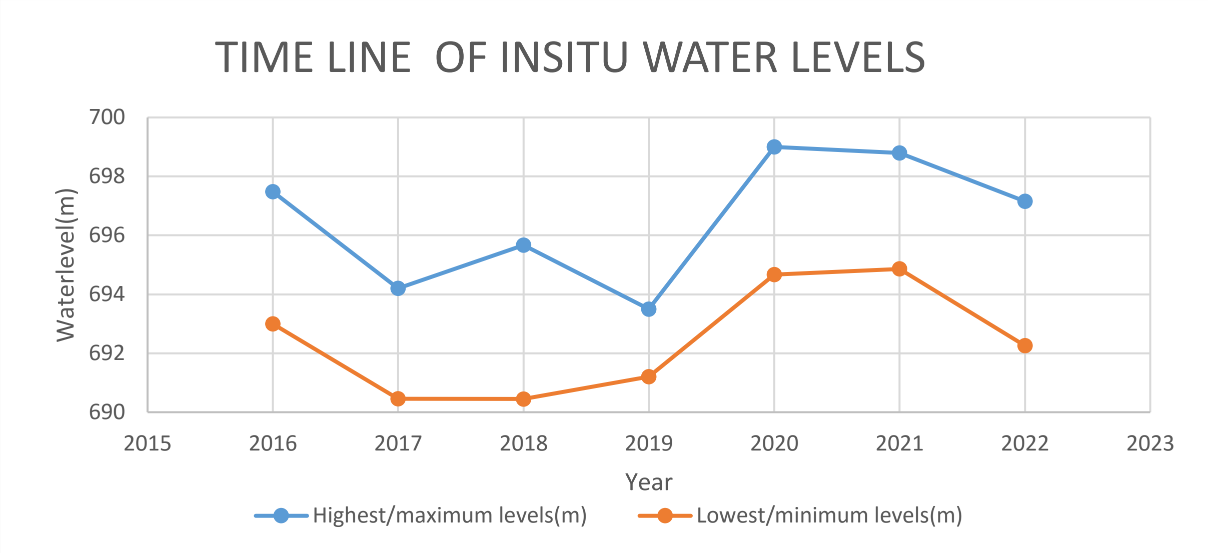


Figure 4.8; Time series and trends of water levels at Mtera dam for satellite altimetry and in-situ water levels

From the above chart the time series analysis of the water level data from 2016 to 2022 showed an irregular increase and decrease in water levels over time. For instance, in 2016 the maximum in-situ water level was recorded at 697.48 meters above sea level, while in 2021, it had risen to 698.8 meters above sea level, more ever for the 2017 lowest in-situ level were recorded to be 690.460 meters above sea level while in 2018 decrease slightly to 690.45.

More ever in 2016, the maximum satellite altimetry water level was recorded at 700.133meters above sea level, while in 2019, it had decrease to 696.293meters above sea level as shown in the chart below, this upward trend suggests a potential long-term change in the hydrological regime of the dam, which could have implications for water resource management.

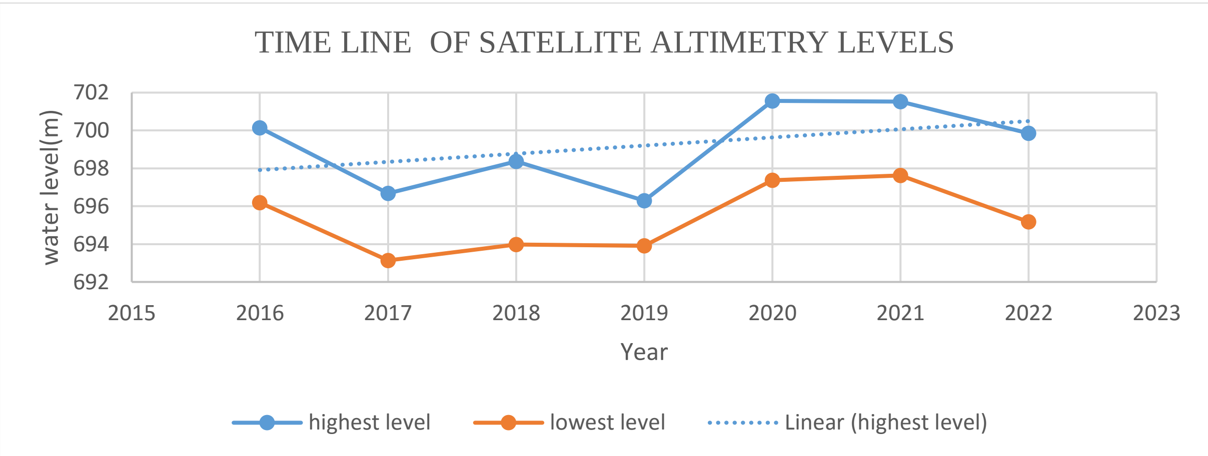


Figure 4.9; Time series and trends of water levels at Mtera dam for satellite altimetry maximum and minimum water levels

`

4.2.6 Temporal Trends of Dam area

The dam area analysis showing an increasing and decreasing patterns over the years for instance during 2016 water area were calculated to be 506748000 square meters but in next year 2017 decreases to 383892000 square meters and even decrease more at 2019 to 337452000 square meters and The water area at 2020 were calculated to be maximum at 612609000 square meters this is due to high rainfall at the year as shown in the figure below.

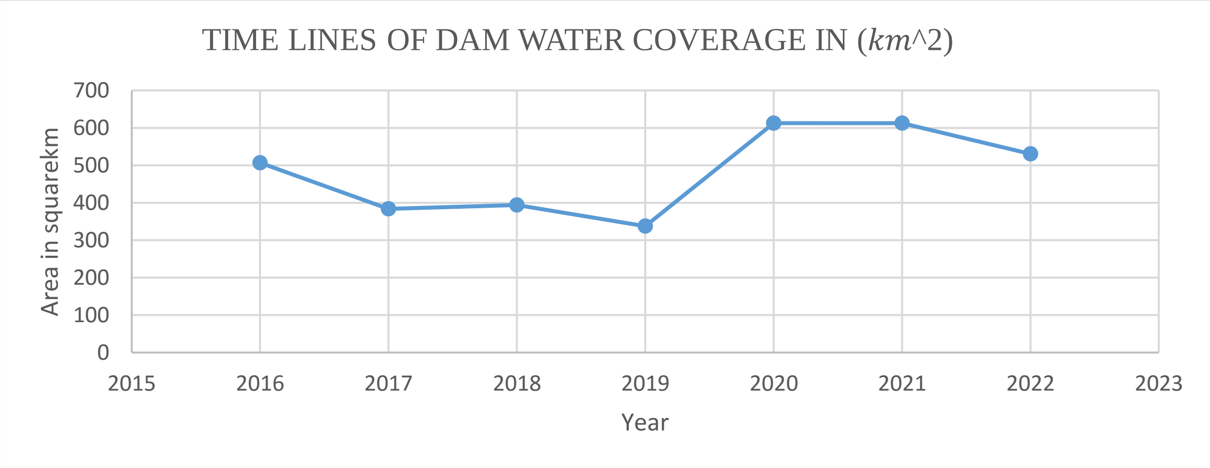


Figure 4.10; Time series and trends of water levels at Mtera dam for satellite altimetry maximum and minimum water levels

4.2.7 Temporal Trends of water volume

Time analysis for the water volume reveals an interesting pattern and trend between the two-kind satellite altimetry and in-situ as shown from the figure 4.11 below.

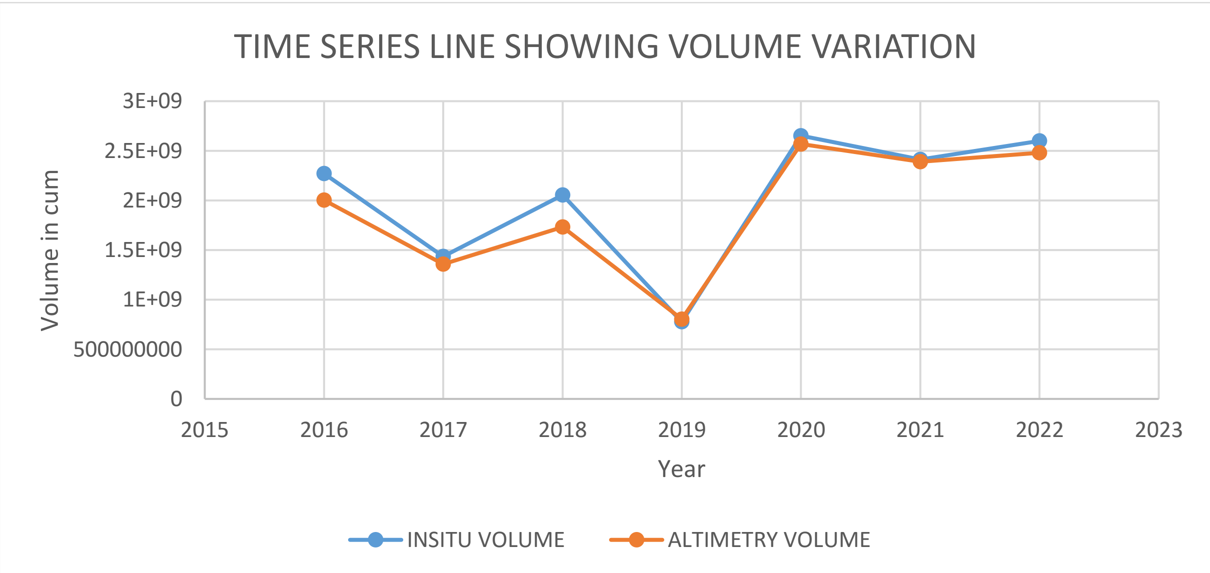


Figure 4.11; Time series and trends of water volume at mtera dam

`

4.2.8 Seasonal Analysis

To further investigate the seasonal variations in water levels, a seasonal analysis was conducted using Fourier analysis.

The Fourier analysis revealed distinct seasonal patterns within the water level time series. The dominant seasonal component corresponded to the annual cycle of the rainy and dry seasons. For instance, during the rainy season (typically occurring from April to June), the water levels peaked, reaching an average of 697 meters above sea level. In contrast, during the dry season (usually from August to September), the water levels decreased, reaching an average of 693 meters above sea level. This consistent seasonal pattern demonstrates the influence of rainfall on the dam's water levels.

4.2.9 Short-Term Fluctuations

The time series analysis also highlighted short-term fluctuations and irregularities in the water level data, reflecting the dynamic nature of the hydrological system.

From the results obtained an analysis of the residual component, representing the deviations from the long-term trend and seasonal patterns, revealed notable short-term fluctuations. These fluctuations could be attributed to factors such as heavy rainfall events, variations in river discharge, or operational changes in the dam. For instance, in July 2021, a significant spike in water levels was observed, reaching 698 meters above sea level. This spike coincided with an intense rainfall period, indicating the sensitivity of water levels to short-term hydrological events.

By examining the temporal trends, seasonal patterns, and short-term fluctuations, the time series analysis provided valuable insights into the behavior of water levels at the Mtera Hydroelectric Dam. These findings contribute to a better understanding of the dam's hydrological dynamics and can inform organization in proper planning, dam operations, and flood management strategies.

4.3 Discussion of the Results

This research has yielded several noteworthy findings. The study compared satellite altimetry data with in-situ measurements of maximum and minimum water levels over a period of seven years (2016 to 2022) and incorporated satellite images data to complement the analysis. Additionally, area data was included in the assessment to provide a comprehensive understanding of the dam's hydrological characteristics.

`

The statistical analysis revealed encouraging results for water level and volume estimation using satellite altimetry data. The strong positive linear relationship between the satellite altimetry and in-situ measurements, as indicated by the high correlation coefficient 0.956 and R^2 value approximately 0.782, underscores the accuracy and reliability of satellite altimetry data. This demonstrates the potential of satellite altimetry as an effective tool for water level monitoring, particularly when in-situ measurements may be limited or challenging to obtain.

The regression analysis further confirmed the viability of using satellite altimetry data to estimate water volumes. The equation of the best-fit line derived from the analysis provides an efficient means of estimating water volumes based on satellite altimetry data. This finding has significant implications for water resource management, allowing for the continuous monitoring of water volumes at Mtera Dam and facilitating informed decision-making.

However, the presence of a bias 126.154, 036.14 cubic meters suggests a systematic deviation between satellite altimetry and in-situ measurements. Although this bias is relatively small compared to the total volume estimates, it is essential to consider its impact on specific applications, especially those requiring precise volume measurements. Further research could focus on refining the satellite altimetry algorithms to minimize bias and improve the overall accuracy of volume estimation.

The incorporation of area data provides valuable insights into the dam's hydrological characteristics. The mean area of 498,331,857.14 square meters, standard deviation of 107,931,587.71 square meters, and variance of 11,649,942,857,142.86 square meters squared) shed light on the variability and distribution of the dam's surface area over the study period. Understanding the spatial aspect of water bodies is essential for managing water resources effectively.

The comprehensive analysis of satellite altimetry data, in-situ measurements, and area data collectively contributes to a robust understanding of water level monitoring and volume estimation at Mtera Dam. The research findings demonstrate the utility of satellite altimetry as a cost-effective and efficient alternative to traditional in-situ measurements for hydroelectric resource management and hydrological studies.

The accuracy assessment of satellite altimetry data provides a solid foundation for enhancing hydrological modeling, forecasting, and decision-making processes related to Electricity production. In conclusion, this dissertation research has made significant strides in assessing the accuracy of satellite altimetry data for water level monitoring and volume estimation at

`

Mtera Dam. The positive correlation and strong linear relationship found between satellite altimetry and in-situ measurements highlight the potential of satellite altimetry as a reliable tool for water level and volume estimation.

`

CHAPTER FIVE

CONCLUSION AND RECOMMANDATION

5.1 CONCLUSION

The combination of satellite altimetry and Landsat imagery data allowed for a comprehensive detection of dam water dynamics. Through the use of satellite altimetry, the study has been able to monitor the water level changes and volume estimations with respect to the climate change. The results have been revealed to have a strong positive correlation of 0.937 and 0.956 of the water surface level and surface volume for both satellite altimetry and in-situ data. The fluctuation in the dam's maximum and minimum levels consistently influenced the dam area change and the storage volume change.

Time series lines and trends of the water levels for daily and annually showing an interesting pattern for both in-situ and satellite altimetry data in which all of them pertain the similar trends of unusually changes of water level and volume due to seasonal variations of rainfall at the region.

The Satellite Altimetry data demonstrates a high correlation and R-squared value as 0.782 and 0.956 for volume and levels with the In-situ reference data, indicating a strong agreement and reliability in estimating the volume of Mtera Hydroelectric dam.

However, there is a bias in the Satellite Altimetry estimates, showing a systematic underestimation of the dam's volume compared to the In-situ measurements. The bias can be due to difference in height systems and this bias should be taken into account when using the Satellite Altimetry data for volume estimation.

The RMSE value of 147.69 million m^3 is relatively high, which suggests that there are variations between the two datasets, but they are within an acceptable range considering the scale of the dam's volume of about 2.9 billion m^3.

In summary, the analysis indicates that Satellite Altimetry data can be a valuable source for estimating the volume of Mtera Hydroelectric dam, but the systematic bias should be considered and appropriate adjustments made to ensure accurate volume assessments. The high correlation and R-squared values provide confidence in the overall agreement between the two datasets. thus, the satellite altimetry data can still be considered be used to provides valuable information about water level variations at Mtera Dam since the differences between the satellite-derived data and in-situ measurements are relatively small.

`

5.2 RECOMMENDATION

This research has the limited in using the maximum and minimum water levels to estimate the depth of the water at the Mtera dam and this is surface depth were the one which used to estimate the volume of the dam, the depth was not the actual depth this is due to the lack of the bathymetric survey at the dam, thus from this study the following recommendations must be taken into considerations.

Conduction of bathymetric surveying to the Mtera dam so as to have accurate volume calculation, since bathymetry provide the map for underwater surface, this will help to determine exact depth of the Mtera dam instead using depth between minimum and maximum water level.

Long-Term Monitoring and Analysis: Continuous monitoring and analysis of water levels and volumes using satellite altimetry data can provide valuable insights into the dynamics of water bodies. Long-term data collection will facilitate the identification of trends, seasonal variations, and long-term changes, enabling better Electricity resource management and planning.

Continued Monitoring and Validation: Sustained monitoring of water levels using satellite altimetry data and in-situ measurements should be continued to ensure the accuracy and reliability of the collected data. Regular validation exercises should be conducted to identify and correct any biases or inconsistencies.

Refinement of Satellite Altimetry Algorithms: To further improve the accuracy of volume estimation and minimize bias, future research should focus on refining satellite altimetry algorithms. Incorporating additional calibration techniques and data fusion methods may enhance the precision of water level estimates and volume calculations.

`

REFERENCES

Mugabe F.T. (2010). *Temporal and Spatial Variability of the Hydrology of Semi-Arid Zimbabwe and its Implications on Surface Water Resources. PhD Thesis, Faculty of Agriculture, University of Zimbabwe.*

Mwalyosi R. (1986). Management of the Mtera Reservoir in Tanzania.

Adam. (2018). *Monitoring of the Lake Victoria surface height variations by radar satellite altimetry technique. A dissertation for BSc. in Geomatics Ardhi University. Dar es salaam,Tanzania. .*

Aggarwal,C. (2014). *Data preprocessing. Data Mining: The Textbook, pp. 53-78.*

Alsdorf,D.Birkett, C. Dunne,T. Melack, J & Hess, L. (2001). Water level changes in a large Amazon Lake measured with spaceborne radar interferometry and altimetry. GeophysRes Lett.28:2671–2674.

Aronoff, S. (2005). *Remote sensing for Gis managers,Redlands,California 1-58948-081,3-225-232.*

Asuero, A. (2006). *The correlation coefficient;An overview Critical Reviews and Analytical Chemistry.*

Azizi M. (2017). *Intergration radar altimeters and Optical imagery data forestimating water volume variations in lakes and reservoirs;a case study lake Nasser.*

Birkett C,Reynolds,B & Doorn B. (2011). *From Research operations: The USDA Global Reservoir and Lake Monitor, in: Coastal altimetry. (S. Vignudelli, A. Kostianoy, P.Cipollini, J. Benveniste, & B. H. Springer, Eds.) doi:10.1007/978-3-642-1279-0_2.*

Burrough,P.P.,Rachael,A.M,.& Christopher,D.L. (2015). Principles of Geographical information Systems,Oxford University press. pp. 85-88.

Cetinkaya . (2013). *Comparative assessment of remote sensing–based water dynamic in a dam lake using a combination of Sentinel 2 data and digital elevation mode.*

Chelton,C.B.,Michael,G.S.,Roger,M.S.,Thomas,j.F.,Jeroen,M.M.,James,C.M., &Jonathan,g. (2019). Prospects for future satellite estimation of small scale variabilty of ocean surface velocity and vorticity.

Crétaux,J.F.,& Birkett,C. (2006). Lake studies from satellite radar altimetry. 338, 1098–1112.

`

Crétaux,J.F.,Abarca-del-Ri ó,r.,Berge,N.m.,Arsen,A.,clos,G & Maisongrande,p. (2015). Lake Volume monitoring from space.(201637;269-305,DOI 10.1007/s10712-016-9362-6.

Dancey,P & Reidy,J. (2017). *Statistics without maths for psychology. Pearson, pp. 184-190.*

David& wolock,D.M. (1994). Effects of Digital elevation model map scale and data resolution on Topograpy- based model.

Fei Li . (2016). *on monitoring changes in the water volume of Hulun Lake by integrating satellite altimetry data and Landsat images between 1992 and 2010.*

ghashghaie,M & Nozari.,H. (2018). Effect of Dam construction on lake Urmia;time Series Analysis of water level via ARIMA.

Ghosh. (2017). intergration of satellite altimetry for global groundwater storage changes.

Handoko,E.Y. (2017). Assessment of Altimetric Range and Geophysical Corrections and Mean sea level .

Handoko,E.Y. (2018). Merged Envisat and Jason Satellite Altimeters using Crossovers adjustment to determine sea level Variability.

Huisman & Rolf D. (2009). *Principles of Geographic Information Systems.* Enschede,The Netherlands: the international Institute for Geo-information Science and Earth observation.

Hwang & Wang,H. (2016). Examining relationship between Watershed Urban Land Use and Stream Water Quality Using linear and Generalized Additive Models.

Irmak,S. (2018). *Climate driven Crop yield and yield variability and climate change impacts on the U.S great plains Agriculture production.*

Jensen. (2005). Introductory digital image processing: A remote sensing perspective. Prentice Hall. 226-231.

Jiawei H. (2022). *) Remotely sensed reservoir water storage dynamics (1984–2015) and the influence of climate variability and management at a global scale.*

Kutner,M. (2005). *Applied linear statistical models. McGraw-Hill/Irwin pp 199-210.*

Li cheng . (2018). *Managing the three Gorges Dam to implement flows in the Yangtze river.*

`

Mc Feeters, S. K. (1996). The use of the normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing. .

Misra & Baraj. (2015). A study on the sholeline changes and LAND-use/Land-cover along the south Gujarat Coastline.

Montgomery. (2014). Applied statistics and probability for engineers. John Wiley & Sons.

Muala,E. (2014). *Estimation of reservoir Discharge from lake Nasser and Roseires in the Nile Basing Using Satellite Altimetry and Imagery Data.*

Mwandosya. (1998). *The Assessment of vulnerability and Adaptation of Climate Change Impacts in Tanzania. .*

Ricko,M.,Carton,J.A.,&Birkett. (2011). investigating Regional Scale Resorvoir water level Modeling.

Sulistioadi YB. (2022). Satellite radar Altimetry for monitoring small rivers and lakes in indonesia.

Tim,B.,Adamovic, M.,Emiliano, G.,Christian, S.,Andrew, C.,Jean ,P.,Ade, Re.,&Berny, B.,. (2019). A global lake and reservoir volume analysis using a surface water dataset and satellite altimetry. 669-690.

Tourian, J. (2012). *Controls on satellite altimetry over inland water surfaces for hydrological purposes UN. (2020). climate change report .*

Yawson D. (2006). Impact assessment of mtera and kidatu reservoirs on the Annual Maximum Floods at stiegler's Gorge of the rufiji River in Tanzania.

Zaitchik B,Johns H,Rolf R,Matt R. (2008). Assimilation of GRACEterrestrial Water Storage data into land surface model;Results mississippi River Basin.

Zhang . (2009). *Exploring the water storage changes in the largest lake (SelinCo) over the Tibetan Plateau during 2003–2012 from a basin-wide hydrological modelling Water Resources Research 10.1002/2014WR015846.*

`