SEDIMENT YIELD ANALYSIS OF THE MWACHE RIVER BASIN AND ITS IMPACTS ON THE MWACHE MULTI-PURPOSE DAM IN KWALE COUNTY, KENYA.

BY

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A Research Project Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Arts in Water Resources Management of the Department of Geography, Population and Environmental Studies, University of Nairobi

JANUARY 2024

DECLARATION

This project is my original work and it has never been submitted in any other institution for an award.

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This research project has been submitted for examination with our approval as university supervisors.

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DEDICATION

I dedicate this work to my loving mother Linah Jewa and to my loving father Matano Mwasina for their unconditional support and passionate involvement in my academic progress.

ACKNOWLEDGEMENT

All praise be to Allah, the Almighty for His grace and for guiding me to complete this project. I also concede the contributions of my supervisors **Dr. Shadrack Mulei Kithiia** and **Dr. John Moenga Nyangaga** for the untiring support they gave to me. Their consistent guidance and corrections assisted me to complete my research study and realize this breakthrough accomplishment. It was a great honor for me to have both of you as my supervisors. The regular and constant follow ups over and above your formal working hours allowed me to finish my project.

I'd also like to express my gratitude to the rest of the lecturers at the University of Nairobi's Department of Geography, Population, & Environmental Studies, as well as all the other personnel at the university, for their contributions to my achievements.

My sincere gratitude also goes to the Water Resources Authority, Mombasa sub-regional office manager and his team for their support during data collection, officers from Kibwezi and Loitoktok WRA offices during data interpretation, and everyone else who assisted me in one way or the other.

Last but not least, I'm grateful to my own lovely family for their encouragement and support in assisting me in fast-tracking the project progress. I also thank them for their time sacrifice and financial support during my academic journey. This would not have been possible without their relentless assistance and support. My feeling for them is immeasurable.

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LIST OF ABBREVIATIONS

ADCP	Acostic Doppler Current Profiler
APHA	American Public Health Association
ASALs	Arid and Semi-Arid Lands
DEM	Digital Elevation Model
DEWS	Drought Early Warning System
EDI	Equal Discharge Increment
EIA	Environmental Impact Assessment
GHT	Gauge Height Time
GIS	Geographical Information System
GPS	Global Positioning System
HRU	Hydrologic Response Unit
LULC	Land Use/Land Cover
NDMA	National Drought Management Authority
RAP	Resettlement Action Plan
RGS	Regular Gauging Station
SST	Simple Settlement Theory
SV (sv)	Surface Velocity
SWAT	Soil and Water Assessment Tool
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WELB	Water Edge Left Bank
WERB	Water Edge Right Bank
WRA	Water Resources Authority

ABSTRACT

Water reservoirs in the form of dams and water pans face the challenge of excessive accumulation of sediments leading to reservoir siltation and reduced lifespan. Sedimentation is exacerbated by the ever-changing, retrogressive and environmental degrading land use practices particularly in most arid and semi-arid lands.

The objectives of this study were to establish the sediment yield from Mwache river basin, to assess the comparative contribution of land use-land cover types on sedimentation and to estimate the life expectancy of the Mwache multi-purpose dam located within the river basin. Regular gauging stations (RGS) corresponding to three diverse land-use-land-cover types were selected; Chigutu stream RGS on shrub land, Maji ya Chumvi stream RGS on grass land and Mwache dam site stream RGS on annual crops. Stream cross-section area and flow rate measurements from each of the three streams were taken and water samples collected using equal discharge increment (EDI) procedure. The water samples were analyzed for total suspended solids using APHA 2540 analytical method of the year 2005. Analysis of the data collected was done using simple linear regression model and hypothesis tested using the student's t-test statistical analysis to establish whether there were significant variations in sediment yield from the different land use-land cover types in Mwache River basin.

The estimated volume of sediments from Chigutu, Maji ya Chumvi and Mwache dam-site streams were 20,235m^3, 7,948.571m^3 and 35,510m^3 corresponding to shrub land, grass land and annual crops respectively. On the best sediment yield reliability test by simple linear regression model, shrub land had a coefficient of determination r^2 of 92.65%, grass land 72.13%, and annual crops 66.86%. The estimated annual sediment yield was 46.038 tons/year and the estimated life expectancy for the Mwache multi-purpose dam was 202.8 years implying that the dam construction was viable similar to results from the project design report which estimated the lifespan at 291.3 years in the year 2014. However, with the r^2 values for all the three land-use-land-cover types being strongly positive, sedimentation is still an issue albeit the measures which have been put in place to address it.

This study therefore recommends to the Water Resources Authority, Coast Development Authority and other involved stakeholders to sustain the periodic sediment yield assessments at the various gauging stations within the Mwache basin, and to intensify the frequency of monitoring of the sediment yield mitigation measures put in place under the various land use-land cover types, priority order being annual crops which had the most yield, followed by shrub land which had the second most yield and finally grass land which had the least.

CHAPTER ONE: STUDY BACKGROUND

1.0 Introduction

Residents in the arid and semi-arid lands (ASALs) of the Kenyan South Coast rely so much on surface water sources mainly dams and water pans for their daily water uses (National Drought Management Authority-NDMA, Kwale county Drought Early Warning System-DEWS monthly bulletins for a five years average from the year 2018 to 2021). The common water uses in these areas are; domestic, irrigation, livestock consumption as well as habitat for aquatic ecosystem including fish and the aquatic plants which are a source of food to the communities.

The Mwache multi-purpose dam in Kinango sub-county, Kwale County has created a lot of optimism to the residents of the host community (Kasemeni ward) and the neighbouring communities i.e., the rest of the wards in Kinango sub-county and the neighbouring city county of Mombasa. This water reservoir is projected to impound enough water for human and livestock consumption as well as for crop production through irrigation. Residents from the neighbouring county of Mombasa are also set to benefit since water from the dam will be supplied to their county and will go a long way into solving the perennial water shortages in this coastal city.

The anticipated challenge is that the dam is located in an ASAL river basin, where communities in ASALs are typically known to employ some degrading land use practices which end up exposing the soils to erosion and with the potential of significantly contributing to sediment yield ultimately reducing the stowage volume of the dam, which is the main driver and reason for this study.

1.1 Background

The Mwache multipurpose dam project emanated from the need to scale-up investments in water resources development by the Government of Kenya in the bid to bridge the water scarcity gaps as part of the focus of Kenya’s Vision 2030. The project is one of the priority projects and has therefore been factored in the principal plan for water supply for the coastal region, with funding from French Development Agency (AFD) through the World Bank under the project named water and sanitation service improvement. The project has three major components; construction of the reservoir, auxiliary infrastructure to convey water to Kwale and Mombasa counties and investment in irrigated agriculture on an initial 100 hectares of land.

The proponents of the Mwache Multi-purpose dam have put in place measures to control excessive erosion and sedimentation as outlined in the impact assessment reports on the environment and social welfare. However, it is prudent to establish sediment yield from the basin to form a basis for the various mitigation measures put in place, as well as to enable setting up of a monitoring plan for the various structural measures proposed and those already installed.

Study findings from this research supported the analysis of sediment generated from the various land use-land cover types within the river basin, and attempted to estimate the duration it will take for the dam to completely fill up with silt without mitigation measures, thereby informing the prioritization and monitoring frequency for the various ongoing sediment yield mitigation measures along the various land use-land cover types.

1.2 Statement of the Problem

Dams serve many purposes including; provision of equitable and reliable water for agricultural production, domestic use, industrial use, hydro-power generation and flood control or control of water quality downstream. Building of dams entails the erection of a barrier that will retain water by inhibiting water outflows, although with implications on the quality, quantity and the movement of matter and transmission of energy in the watercourse (Poesen *et al*., 2010; Szatten *et al*. 2018 and Pellegrini *et al*., 2018). One of the processes interrupted by construction of dams is sediment transport. Dams collect transported sediments which result in diminution of their design capacities (Pellegrini *et al*., 2018), and this coupled with land degradation, heavy pressure from livestock, denuded groundcover, catchment erosion and siltation –typical aspects common in arid and semi-arid lands (ASALs), has been a major cause of dam failure (Bessenasse *et al*., 2012, SASOL and Maji na Ufanisi, 1999). Therefore, sediment transport and survey of siltation processes is crucial to establish appropriate mitigation measures to minimize sedimentation and siltation problems. (Kamtukule, 2008 and Moulla *et al*., 2012).

The Government of Kenya with funding from the World Bank is constructing Mwache multipurpose dam in Kasemeni ward, located in the ASALs of Kwale County at an estimated cost of USD 17 million (KES. 20 billion). The commissioning of dam excavation works was done on the 7th day of April 2023 by H.E. the president of the republic of Kenya. It is located on Mwache river catchment, with the river slope estimated at less than 1% implying physically slow-moving River, and characterized by high water holding and storage ability, while deterring sediment conveyance, which is ideal for dam construction downstream

(Mwache Dam EIA report 2016). Although sediment yield studies and drainage characteristics affecting water flow from the tributaries contributing to the channel flow have been done, comparative sediment yield from different land use-land cover types in the basin had not been established which is necessary to aid in selection of appropriate sediment management practices for specific LULC type.

This present study therefore, sort to establish the sediment yield from Mwache river basin, contribution of land use-land cover types to sedimentation and to estimate the duration it might take for the dam to be silted up if appropriate mitigation measures are not put in place.

1.3 Objectives of the Study

The general objective of the study was to conduct sediment yield analysis of the Mwache River basin and its impacts on the Mwache multi-purpose dam. The specific objectives were;

1. To analyse the sediment yield from Mwache River basin
2. To assess the comparative contribution of different land use-land cover types to sediment yield in the Mwache River basin.
3. To estimate the time/duration taken for the sediment load to completely silt up the Mwache multi-purpose dam

1.4 Research Questions

The study is aimed at answering the question: is the sediment yield from Mwache river basin significant enough to cause excessive dam siltation. The specific study questions were:

1. What is the amount of sediment yield from Mwache river basin?
2. How are the land use-land cover types differently affecting sediment yield in the basin?
3. How long will it take the sediment load to silt up the Mwache multi-purpose dam?

1.5 Hypothesis

H_0: The variations in land use-land cover types in Mwache River basin does not significantly affect the sediment yield.

1.6 Significance of the Study

Kenya is experiencing the challenge of inadequate renewable water resources, especially in the arid and semi-arid lands (Kimuyu, 1998). Construction of multipurpose dams for equitable and sustainable water supply for urban and rural communities is bridging this gap; however, dams' siltation has been a major drawback. Studies have shown that reservoir siltation can shutter water storage efforts in less than 25 years especially in small to medium size reservoirs (F. Okafor *et al*., 2011). In other studies, catchment erosion and siltation rates have been found out to be high enough to reduce the reservoir storage capacity by up to 12% annually (M. Bessenasse *et al*., 2012).

The Government of Kenya is investing an estimated KES 20 billion in the construction of Mwache multipurpose dam which is exposed to the above challenges. Although some catchment conservation and siltation mitigation measures have been initiated in the River basin area (Mwache EIA report 2016), survey of sedimentation process and estimating the sediment yield is crucial for assessing its intensity, which will aid the implementation and monitoring of the sediment yield mitigation interventions to minimize the excessive reservoir siltation risk.

The purpose of this study was therefore to establish the contribution of the various land use-land cover (LULC) types within the Mwache River basin to sedimentation process, and recommend the relative sediment yield monitoring frequency for each land use-land cover type to enhance the applicability, relevance and sustainability of the ongoing sediment yield mitigation actions.

This study was thus relevant since it sought to establish the volume of sediments entering the Mwache River with the ultimate destination being the multipurpose dam. Sediment yield into rivers is the biggest risk to water pans and dams, and analysis of sediment yield would enable the dam project proponents to establish a well-informed sediment monitoring plan and maintenance of the various structural measures put in place to control excessive sedimentation, with the ultimate goal being to increase the lifespan of the dam and economic value for the donor and tax payer's money invested in the project. Moreover, the outputs of this study would also contribute to the Kenyan vision 2030 economic pillar on ensuring food security for all, through the dam's irrigation component expected to enhance irrigated agriculture for improved and reliable crop production as well as provision of safe and clean water.

1.7 Limitation of the Study

Mwache river basin has several documented land use-land cover types such as Annual crops, Bareland, Forested areas, Grassland, Perennial crops, Riverine vegetation, Shrubland, Urban areas, Water body and Wetland. These land use-land cover types are changing at a very fast rate. This research could not factor the changing trend in land uses neither could this research factor all the land uses. It only sampled three different land uses to conduct the comparative sediment yield studies.

Measurement of total suspended solids is very necessary for sediment yield studies; however, the river flows and water levels were too low during the research since the County was facing severe drought and reduced river flows and the nature of some of the equipment used required higher river levels and river flows. To overcome these challenges, current meter was used in areas where the ADCP could not be used.

1.8 Definition of key concepts and terms

Land degradation -is the retardation in land's productive value over an extended period of time. (Millenium Ecosystem Assessment 2005a; Vogt *et al.*, 2011). A closely associated term is desertification, which is "degradation of land in dry sub-humid, semiarid and arid areas resulting from climatic variations and anthropogenic activities" (Thomas, 1997). Outcomes of desertification are manifested in a number of processes which are active in the ASAL environments and are limiting factors to exploitation of the various land use potential in such ecosystems (Collado *et al.*, 2002).

Land Assessment -Assessment deals with evaluation of the land use status, e.g. By estimating land use condition

Land monitoring -is concerned with the time component and is the periodic assessment of land condition at distinct durations to examine the changes. When affected areas and regions under threat have been identified, it highlights the predicament of the depreciating productive value of the land and aid the crafting of strategies to minimize and reverse the trend by taking suitable management decisions (Del Barrio *et al*., 2010).

Land cover -refers to the substantial material covering the earth's surface, demonstrated by the spread of flora, aquatic resources, humus, land and anthropogenic activities like human settlements (Ramachandra and Kumar, 2004).

Sediment transport -refers to the conveyance of like topsoil, grit, stones, pebbles, rocks, etc. in waterways, and the substance conveyed is the load. Load could be sediment suspended in water, moving at the bed bottom or dissolved in the flowing water**.**

Sediment Rating Curve –is a model which depicts the corelation in sediment yield from the discharge (Benselama *et al*., 2019).

S**iltation** refers to the build-up of elements of sludge, silt and other loads in the reservoir. Siltation rate is determined by two major factors; the sediment generated from and getting out of the watershed and the correlation between dam's storage volumes to its annual water inflow.

Sediment yield is defined as the quantifiable sum of sediments discharged from a basin at a specific location within a defined period of time (Boukhrissa *et al*., 2013). The sediments could either be suspended in the transport media, or bed materials (Garde and Raju 2000).

Digital Elevation Model (DEM) expresses the landscape altitude and geometry of basins and sub-basins. It is a prerequisite input of the Soil Water Assessment Tool (SWAT) and many other models. DEM is used together with other data on soil types, land cover types and land uses to delineate a basin and divide it into an array of smaller basins and hydrologic response units (HRUs). The most important input parameter when developing a SWAT model is the resolution of the Digital Elevation Model.

Soil map: it displays the various soil types in a given area mostly exhibiting the physical and chemical properties of the soil. Like DEM, soil data resolution also has significant influence on the modelling of sediment load, nutrient content and the overall stream flow.

Land use map: this exhibits the various kinds of land uses in a given watershed. The data on land use has a substantial impact on the streamflow modelling. The detailed the land use map is, coupled with a comprehensive analysis of the land cover, the more accurate the modelling will be. The runoff and conveyance of sediment in a basin are influenced by both the type of land use and the land cover (Briak *et al*., 2016).

CHAPTER TWO: LITERATURE REVIEW

2. 0 Introduction

Past researches have been done on the subject of siltation of water reservoirs. The reviewed literature herein focused on the appraisal of studies by other scholars' which corelate with the current study, the existing theories on sediment yield, emerging technologies for monitoring and assessment of changes in land use, sediment yield analysis, specific water resource management surveys and studies done within the area of study, and also a critique of the reviewed research works and existing knowledge gap and how this study intends to address the gap.

2.1 Empirical Review

In this section, past researches related to the three specific objectives of this study have been reviewed. A concise critique has also been done highlighting areas of adequacies and inadequacies in the past studies which further justifies the need for this study.

2.1.1 Analysis of sediment yield from River basins

A study on estimation of sediment yield and highest out flow in Nepal's Sarada River Basin by Chalise *et al.*, 2019 used a computer-based approach. The model called Intensity of Erosion and out flow (IntEro), factored in lithology and soil type, topography and relief, precipitation, temperatures, land cover and the erosion patterns. The basin's maximum outflow was found to be 1918 m^3 s^{-1} and coefficient of erosion value of 0.40 obtained, indicating an average strength surface erosion. The annual aggregate soil loss was 10.74 Mg ha^{-1} which compares well with the findings from the erosion plots. The results indicated that catchment characteristics such as topography, hydrology, geological composition and porousness of rocks, types of the land cover and the uses as well as the amount, frequency and magnitude of the rains had significant effect on sediment yield.

This study helped the researcher to interact with modeling approach in determination of sediment yield at the global perspective in relation to the current research.

Similar research was conducted by Benselama *et al.*, 2019 to estimate and analyze the variability of sediment conveyance in suspension at diverse time scale in North-West Algeria's Wadi El Maleh watershed. The total catchment area was 932.56km^2 and they obtained water discharge from a rating curve using the measured water depth at the river gauging station. Samples of turbid water were collected using 50 cl bottles at each reading, then filtering was done and filtered sediments were placed in an oven set at a temperature of 105^{o}c for 30 minutes to dry them up. The results indicated an annual loss of 294.29.10^3 kg/km^2/year. They also found out that sediment transport mainly occurred during floods, with a change in suspended sediment transport overtime being evident, and with variations at specific time scales.

In 2021, Kuti and Ewemoje conducted research to determine the impacts the ridge of contour lines on sediment yield. The research specifically focused on comparatively assessing the effects between ridging along against ridging across the slope on sediment yield in Chanchaga basin, Nigeria. The study used SWAT model for simulation of sediment yield and stream flow in the basin. The basin was divided into several smaller sub-basins and further divided into hydrologic response units informed by land use type, the gradient and surface conditions. The concept of the ratio of water entering a body to water leaving the body was applied in simulation of the sediment yield (Khoi *et al*., 2017). The findings indicated that ridging across the slope reduced the yield while ridging along the gradient was increasing the sediment yield.

The two researches by Benselema *et al.,* 2019 and Kuti *et al.,* 2021 gave the researcher the continental view of sediment yield studies and variations in the findings obtained from using the gauging and computer modeling approaches respectively.

Another study was conducted by Njogu and Kitheka in 2017 in Kenya's upper Tana catchment. They assessed the contribution of rainfall and river discharge to sediment yield based on rainfall data of over 53 year's period. To determine applicability of modeling in streamflow and sediment yield, simulation was done using SWAT model and they established that there were concrete variations both in the river flow and in the sediment coming out of the basin. The annual river discharge was 128 m^{3}s-1 and with an increasing trend in sediment yield ascribed to the changes in land use and climate variability. The analysis also exposed a weak relationship between sediment yield and rainfall but a strong association between rainfall and streamflow with r value of 0.9 significant at p=0.05. The study also established strong relationship between simulated and observed river discharge and sediment yield. This study therefore aided the researcher to affirm his confidence in the data collection approaches was intending to use since similar approaches have successfully been used locally. The study also justified the need for triangulation of gauging procedure of sediment yield analysis with modeling approaches.

2.1.2 Contribution of land use and land cover conditions to sediment yield

To establish impacts of land use-land cover change on runoff and sediment yield in India along the upper Tapi River sub-basin, Munoth *et al*., 2019 conducted a study using SWAT model. They assessed land use dynamics by analyzing four land use maps at a time series gap of 15 years, 10 years and six years, that is the years 1975, 1990, 2000 and 2016. Substantial incline in land under agricultural production by 18%, and decline in land under forest and range by seven percent and 10% respectively was established. The implications of LULC changes for four diverse conditions were assessed and the findings indicated that LULC changes had increased surface runoff by an estimated 36%, yield of water by approximately 22%, and yield of sediment by 22% from the first to the fourth scenarios. This study relates to the researcher quest to establish the variations in sediment generated from different land use-land cover types within a basin.

A similar model was again used by Leta *et al*., 2017 at Finchaa Hydropower Reservoir in Ethiopia to evaluate sensitivity together with patterns of land use-land cover change on sediment yields and stream flow. Shuttle Radar Topographic Mission (SRTM) digital elevation model, LULC map, soil characteristics map and parameters related to precipitation, temperature, evaporation, humidity, windspeed and direction, solar radiation, and atmospheric pressure were some of the auxiliary data used. The research considered four dissimilar land use-land cover types which were; agriculture land, grassland, afforestation and deforestation. The results showed that afforestation land use-land cover type had the most significant reduction in runoff, soil erosion and sediment yield at the sub-basin level while the other three also exhibiting varying degrees. This therefore implies that LULC changes have divergent impacts on reservoirs and thus necessitating further research to identify best-bet management practices for each specific LULC type.

A study was done in Tanzania's Little Ruaha river basin by Chilagane *et al*., 2021 to assess the impacts of land use and land cover changes on surface runoff and sediment yield. Their findings indicate that average annual surface runoff and average annual total sediment load increased while the average annual base flow and ground water shallow aquifer recharge decreased for any specified LULC type.

Kithiia, (1997), conducted a study on land use changes and their effects on sediment transport and soil erosion within Athi drainage basin in Kenya. He found out that land uses in the basin change downstream, from agricultural dominated in the upper zone to industrial and settlement towards the capital city, and livestock keeping and small-scale irrigation towards the intermediate and lower zones of the basin. Changes in land use, soil types and the climatic conditions of the zone were among the factors found to influence soil erosion and sediment transport.

Nyangaga, (2008), conducted a study in Itare sub-basin of the Lake Victoria basin, Kenya. His aim was to observe the land use changes that have happened and the associated implication on quantity of water in streamflow and quality of water in terms of turbidness. He established that the overall flow and the drought flow increased but the continuous flow reduced over time. He also established that there were variations between dry and wet season flows where the former diminished while the latter augmented. There was increased turbidity which is indicative of degraded water quality. Turbidity was catalysed by the land use changes which amplified the quantities of soil particles and sediments in the water.

At the Mwache multipurpose dam, a baseline survey report of the year 2018 identified untenable land utilization practices and highlighted some environmentally degraded hot spot areas. The survey encompassed spatial mapping of the various land use practices in the basin and the degraded hotspot areas occasioned by the untenable land uses with the help of the SWAT tools together with land use-land cover maps extracted from 2016 Kenya land cover imagery data.

The catchment was delimited into various basins based on a number of reach outlet identified. These basins were separated into unique Hydrological Response Units (HRUs) that had homogeneous hydrologic response based on the type of soils, the cover and the slope classification.

Temporal trends of precipitation and river discharge for Mwache catchment were spatially and temporally analysed. Delimitation of the sub-catchment DEMs was done and the surface drainage patterns analysed. Other characteristics like slope length of the terrain and gradient and, the stream network features such as channel length, slope, and width were obtained from the digital elevation model. Flow direction and accumulation, and the stream grid of the sub-catchments were also derived.

Potential land use-land cover changes were modelled and according to Verburg *et al.,* 1999, the changes were deemed as being catalysed by; -

1. Scarcity of resources which exerts more pressure of production on the already strained resources,
2. Interference caused by policies which may conflict with the socially constructed norms,
3. Diversification of livelihood opportunities created by markets,
4. Unsustainable coping capacities which increase community vulnerability, and
5. Weak social institution and inability to control access and utilization of resources.

A consolidative approach that combined the various viewpoints of; the agent-based, the systems, and the narrative approaches by Lambin, (1999) and Lambin *et al*., 2003, was used in Mwache socio-economic and cultural perception survey. LULC change was viewed to be influenced by factors such as;

- Community underlying vulnerabilities is related to the timing and location of human elements and other productive assets like livestock and their exploitation of land due to lack of diversified options,
- Prevailing policy frameworks is related to the existing governance structures and measures put in place by the state which will either deter or encourage sustainable land exploitation,
- The pressure exerted on the land with regards to the carrying capacity or stocking density against the available land,
- Available livelihood opportunities in terms of land usability and what are resources, goods and services that the land can offer, and
- The social organization structure with regards to land tenure systems and the nature in which the land is owned within the society, and who has control of the land.

2.1.3 Estimation of the time/duration taken for the sediment load to completely silt up a reservoir.

Snyder *et al*., 2004 conducted a study to quantify the weight and magnitude of sediment conveyed along Yuba River in Northern California and ultimately deposited behind the Englebright Dam in Englebright Lake. They used two simple extrapolation approaches according to the divergent format of sediment movement to convert from a vertical sediment arrangement to an entire volume.

The first approach was the variable layer thickness, which works on the assumption that in any set of aggregated sub-samples, the perpendicular distribution of sediment is a representative of all the points in that region and that comparatively, each layer's thickness remains constant when equated to the whole column in the entire region.

The constant layer thickness on the other hand worked on the principle where a perpendicular sediment section is placed in the context of a cross section of a crosswise reservoir and alluvial layers deposited parallel to the floor of the lake surface. This approach assumes that the reservoir fills from down to top and the oldest alluvial layers are located in the bottommost parts of the reservoir.

They found out that in a span of 60 years between 1940 and 2001, the Lake collected $21.9x10^6$ m^3 of sediments, occupying 25.5% of the design capacity.

Shiferaw and Abebe, (2020) used the most recent version of Golden Surfer 16 and ArcGIS 10.5 to examine sediment transport processes and estimating sediment accumulation limits at Ethiopia's Abrajit Dam in North Gojjam sub-basin, Blue Nile basin. The accumulation limit was established using surface volume calculation and surface differencing synchronized into ArcGIS 3D spatial examiner device by working out the volume underneath the reference surface. The volume of deposited sediments was estimated using surface distinction method from disparities between the original accumulated limits combined with the measurement of the depth of water in the reservoir. Using the ArcGIS Raster Math-less device, the dregs was determined by deducting store bed height thickness raster image of when the dam started operating from thickness of the store bed height raster image taken at the time of the research, and the assessment of annual sediment yield analyzed by dispersing the volume of retained sediment from the cumulative years of operational life of the dam.

The dam storage loss or the reservoir life expectancy (LE) was computed as;

$$LE = \frac{DSV}{SR} \qquad \textit{Equation } 2.1$$

Where; LE =Reservoir life expectancy (years)

DSV=Reservoir dead storage (m^3) and

SR=sediment deposition (m^3 year $^{-1}$)

The overall findings of the research indicated that 20% of storage limit of the reservoir was filled by 343,700m^3 dregs collection within 12 years since starting operating. Additionally, an annual aggregate of 28,641.675m^3 residue volume was being collected, thereby influencing the repository life range to around 12 years.

Kiringu *et al.,* 2022 in their study to model sediment yield and the appropriate mitigation measures for Thwake Dam in Kenya using SHETRAN model to determine accumulated sediment loads in the long-term period, they took into consideration the land use changes for three case scenarios; at the year 2000, 2016 and predicted the year 2100 using land change modeller. The sedimentation rate was estimated at 17.62mt/a, 17.60mt/a and 16.08mt/a for the three case scenarios respectively. They deduced that land use change induced sediment yield is predicted to marginally decrease by more than 10% over a period of time. Results obtained from delta change with calibrated SHETRAN model approach predicted that there could be an upsurge in sediment yield by up to 47% compared to the present estimates.

Studies conducted at the Mwache multipurpose dam site during the design stages estimated the anticipated sediment load and subsequently installed two check dams on the upstream of the dam's sub-catchment. The sediment load generated annually from each check dam was estimated from land use maps and corresponding assumptions of sediment generation from each land use type. Each check dam was assumed to be emptied regularly and in a very abnormal situation, at least every three years. The check dams' effectiveness in intercepting sediments was estimated using Brune empirical curve. The estimate was repeated for each of the three years assuming available storage had decreased due to the previous year's trapped sediment. Average trap efficiency for the three-year cycle of each check dam was thus estimated, a sustainable commercial operation for the removal and use of the sediment assumed, and any dregs material not interceded by the ditch checks was routed downstream and added to the sediment load of the downstream sub-basin. Finally, an annual sediment load for the main dam was estimated. Sediment accumulation in the reservoir and sediment deposition profile were estimated using the method of Borland and Millar. The projected sediment deposited in the Mwache multipurpose considering no flushing from the main reservoir was 25.8 million m^3 after 50 years, and 43.6 million m^3 after 100 years.

2.2 Summary of reviewed literature

Four (4) studies on sediment production from river basins were reviewed. The studies were conducted by Chalise *et al*., 2019, Benselama *et al*., 2019, Kuti *et al*., 2021 and Njogu *et al*., 2017. The studies sought to establish sediment amount coming out of the basins, eventually also establishing other factors exacerbating the sedimentation process such as topography, hydrology, geological composition, permeability of rocks, changes in land use-land cover, amount, duration, magnitude of the rains, and contour orientation. These researches also examined the variations between sediment yield studies with gauging and modeling approaches.

Five (5) other researches on contribution of land use-land cover conditions to the rate of sedimentation were reviewed. Munoth *et al*., 2019, Leta *et al*., 2017, Chilagane *et al*., 2021, Kithiia, (1997) and a study by Nyangaga, (2008). Baseline survey report of Mwache multipurpose dam was also reviewed and the findings formed part of literature review for the current study. All these studies reviewed established that changes in the land condition is a critical contributor to sediment yield alongside other factors such as type of soil and the climate of the watershed. Changes in land use also affected water quality in terms of turbidity due to upsurge of soil particles deposited in the water as well as interfere with the high and low season flows, with the former flows being enhanced due to the loose soils occasioned by the bare and exposed land permitting more runoff, while the latter flows being depressed due to sluggishness of flow caused by resistance of the loss soil particles and sediments.

On estimation of duration taken for a reservoir to be silted up, Snyder *et al*., 2004, Shiferaw *et al*., 2020 and Kiringu *et al*., 2022 studies were reviewed, alongside the results from studies conducted at Mwache multi-purpose dam site in 2014 during project design stages. The findings established varying dams' lifespan depending on factors such as land cover-land use, among others.

2.3 Critique of reviewed literature

The reviewed studies above have identified critical factors which influence sediment yield. They include; topography, hydrology, geological composition, permeability of rocks, changes in land use-land cover, amount, duration and intensity of rains, and contour orientation. The researches have also shown the significance of land cover condition to the whole sedimentation process. On duration sediment yield would take to silt up a reservoir, land use-land cover was also implicitly portrayed as a contributing factor. Reviewed studies done at the Mwache damsite also gave a good insight to the current study. However, the reviewed researches on the multipurpose dam did not explicitly conduct a comparative analysis to establish sedimentation rate from diverse land use-land cover categories. Sediment yield from River basins in these studies have been treated as a total sum from all the land use-land cover types within those specific basins. Land use-land cover being an important contributing factor to sedimentation process, and also being a dynamic and area specific factor owing to the ever-changing land uses occasioned by urbanization and conversion of land from agriculture to human settlement and industrialization, studies to explicitly and comparatively assess rate of sedimentation from different land cover types. Specifically, within Mwache watershed these studies ought to be done to inform land cover type specific mitigation measures and development of sediment monitoring plan.

2.4 Knowledge Gap in Literature Review

Mwache Multipurpose dam is a flagship project in Kenya's attempt to realize the economic pillar of the vision 2030. From the various studies done on the Mwache multipurpose dam ranging from feasibility studies, hydrological studies, environmental and social impact assessments, impacts of proposed interventions in the protection of Mwache catchment has been assumed to be bio-physical though driven by socio- economic and cultural factors. Therefore, land use change is a significant factor as it has an impact on both the ongoing and the proposed catchment conservation interventions.

Despite the relevance of LULC types on sedimentation process as evidenced from the various reviewed literatures, the proponents of Mwache multipurpose dam did not factor in comparative analysis of sediment generated from different LULC types in Mwache river basin. Comparing sediment generated from the various LULC types will enhance the objectivity in selection of appropriate catchment conservation strategies and development of sediment monitoring frequency and plan for the various conservation structures proposed and those already in place.

2.5 Theoretical Framework

This section examines two suppositions upon which this study was based. The two theories are the unit stream power theory and the simple settling theory.

2.5.1 Unit Stream Power Theory

According to Bagnold (1960), when water (which is regarded as a real substance) impels another real substance (in this case the sediment) to move, water will always have to expend energy to the sediment in order to keep the sediment in motion against some dynamic resistance. Because of the resistance therefore, some power will have to be used to sustain the movement within a specified time. The stream or river in this case functions like transporting machine under the dynamic equation;

Rate of work done is the product of efficiency and available power

Also, rate of work done is the available power subtract the unutilized power. Stream power is thus a product of stream discharge, gradient, and the mass of water, which directly relates with sediment conveyance. This correlation has been used to classify sediment movement and examine geomorphic questions on the basis of time series and geographical coverage from the instantaneous rate of sediment conveyance at a river cross section (Bagnold, 1966).

Yang (1996) established that determination of total sedimentation rate and conveyance from a river basin irrespective of the transporting medium (be it rill, sheet or river flow) can be done using the stream power theory, while the actual sediment yield into river basin generally or a reservoir in particular can be determined using consistent and rational methods. Such findings can be used for development of watershed and channel network models to perform other reservoir operations and sedimentation management functions to prolong the lifespan of the reservoir.

2.5.2 Simple Settling Theory (SST)

The Simple Settling Theory by Smith (1998), states that, there is a critical hydraulic threshold which any flow discharges lower than it, sediment transport or re-entrainment is assumed to be negligible. When such happens, it becomes simple to predict the sediment deposition rate as a function of the sediments fall velocity, the sediment concentration and the unit discharge. The SST theory relies on two major assumptions which are not tested;

I. That the fall velocity of a grain in a moving fluid is comparable to the fall velocity of the same grain in standing water, and

II. That there is a continuous, complete remixing of sediment and water, i.e. there is no vertical sediment concentration gradient within the flow.

These assumptions are difficult to verify directly, considering the fact that overland flows are often only a few millimetres deep and heavily laden with sediment. Testing the SST has therefore to be carried out indirectly, by comparing predicted and observed grain-size distributions and sedimentation patterns. This study adopted the simple settling theory with its assumptions since they cover for the missing information.

The unit stream power theory by Yang (1996) and Bagnold (1960), and the simple settling theory by Smith (1998) reviewed had some adequacies and inadequacies. According to the former theory, it was established that water uses some energy (power) to transport sediments from the catchment into the stream channel all the way to the reservoir, failure to which the sediment will not be delivered. The latter theory established that there is a critical hydraulic threshold that should be exceeded by any flow for sediment transport to be possible. The thinking behind these two theories was the fact that not all the sediment yielded from the river basin enter the river channel. For the sediment that ends up in the river channel, not all of it is transported along the channel and deposited in a reservoir. However, for the stream power theory being a product of river discharge, gradient, and the mass of water, other factors like surface resistance, which would either hasten or slow the flow velocity ought to have been factored. Surface resistance could be as a result of factors such as LULC types.

2.6 Conceptual Framework

This section examines various concepts regarding the reasons and assessment of LULC changes in ASAL areas, sources and measurement of sediment yield, and life expectancy of water reservoirs. At the tail end of this section, a concept model describing the interaction between the dependent and independent variables of this study is discussed and the anticipated results and recommendations elaborated.

2.6.1 Causes of land use-land cover change in the study area

Arid and semi-arid lands (ASALs) are areas facing erratic rainfall, extended dry spells, droughts, water scarcity and inadequate knowledge and technical knowhow on water resources management. Population growth in these areas has also been on a sharp increase, and coupled with low- and declining-income sources and unsustainable livelihood options, it piles pressure on the environment hence leading to serious environmental degradation. These unsustainable livelihood coping strategies cause long-term degradation. Some of them include; establishment of farm plots and farming in areas of natural depression where water accumulate, mobile stock grazing, cultivating along seasonal rivers, among others (Darkoh, 1996).

Some land use practices have tacit negative impacts on water storage capacity particularly in South-Eastern parts of Kenya, which is part of the ASALs. These practices are destructive to the environment and natural resources and they include; livestock overstocking, subsistence cultivation with or without irrigation, intensive cultivation and deforestation activities among others. Communities in these areas go extra miles to be able to practice the above activities for their daily living, or venture into other similar activities notwithstanding the adverse effects. The environmental impacts of the above activities are; sheet/rill erosion in the farm areas, landslides on farmlands, sand harvesting/quarrying, encroachment on wetlands and water over-abstraction, which eventually leads to desertification, soil attrition and eventually reservoir sedimentation (Luwesi, 2009).

According to the Agricultural Sector Development Strategy (ASDS 2010-2020), soils in Mwache catchment are estimated to be 40% sandy and thus largely unsuitable for agricultural production. The community living in the watershed is predominantly dependent on rain-fed agriculture and since the soils are not very supportive, they are forced to resort to unsustainable and environmental degrading livelihoods such as illegal timber harvesting and excessive cutting down of trees for charcoal making, unsustainable quarrying and sand harvesting with minimal or no efforts at all towards reforestation and rehabilitation of quarries and sand harvesting sites.

2.6.2 Assessment of land use-land cover changes

LULC changes in ASALs has become a recurrent norm and therefore assessment of changes in land use is thus necessary to establish the impact it has to the water resources. In LULC assessment process using remote sensing approach, soil and vegetation properties are concrete items (Hill *et al*., 2004). However, it is important to define some proxy indicators related to degradation, increase of combustible vegetation volume, erosion among others since no direct indicators of degradation are depicted from satellite-based data (Perez-Trejo, 1994; Verstraete, 1994).

Remote sensing data are of paramount importance in the viewpoint of assessment of various biophysical and environmental processes like land use changes and land cover conditions. They permit demonstration and investigation of the status and progress of flora and fauna at diverse scales and with diverse coverage in space because the information used in remote sensing technique adheres to the key principles relevant in the frame of monitoring and observation i.e., repetitiveness, objectivity and consistency (Hill *et al*., 2004).

2.6.3 Sediment yield sources and measurement

Solid loads in rivers originate from weathering of unrefined rock material by a mixture of biochemical, chemical or mechanical processes, and as the river flow velocity decreases, its capacity to transport sediment load decreases, a situation common as the river enters a reservoir, and this is due to increased cross-sectional area. The sediments will settle down in a particular order and in a specific location determined by cessation of drag force on particles rolling along the stream bed (bed load), reduction in turbulence level which controls the capacity of flow to maintain sediment in suspension and development of density currents. Physical sediment particle size is also an important factor since as the sediment particles have settled out of flow, they assume an initial density which is a function of the particle size. This density of deposits will determine the mass of sediment and volume of storage occupied. The lower the density, the larger the storage volume occupied (Mahmood, 1987).

Grimshaw and Lewin (1980) identified channel sources resulting from the bed and banks of stream and its tributaries, and non-channel sources which are derived from within the catchment, as being the two major sources of sediments in rivers. The latter source of sediments may be highly variable due to production mode and transport. The sources of non-channel sediments are; soils which are exposed to erosion, and as such are conveyed to the channel via gullies, rill, runoff erosion, mass failure within the catchment like landslide, among other anthropogenic activities all affected by such factors like; vegetation cover, land use and soil types.

However, not all detached particles are transported out of a watershed since particle detachment occurs by its entrainment and transportation is by water. And as such, they are deposited along the way, starting right from sides of the slopes, at the foot of slopes all the way into the channels as well as on the flood plains. Sediment Delivery Ratio, D therefore is the portion of on-site eroded sediment in a given defined basin area that is conveyed to a given downstream location. It is affected by factors like; size and texture of eroded particles, relief and the area of storage available for sediments in the basin. Generally, delivery ratio for smaller basins is nearly 100 percent, while for larger basins it is assumed to vary according to the equation;

$$D = a / A^b \qquad \textit{Equation } 2.2$$

Where; a is a constant, A is area of the basin and b varies from 1/4 to 1/8.

Sediment yield is affected by the magnitude of erosion in the catchment and the competence of the stream system to carry sediment material out of the watershed. It is also worth noting that not all eroded material from the watershed will result into sediment yield, some will settle at the base of the slopes, while some will find its way to lakes and flood plains within the watershed. The sediment yield that originates from gullies and stream channels within the watershed do find its way to major water courses and thus form part of sediment load.

Sediment yield is measured in tonnes per year or kilograms per year. As the sediment load moves downstream, it is interjected by barriers such as dams and reservoirs and starts depositing as soon as it enters the reservoir. The deposition process continues and spans upstream forming what is referred to as backwater deposits in line with the phenomenon of causative hydraulic. In this scenario, the deposits in the reservoirs will either be overbank, delta, or bottom-set beds; the names are in relation to their shape and location. Over-bank deposits refers to sediments settling over the preceding high bank or valley slopes, delta is made up of deposit of coarse material that is the first to drop out while bottom-set beds are the fine sediments that may be conveyed farther downstream by density currents (Mahmood, 1987).

2.6.4 Methods of estimating current sediment yields and forecast yields

Sediment yields future estimation is affected by the high inter-annual rainfall variability resulting into large disparities in sediment yields between years, the low accuracy of available methods for estimating soil loss and sediment transport, and the influence of future changes in the catchment condition. Precise sediment yield forecasts are however not so essential, therefore quite large inaccuracies in forecasted sediment yields will be acceptable, provided the procedures used during estimation enables rapid identification of dams that will have a very short lifetime during the design stage of projects.

A study by Gikonyo (1994) categorized the sediment yield estimation approaches into gauging and mathematical modelling, and the choice of the approach to be used is dependent on the amount of data available and the data quality for basin under study.

Gauging is the approach where purposely measured water and sediment concentration data is used for sediment yield computations. Reliability and correctness of this technique is enhanced by increasing the frequency of data collection.

Mathematical modelling approach requires less rigorous data collection and measurement procedures for determination of sediment yield, it deals with the conversion of available data on water and movement of water on land, and information like precipitation and watershed characteristics into sediment yield. This is achieved through simulation as opposed to actual data collection, which is both less costly as well as provides the ability to analyse various case scenarios by simply changing the model parameters within some expected ranges.

This study used the gauging approach and there were some challenges such as the constant low flows at the stream points. This challenge was addressed by liaising with the Kenya meteorological department and getting access to the weekly rainfall forecast to assist in planning for the field visits for data collection. However, during the whole period of data collection, the catchment and the county at large received very low precipitation and the rains were too erratic.

2.6.5 Conceptual model on sediment yield and reservoir sedimentation

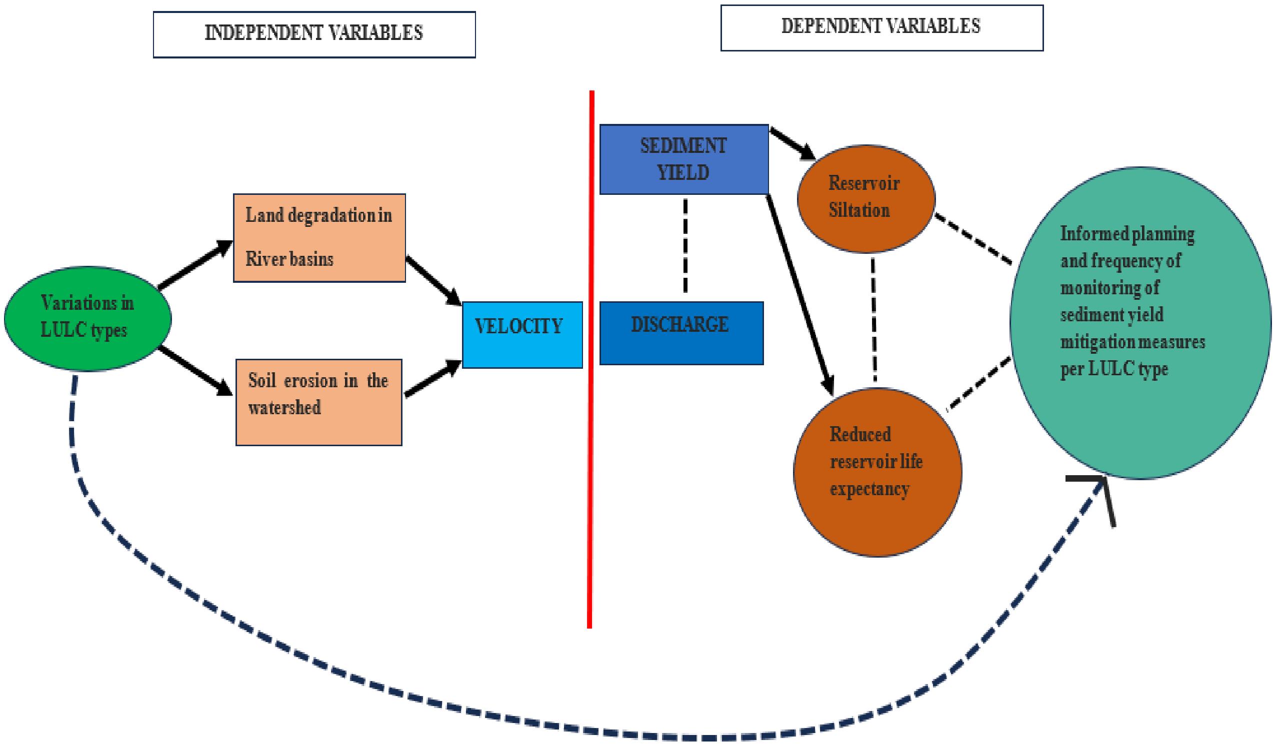

Figure 1: Conceptual model on sediment yield analysis *Source: Researcher 2019*

A review of the concept on dependent and independent variables by Kerlinger (1986) was done and aligned with this research to show the relationship between land use and land cover change, and reservoir siltation.

The conceptual framework indicated above is a schematic diagram indicating the variables included in this research. It shows how the dependent variable is influenced by the independent variable. This study will take the form of a non-experimental research, where the independent variables will not be manipulated, but has some effect on the dependent variables (Kerlinger, 1986). The researcher wishes to contextualize some of the factors that contributes to the behaviour of the dependent variables relative to the specific study area as part of the objectives of this research. The dependent variable refers to the status of the 'effect'(or outcome) in which the researcher is interested; bearing in mind from the theoretical framework that not all the presumed causes (independent variables) are directly responsible for the effects (dependent variables).

The conceptual model in figure 1 illustrates that only one independent variable i.e., variations in LULC types, is explicitly examined although the contribution of the other independent variables to the behaviour of the dependent variables have also been implicitly taken into cognizance. Measurements of flow rate from different land use-land cover types as the independent variable which causes land degradation and soil erosion in Mwache River basin, will affect the discharge which is the measured dependent variable. Consequently, this will affect the sediment generation from the various LULC types and ultimately affecting the life expectancy of the Mwache multi-purpose dam on the downstream of the basin. The variations in discharge and thus sediment yield from various LULC types will inform the required level of monitoring of sediment yield mitigation measures for each of the LULC types.

CHAPTER THREE: STUDY METHODOLOGY

3.0 Introduction

The research design adopted for this study and justification for choice of the design are examined in this chapter. This section highlights the area and scope of study, the method and equipment used for data gathering, instruments for data collection and sampling procedure and the laboratory procedure for determining the total dissolved solids and total suspended solids.

The researcher identified three water sample collection stream points within the basin based on distinct LULC types. Equal discharge increments (EDI) procedure was used to collect water samples and subsequently analysed for total suspended solids (TSS). An acoustic doppler current profiler (ADCP) equipment was also used to measure flow velocity which aided the computation of discharge and in the estimation of sediment yield where high flows were established (Herschy, 2009). However, in most cases current meter was used since the timing of data collection coincided with low flows as the study area was experiencing drought conditions with depressed rainfall amount received for the better part of the year of study.

3.1 Research design

The study used correlational approach to quantitatively establish the comparative sediment generated from three diverse LULC types i.e., shrub land, grass land, and annual crops. Samples of water from streams located in the three LULC types within Mwache River basin were collected and analysed. This enabled the researcher to assess the relationship between land use-land cover types and the sediments generated from the Mwache River basin.

3.2 Study area

The study was conducted in Mwache River basin in Kinango Sub- County of Kwale County, covering three stream points at Chigutu, Maji ya Chumvi and Mwache in the three wards of Mackinon Road, Samburu-Chengoni and Kasemeni respectively. The three stream points were selected from the four major streams within Mwache River basin and they fall under varied land use-land cover types hence making them appropriate for the study. The stream points also fall in areas where the Water Resources Authority had already established river gauging stations which would make it easy for future and subsequent sediment yield and other river flow monitoring studies.

Mwache River basin comprises of four major streams;

1. Ngoni stream originating from Pemba and Taita hills and joins Mwache River on the upstream sections of the Mwache multipurpose dam site. This is where the Mwache dam site stream point is located and it falls under annual crops LULC type.
2. Mavuweni stream which rises from the northwest parts upstream of the dam area. Mavuweni stream joins Maji ya Chumvi River towards Mwache. This is where the Maji ya Chumvi stream point is located and it falls under grassland type of LULC.
3. Mwangombe stream which originates from hills on the north-eastern covering Tsavo areas to Chigato River eventually joining the Mwache channel at Ngoni. This is where the Chigutu stream point is located and it falls under shrubland LULC type.

The fourth major stream within Mwache river basin is Mnyenzeni stream which forms from the foot of a number of hills among them Chigato, Mkanyeni, Chikuyu and Mabesheni and joins Mwache River at Miyani area a short distance upstream of the dam wall and it also falls under annual crops LULC type.

Over 70% of the Mwache river basin has slopes ranging between 0-5% and the soils are predominantly sandy (ASDS 2010-2020) which implies that they both permit siltation and are unfavourable for agricultural production. For inhabitants' whose main livelihood is subsistence farming, they have to find alternatively sources of food and income which exposes them to illegal and retrogressive practices such as excessive logging, overstocking and farming on riparian zones which all promote environmental degradation and further enhancing sedimentation.

Land use-land cover assessment and setting up of water sample collection stations for sediment yield analysis was done within Kinango sub-county, particularly Samburu-Chengoni, Mackinon Road and Kasemeni wards. The wards have a total catchment area of 2049 km^2 and a population of 143,120 people; 68,957 men and 74,163 women (Census, 2019). The population in the study area are largely livestock keepers but also practising crop farming (Kwale county Short Rains Assessment and Long Rains Assessment reports 2018). These types of livelihoods practiced by the study population exposes the soils to erosion which could be a catalyst for sediment yield. (Bessenasse *et al.*, 2012, SASOL and Maji na Ufanisi, 1999).

Mwache river basin straddles from Taita Taveta County in the Taita hills to the west through to Kwale County and draining into the Indian Ocean at Mwache creek in sections of Kwale and Mombasa Counties. It has a basin area of 2,250km^2 with a total length of 110km from an altitude of 300m a.m.s.l. down to 20m a.m.s.l. at the dam. The proposed dam site is in Kasemeni ward, Kinango sub-county in Kwale County. The map below shows the study area clearly indicating the flow of major streams/rivers within the basin, LULC types and the three sampled stream points where water samples were collected;

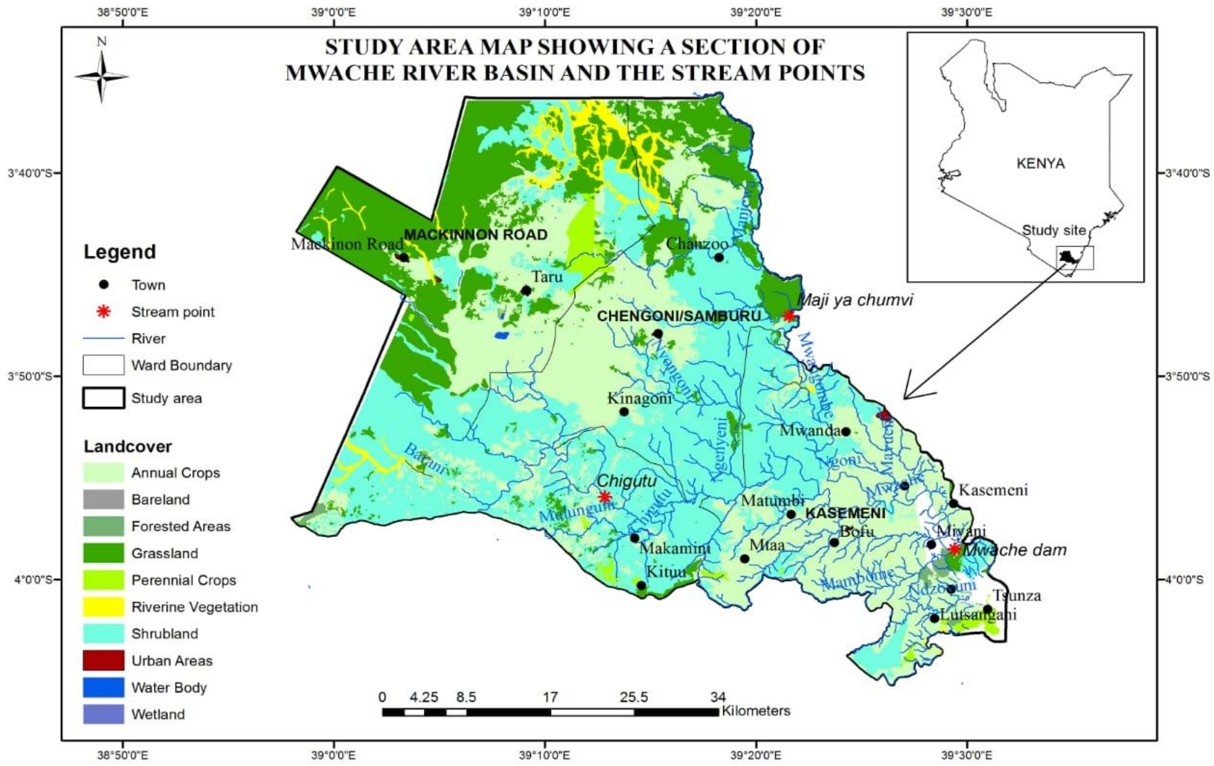

Figure 2: **Study Area Map** *Source: Kwale County spatial plan 2018*

3.3 <u>Methodology</u>

The research study involved assessment of the land use and land cover condition of Mwache river basin, particularly focusing on three administrative wards, i.e., Mackinon Road, Samburu-Chengoni and Kasemeni as a section of the larger Mwache river basin on the upstream of the proposed Mwache multi-purpose dam site. LULC assessment was done by acquiring Digital elevation model for the area, LULC map, soil map and drainage/topography map, and three water samples collection stations/stream points established.

ADCP equipment was used where high flows were established, to measure the discharge at a given cross-sectional area within a specified time period thus enabling the establishment of point flow velocity and the mean flow velocity for each of the three stream points. However, where the river flows were relatively low, as it was in most cases during the sampling period due to the persistent drought in most parts of Kwale county, current meter device was used.

Sediment samplers were used to collect samples using equal discharge increment procedure. Duration taken to gather the samples and the cross-section area of each of the stations was recorded for purposes of discharge computation. In this procedure, suspended sediment was collected by lowering and raising the sampler in a continuous transit rate at each of the river cross-section segments which had been sub-divided on the basis of having nearly equal discharge. The samplers helped to collect specimens of the water-sediment mixture in a vertical dimension. The concentration at different depths was averaged and sediment concentration calculated. The sediments samples collected from each segment were then averaged to get the sediment concentration in each stream (Awal *et al*., 2019).

The three (3) sampling stations/stream points a long Mwache River basin where water samples for analysis of total suspended solids (TSS) were collected, were selected from three dissimilar LULC types; (i) a section of the catchment area under shrub land (ii) a section of the catchment area under annual crops and (iii) a section of the catchment area under grassland.

3.4 Instruments for data collection

The equipment used during the data collection process were current meter and depth integrated sediment sampler.

3.4.1 Current meter

This device was used to measure the velocity of flowing water in the three stream points, i.e., Mwache, Chigutu and Maji ya Chumvi. The device has a blade that spins when immersed in the flowing water (Herschy 2009).

The principle applied is that the speed of water is proportional to the angular velocity of the rotor in the device. The velocity of water at each point is calculated by summing up the number of rotor revolutions made within a specified time interval. The numbers of rotor revolutions are established by an electrical circuit through the contact chamber. Contact points in the chamber compete an electrical circuit at specified revolution frequencies, which is either contact points may complete the circuit once per revolution or once per specified number of rotor revolutions signaled by an electrical impulse which produces a clicking sound and registers on the counting device, and the time intervals within which meter revolutions are counted are timed with a timer.

3.4.2 Depth integrated sediment sampler (Model D-49)

This device was used to collect the water samples for total suspended solid and total dissolved solids analysis. The sampler was immersed in the flowing water from the surface of the water to the bed of the stream, then instantaneously reversed and raised to the surface at a uniform rate. The process was repeated as the sampler collects water samples each time it is submerged. At each of the verticals one sample is collected along the stream cross section. The sampler is made up of a cast bronze material, streamlined body within which a sample collection bottle either round or square pint shaped is fitted. The sampler head is hinged to allow access to the sample bottle fitted in it. The head is drilled and tapped and when its calibrated intake nozzle is pointed against the direction of flow it collects the samples. The rate of lowering and raising the sampler from the surface to the streambed and back is dictated by the mean velocity in the vertical, the depth of water and the diameter of the nozzle.

3.5 Method of data collection

The water samples were collected using equal discharge increments (EDI) procedure and subsequently analysed for total dissolved solids (TDS) and total suspended solids (TSS), with the latter being the dominant cause of reservoir siltation (Diplas *et al*., 2008).

The procedure enables collection of discharge-weighted samples representative of the entire cross-section. The flow in the cross-section at the three stream points was divided into increments of equal discharge. Water samples were then collected at the centroid of each equal-discharge increment along the cross section.

It involved the following steps;

- Setting up the samples collection site by clearly demarcating the site
- Assembling the equipment, i.e., the current meter, depth integrated samplers, the sampling bottles and the staff to assist in recording the readings.
- Selection of the number and location of equal discharge increments along the stream cross section which involved the following;
    - Keenly assessing the stream observing the stream width, depth spread, seeming sediment distribution and flow velocity at the cross-section to establish suitability of the site.
    - Actual determination of the stream width from a tagline
    - Measurement of the discharge to be sampled at the cross section

- o determination of the volume of discharge to be represented in each EDI in line with; the purpose for which the study is conducted, channel characteristics along the cross section, volume of sample required for analysis and other variations encountered in field measurements,
- ▪ Division of the cross section into equal discharge increments. This is guided by the principle that every subsample collected at the centroid of each EDI should be a representative of the average stream flow measured for that specific increment. If the mean stream flow of the increment is not represented, then the number of increments is increased by decreasing the volume represented by each EDI up to the point when the mean stream flow value for increment is represented. Ordinarily the number of sampling increments would not exceed 10 nor will they be fewer than 4.
- ▪ Location of the centroid of flow within each increment from the discharge measurements is then established by determining EDI locations directly from the recorded discharge measurements (Diplas *et al*., 2008).
- ▪ Sampling depth and the average stream velocity are then determined at the centroid of each equal-discharge-increment and the transit rate for each centroid that will yield subsamples of relatively similar volume with a variation of within 10 percent margin of difference also established. Normally, the minimum volume for every equal-discharge-increment is the minimum volume for the deepest vertical when compositing subsamples.

3.6 Sampling design and procedure

This section explains the rationale behind the choice of Chigutu, Maji ya Chumvi and Mwache damsite streams as the water sampling streams, the procedure used to collect the samples and the sample size.

3.6.1 Sampling design

Purposive type of non-probability sampling technique was used. Acharya *et al*., 2013. This design was adopted since there were already established River Gauging Stations (RGSs) along the selected streams thus saving the researcher time and financial resources for setting up new RGSs. The purpose of this study was to establish how various LULC types within Mwache River basin affect the sediment yield. The researcher therefore assessed the various LULC types and the streams which pass through them. The four major streams within Mwache basin were falling on three different LULC types, that is; shrub land, grass land and annual crops. To enable assessment of the influence land use-land cover types have on sediment volumes in the basin, three streams with established gauging stations were selected. Chigutu stream on shrub land, Maji ya Chumvi stream on grass land and Mwache stream on annual crops. However, the actual sediment-water mixture samples were collected using stratified approach at the centre of each segment of the stream cross-section area for the three streams under study. Velocity and flow rate measurements within the segments for each stream were also collected.

3.6.2 Sampling procedure

Adopting the EDI procedure, the stream cross-section was partitioned into several vertical segments of equivalent water discharge. The current meter device was used to measure the stream point discharge where the area of each vertical subsection was computed by measuring the width, depth and the water velocity. The width was measured using a steel tape, while the depth was measured using a wading rod. Discharge in each segment is the product of the area of the segment and the measured velocity. The total discharge for the stream point was the summation of all discharges in each of the perpendicular sections.

Depth integrated sediment sampler was used to collect water-sediment mixture specimens in a vertical, in which the concentrations at different depths were averaged. The sediment sampler was immersed and raised from the surface of the water to the bottom and back at the centripetal vertical at each equal discharge sections which enabled collection of depth integrated samples. The downward and upward transit rates varied but total traverse time was kept constant permitting for time compensation in order to attain matching volume samples. A discharge weighted average for the whole cross-section was obtained from the perpendicular section sediment concentration means. Information on the stream-flow distribution for the selection of sampling verticals in the cross-section was provided by the WRA officers from their routine office mandate. Sites with stable stage discharge relations had been identified, the verticals were located at the midpoint of each equal increment in discharge while ensuring they were not less than three verticals per cross-section sampling point in order to achieve representative samples.

3.6.3 Sample size

The number of samples collected was determined by the number of sampling increments established across the stream (Edwards and Glysson, 1999). During this study, 11 samples were obtained at the Mwache stream near the dam site where the stream channel was broad, while 10 samples each were obtained from the other two streams of Chigutu and Maji ya Chumvi.

Plates 1 to 4 were taken during data collection exercise to compute stream cross-section area, flow velocity, discharge and water samples collection for analysis of total suspended solids.


Plate 1 Plate 2

Plates 1: Measurement of Flow and Discharge at Chigutu *Source: Researcher 2019*

Plates 2: Measurement of Flow and Discharge at Mwache damsite *Source: Researcher 2019*


Plates 3 Plate 4

Plate 3: Collection of Water Samples for TSS Analysis by WRA team
Source: Researcher 2019

Plate 3: Collection of Water Samples for TSS Analysis by the researcher
Source: Researcher 2019

3.7 Determination of total suspended solids

The TSS was gravimetrically determined using the APHA 2540D procedure. The water sample is sieved through a glass-fiber filter of 47 mm diameter and pore size between 1 and 2 micro meters. The filtered sample is dried in a convention oven at a temperature of between 103 to 105°c for at least 60 minutes. The filter pan which contains the sample is then taken out of the oven and the sample left to cool to room temperature. The sample is then skilfully removed from the pan without touching by the use of pliers or forceps. The dried residue is weighed and recorded as the first weight at 103°c.

The procedure is then repeated for a second time to get second weight at the same temperature. The weight change between first and second readings is calculated which should be equal to, or less than 0.5mg. If the change is more than 0.5mg, the procedure is repeated until such a time when the change between the last and the second-last weight is equal to or less than 0.5mg. When this weight is attained it is recorded as the final weight at 103°c.

The total suspended solids from the sample is computed as;

$$\frac{(A-F)\ x1000}{S} \qquad \textit{Equation } 3.1$$

Where;

A =final weight of residue at 103°C plus the weight of the tared filter in mg

F =Tared filter weight in mg

S =mL of sample volume

TSS therefore recorded in mgl^{-1}

For this procedure, any sample yield of less than 2.5mg or more than 200mg is thus recorded as ‘estimate’ since it has surpassed the conditions for application of this technique. (Baxter, 2017).

3.8 Data collection stream points

Ten different LULC types identified within the Mwache River basin were; annual crops, bare-land, forested area, grassland, perennial crops, riverine vegetation, shrub-land, urban areas, water body and wetlands (*Kwale County spatial plan 2018*). The major streams within the catchment which fall under different LULC types were identified for purposes of data collection for this study. The stream cross-sectional areas for the stream points were also established to ascertain their suitability for water samples collection for purposes of sediment yield analysis. The coordinates for the three stream points were;

i. Chigutu stream point located in Mackinon Road ward on Latitude: -3.946631 East and Longitude: 39.2140855 South, falling under shrubland land use-land cover type.

ii. Maji ya Chumvi stream point located in Samburu/Chengoni ward on Latitude: -3.791875 East and Longitude: 39.3818341 South and on grassland land use-land cover type.

iii. Mwache dam site stream point situated in Kasemeni ward, lying on latitude -3.995997 East and longitude 39.532538 South. This stream point falls on annual crops according to the land-use-land-cover type map.

Figure 3 illustrates the stream points and corresponding land use-land cover types.

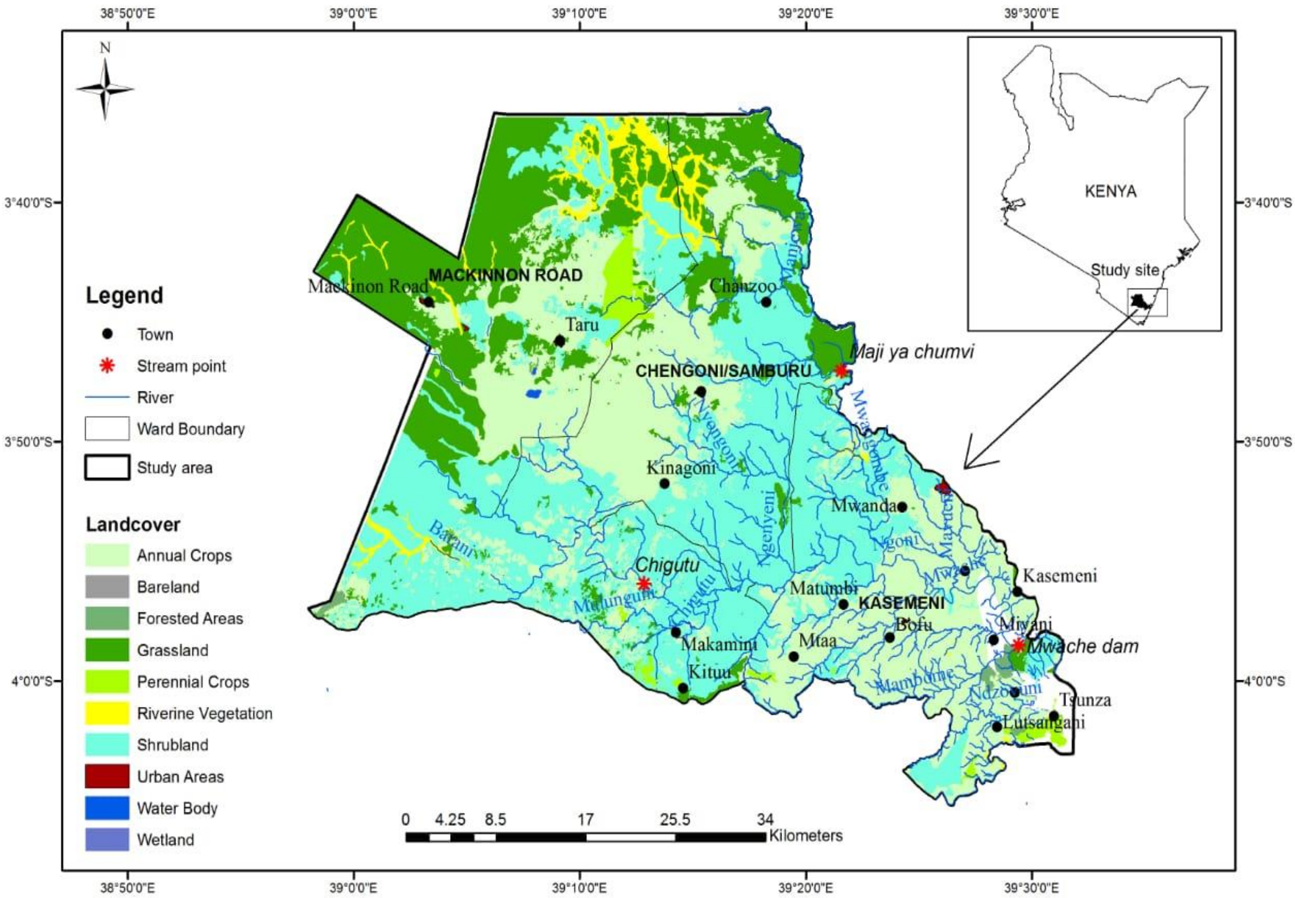

Figure 3: Land Use/Land Cover Map *Source: Kwale County spatial plan 2018*

3.9 Stream points velocity and discharge

The stream cross-section was divided into vertical segments of equal discharge. At each segment, the width and depth were recorded which aided in computation of the area of the segment. Moving across the channel, the number of revolutions of the current meter were recorded at 30 second intervals from the surface velocity (sv) at the water edge right bank (WERB) and at the water edge left bank (WELB) and any depth below 0.6m at the various vertical segments. Other readings were taken from a depth of 0.6m at the centroid of each of the vertical segments across the channel. Number of revolutions, the time interval and depth of observation were recorded. Computation of means in verticals was done and the mean velocity calculated. With the area and mean velocity readings available, the discharge from each of the three stream points was calculated using the equation;

$$q = va \qquad \textit{Equation } 3.2$$

Where q is the discharge at the vertical (m^3/s) segment

v is the mean in vertical (velocity) at the vertical segment (m/s) and

a is the area of the vertical segment which is the product of the depth and width of the segment (m^2).

3.10 Stream points total suspended solids and estimated sediment yield.

To analyse the sediment yield from Mwache River basin. Water samples were collected from the 3 stream points; Chigutu (shrub land), Maji ya Chumvi (grass land) and Mwache dam site (annual crops). Analysis of the water samples was done to establish the total suspended solids (TSS) using the APHA 2540 D analytical method of 2005.

According to Rai *et al*., 2017, sediment yield can be estimated using the equation

$$S_y \text{ (Tons)} = 86.4\, C \times Q \qquad \textit{Equation } 3.3$$

Where;

S_y =sediment yield in tonnes

C =daily sediment concentration in grams per litre (g/l) and

Q = daily discharge in cubic metres per second (m^3/s)

$$S_y\,(m^3) = \frac{1000 \times S_y \text{ (Tons)}}{\ell_s (kg/m^3)} \qquad \textit{Equation } 3.4$$

where;

ℓ_s = density of sediment in kg/m^3

$1\ mg/l = 0.001 g/l$ *Equation* 3.5

$1 g/l = 1 kg/m^3$ *Equation* 3.6

3.11 Estimation of dam's life expectancy

To estimate the time/duration taken for sediment load to completely silt up a reservoir, equation 2.1 was used.

$$LE = \frac{DSV}{SR}$$

Where; LE =Reservoir life expectancy (years)

DSV=Reservoir dead storage (m^3) and

SR=sediment deposition ($m^3\ year^{-1}$)

To determine the sediment deposition rate, equation 3.7 was used.

$$SR = \frac{SV}{T}$$ *Equation* 3.7

Where; SV is the sediment volume in cubic metres (m^3) and

T is duration of sediment accumulation in years

3.12 Method of data analysis.

Simple linear regression model was used since there were only two variables, one independent variable (point velocity) and one dependent variable (discharge) for each of the streams under study. This method was used to determine the linear relationship between point velocity and discharge. Independent two sample t-test type of student's t-test was used to test the hypothesis of the study at 0.05 significance level (Greenland *et al*., 2016).

The simple linear regression model is expressed as $Y = a \pm bX$ where a is the intercept, which is the predicted value of Y when X is zero. b is the regression coefficient which shows how much Y is expected to change with an increase in the value of X. Y is the predicted value of the dependent variable (discharge) for any given value of the independent variable (Velocity), while X is the independent variable expected to be influencing the value of Y.

To establish how well the regression model predicts the outcome, a coefficient of determination, r^2 is calculated by squaring the correlation coefficient, r. The correlation coefficient *r* explains the strength of a linear relationship between variables. Peason's correlation coefficient, r is expressed as;

$$r = \frac{N\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{[N\Sigma x^2 - (\Sigma x)^2][N\Sigma y^2 - (\Sigma y)^2]}}$$

Equation 3.8

Where

N = Number of paired readings

Σxy = Sum of the product of paired readings

Σx = Sum of x readings

Σy = Sum of y readings

Σx^2 = Sum of squared x readings

Σy^2 = Sum of squared y readings

The coefficient of determination, r^2 is calculated by squaring the correlation coefficient and is expressed as a percentage. It measures the proportion of the change (variance) in the response variable (Y) that can be explained by the predictor variable (X) in a regression model. The higher the percentage the higher the proportion of Y value that is influenced by the change in X and the lower the percentage the lower the proportion of Y value that is influenced by the change in X.

To determine whether the correlation between variables was statistically significant, t-test analysis was used. The variables were from two different LULC types i.e. shrub land and grass land, and the t-test analysis was to establish whether the variations in LULC types in the Mwache River basin significantly influenced the sediment yield. Therefore, T-score and p-value for the variables were then computed for a two-tailed hypothesis testing at 0.05 significance level. A p-value less than the significance was the basis for rejecting the null hypothesis (Greenland *et al*., 2016).

CHAPTER FOUR: RESULTS PRESENTATION AND INTERPRETATION

4.0 Introduction

Tables showing the computation of point velocity and flow discharge from the three stream points and results for total suspended solids from the three stream points are well displayed in this section. An in-depth analysis of the sediment volume across the three LULC types is done and estimation of Mwache multi-purpose dam's life expectancy and hypotheses testing to establish whether or not variations in LULC types in Mwache River basin significantly affect the sediment yield is also done. At the end of this chapter, the overall research study findings from each of the three specific objectives are discussed in comparison with findings from past similar studies.

4.1 Chigutu stream flow velocity and discharge readings

Table 1: Flow and Discharge Readings for Chigutu Stream Point

Dist. From initial point	Depth	Width	Area	Discharge	VELOCITY Mean in vertical	Time (secs)	Revolutions.	Depth of observation from surface
0	0	0.1	0	0.000		30	0	sv
0.2	0.05	0.2	0.01	0.003	0.308	30	33	sv
0.4	0.12	0.2	0.024	0.010	0.414	30	45	sv
0.6	0.18	0.2	0.036	0.018	0.511	30	56	0.6
0.8	0.22	0.2	0.044	0.028	0.632	30	59	0.6
1	0.23	0.2	0.046	0.031	0.674	30	63	0.6
1.2	0.25	0.2	0.05	0.036	0.726	30	68	0.6
1.4	0.27	0.2	0.054	0.043	0.799	30	75	0.6
1.6	0.22	0.2	0.044	0.037	0.840	30	79	0.6
1.8	0.16	0.2	0.032	0.023	0.705	30	66	0.6
2	0.07	0.2	0.014	0.005	0.362	30	33	0.6
2.2	0	0.1	0					
TOTAL			**0.354**	**0.2342**	**0.597**			

Source: WRA and Researcher 2019 (14-11-2019 @ Muruhe bridge, Chigutu)

The mean velocity (V) at the stream point was 0.597m/s, from a cross-sectional area (A) of 0.354m^2 and a discharge (Q) of 0.2342m^3s^{-1}.

4.2 Maji ya Chumvi stream flow velocity and discharge readings

Table 2: Flow and Discharge Readings for Maji ya Chumvi Stream Point

Dist. from Initial Point	Depth	Width	Area	Discharge	Velocity (m/s)	Time (Secs.)	Revolutions	Depth of Observation from Surface
					Mean in vertical			
3.7	0.00	0.15	–	–	–			
3.4	0.10	0.30	0.030	0.011	0.3697	30	40.0	sv
3.1	0.21	0.30	0.063	0.017	0.2637	30	28.0	sv
2.8	0.10	0.30	0.030	0.006	0.1930	30	20.0	sv
2.5	0.10	0.30	0.030	0.008	0.2725	30	29.0	sv
2.2	0.15	0.30	0.045	0.020	0.4349	30	40.0	0.6
1.9	0.13	0.30	0.039	0.013	0.3255	30	35.0	sv
1.6	0.09	0.30	0.027	0.008	0.2814	30	30.0	sv
1.3	0.04	0.30	0.012	0.002	0.1312	30	13.0	sv
1.0	0.10	0.30	0.030	0.003	0.1047	30	10.0	sv
0.7	0.10	0.30	0.030	0.006	0.1930	30	20.0	sv
0.4	0.00	0.15	–	–	–			
TOTAL			**0.336**	**0.092**	**0.257**			

Source: WRA and Researcher 2019 (14-11-2019)

The mean velocity (V) was 0.257m/s from a cross-sectional area (A) of 0.336m^2 and a 0.092m^3s^{-1} discharge (Q).

4.3 Mwache dam site stream flow velocity and discharge readings

Table 3: Flow and Discharge Readings for Mwache Dam Site Stream Point

Dist. from Initial Point	Depth	Width	Area	Discharge	Velocity (m./sec.)	Time (Secs.)	Revolutions.	Depth of observation from Surface
					Mean in vertical			
0.0	0.00	0.20	–	–	–			
0.4	0.11	0.40	0.044	0.008	0.1842	30	19.0	sv
0.8	0.20	0.40	0.080	0.020	0.2479	30	22.0	0.6
1.2	0.27	0.40	0.108	0.037	0.3414	30	31.0	0.6
1.6	0.35	0.40	0.140	0.061	0.4349	30	40.0	0.6

2.0	0.30	0.40	0.120	0.068	0.5700	30	53.0	0.6
2.4	0.28	0.40	0.112	0.066	0.5908	30	55.0	0.6
2.8	0.20	0.40	0.080	0.054	0.6750	30	63.0	0.6
3.2	0.16	0.40	0.064	0.019	0.2894	30	26.0	0.6
3.6	0.17	0.40	0.068	0.033	0.4869	30	45.0	0.6
4.0	0.18	0.40	0.072	0.032	0.4453	30	41.0	0.6
4.4	0.09	0.40	0.036	0.013	0.3726	30	34.0	0.6
4.8	0.00	0.20	–	–	–			
TOTAL			**0.924**	**0.411**	**0.422**			

Source: WRA and Researcher 2019 (15-11-2019)

The mean velocity (V) at the stream point was 0.422 m/s in a cross-sectional area (A) of $0.924m^2$ and a discharge (Q) of $0.411m^3s^{-1}$

4.4 Total suspended solids from the three land use-land cover types

The total suspended solids at Chigutu, Maji ya Chumvi and Mwache dam site were $1000mgl^{-1}$, $350mgl^{-1}$ and $600mgl^{-1}$ respectively.

Table 4: Computation of sediment yield in Tons

Stream point	TSS (mgl^{-1})	Daily sediment concentration(C) gl^{-1}	Daily discharge (Q) m^3s^{-1}	Sediment yield S_y (Tons)
Chigutu	1000	1	0.2342	20.235
Maji ya Chumvi	350	0.35	0.092	2.782
Mwache dam site	600	0.6	0.411	21.306

Source: Researcher 2021

Table 5: Computation of estimated sediment yield in m^3

Stream point	Sediment yield (Tons)	Sediment Density (kg/m^3)	Estimated sediment volume (m^3)
Chigutu	20.235	1	20,235
Maji ya Chumvi	2.782	0.35	7948.571
Mwache dam site	21.306	0.6	35,510

Source: Researcher 2021

Chigutu, Maji ya Chumvi and Mwache dam site streams lying on shrub land, grass land and annual crops land use-land cover types had estimated sediment volume of 20,235m^3, 7948.571m^3 and 35,510m^3 respectively. This implies that sediment yield in Mwache River basin varies with land use-land cover type, with annual crops LULC yielding the most and grass land LULC yielding the least.

4.5 Data analysis on sediment yield per land-use-land-cover type

To assess the various LULC types in the Mwache River basin and their contribution to sedimentation, three stream points were identified from three diverse LULC types; shrubland, grassland and annual crops. Computation of mean velocity, discharge and total suspended solids from the three LULC types was done from all the three stream points.

4.5.1 Analysis of sediment yield data from shrub land (Chigutu stream):

Proxy parameters were used to deduce the correlation between LULC type and sediment yield. Among the key parameters collected, which directly influence the sediment yield are flow velocity and discharge (Wahab *et al.*, 2016). Point velocity and discharge from shrub land LULC type were recorded in table 8 and a linear regression analysis conducted.

Table 6: Flow Velocity and Discharge for Shrub Land (Chigutu stream)

Discharge	0.003	0.010	0.018	0.028	0.031	0.036	0.043	0.037	0.023	0.005
Velocity	0.308	0.414	0.511	0.632	0.674	0.726	0.799	0.840	0.705	0.362

Source: Researcher 2021

Number of observations= 10

F (1, 8) = 134.58

Prob > F = 0.0000

R-squared = 0.9265

Root MSE = .00403

Table 7: Linear Regression Analysis of Flow Velocity and Discharge for Shrub Land

Discharge	**Coef.**	**Robust Std. Err.**	**t**	**P>t**	**[95% Conf.**	**Interval]**
Velocity	0.072167	0.0062209	11.6	0	0.057822	0.086513
_cons	-0.01969	0.0026828	-7.34	0	-0.02588	-0.0135

Source: Researcher 2021

Therefore, the model specification along the shrub land is:

Discharge= 0.072167velocity +(-0.01969)

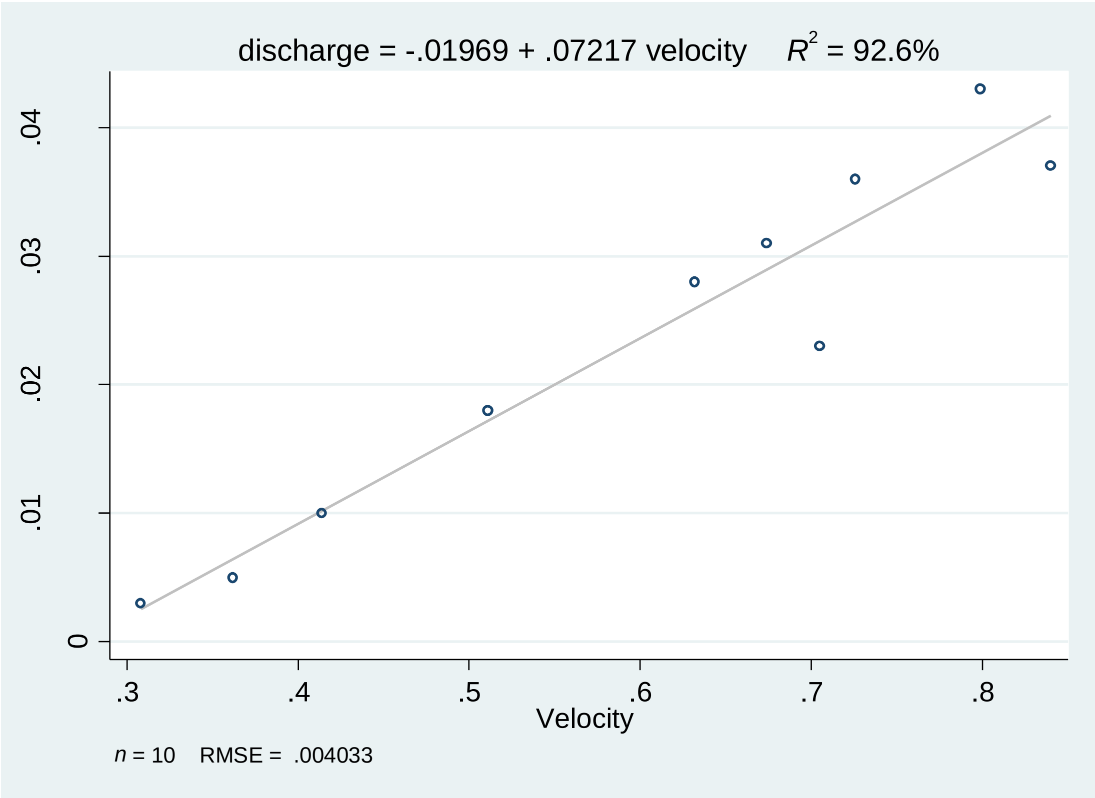

Figure 4: Residual Plot of Discharge (M^3S^{-1}) Against Velocity (MS^{-1}) Along the Shrub Land

Source: Researcher 2021

A linear regression of discharge against velocity at Chigutu stream point showed a robust relationship with an r^2 of 92.6%. The plotted points closely follow the linear pattern all through, which signifies a strong relationship between the dependent and independent variables (Yang, 2022). The findings indicate that the predicator variable is well explained by the independent variable as indicated by an r^2 value of 92.65% hence it's a good fit model. The coefficient value of the constant is -0.01969 which implies that for every one unit increase in the discharge of water carrying along sediments, the flow velocity decreases by 0.01969 cubic metres. Deductions can also be made that there is a significant relationship between velocity and discharge along the shrub land use type since the p-value of 0 is less than 0.05 level of significance. This therefore affirms that there is a strong relationship between discharge, which is the proxy variable for sediment yield, and the flow of velocity in shrub land use land cover type in Mwache River basin at 95% confidence level. The proportion of discharge explained by the velocity of flow is 92.65% (coefficient of determination).

4.5.2 Analysis of sediment yield data from grass land (Maji ya Chumvi stream):

Velocity and discharge from Maji ya Chumvi stream point were recorded in table 8 and a linear regression analysis conducted.

Table 8: Flow Velocity and Discharge for Grass Land (Maji ya Chumvi stream)

Discharge	0.011	0.017	0.006	0.008	0.020	0.013	0.008	0.002	0.003	0.006
Velocity	0.3697	0.2637	0.1930	0.2725	0.4349	0.3255	0.2814	0.1312	0.1047	0.1930

Source: Researcher 2021

Number of observations= 10

F (1, 8) = 45.74

Prob > F = 0.0001

R-squared = 0.7213

Root MSE = .00328

Table 9: Linear Regression Analysis of Flow Velocity and Discharge for Grass Land

Discharge	Coef.	Robust Std. Err.	t	P>t	[95% Conf.	Interval]
Velocity	0.047857	0.007076	6.76	0	0.031539	0.064174
_cons	-0.0029	0.001627	-1.78	0.113	-0.00665	0.000855

Source: Researcher 2021

Therefore, the model specification along the grass land is:

Discharge= 0.047857velocity +(-0.0029)

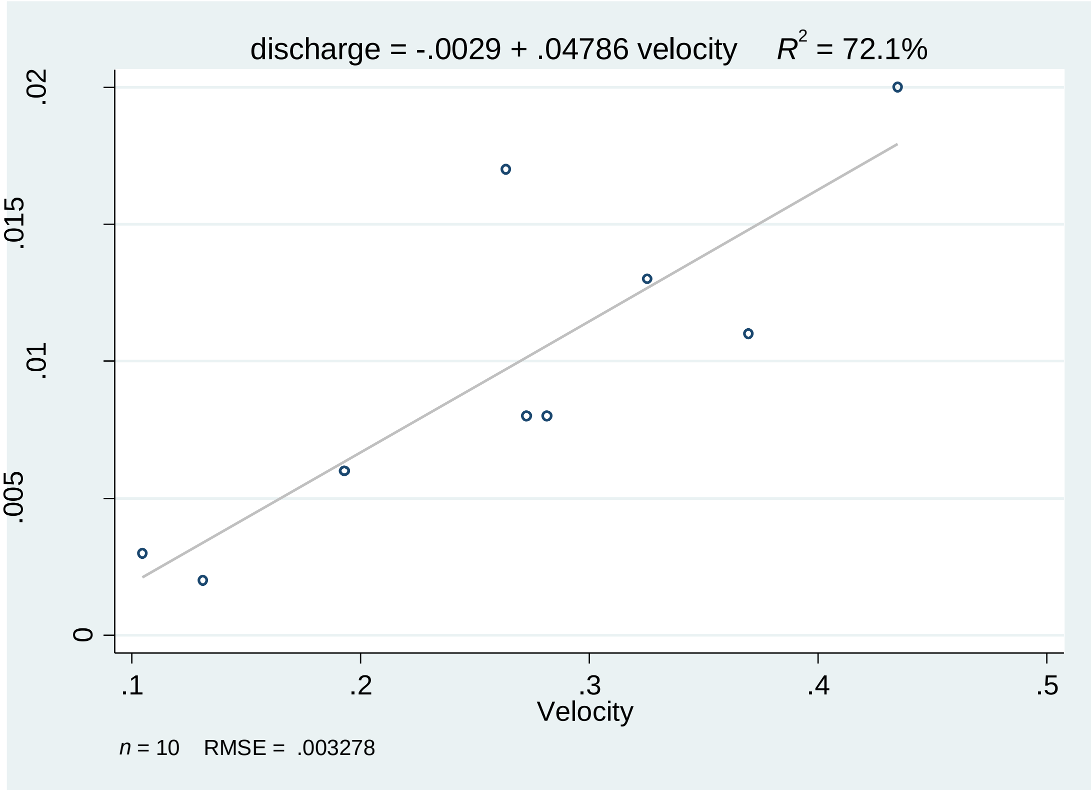

Figure 5: Residual Plot of Discharge (M^3S^{-1}) Against Velocity (MS^{-1}) Along the Grass Land

Source: Researcher 2021

Figure 5 illustrates linear regression model between the independent (Velocity) and predicator variable (Discharge) along the grass land of Maji ya Chumvi stream.

The findings indicate that the predicator variable is well explained by the independent variable as indicated by an r^2 value of 72.13% hence it's a good fit model. The plotted points closely follow the linear pattern at the beginning of flow measurements but slightly digress and scatter towards the end. This is typical of a sensible association between the variables **(**Yang, 2022). The coefficient value of the constant is -0.0029 which implies that for every one unit increase in the discharge of water carrying along sediments, the flow velocity decreases by 0.0029 cubic metres. Deductions can also be made that a significant relationship between velocity and discharge along the grass land exists since the p-value of 0.0001 is less than 0.05 level of significance. With regards to this study therefore, it reveals that grass land LULC type significantly affects sedimentation processes in Mwache River basin at 95% confidence level with a high coefficient of determination of 72.13% which is the proportion of discharge influenced by the flow velocity.

4.5.3 Analysis of sediment yield data from annual crops (Mwache dam site stream):

Velocity and discharge from Mwache dam site stream point was recorded in table 12 and a linear regression analysis conducted.

Table 10: Flow Velocity and Discharge for Annual Crops (Mwache dam site stream)

Discharge	0.008	0.020	0.037	0.061	0.068	0.066	0.054	0.019	0.033	0.032	0.013
Velocity	0.1842	0.2479	0.3414	0.4349	0.5700	0.5908	0.6750	0.2894	0.4869	0.4453	0.3726

Source: Researcher 2021

Number of observations = 11

F (1, 9) = 30.86

Prob > F = 0.0004

R-squared = 0.6686

Root MSE = .01321

Table 11: Linear Regression Analysis of Flow Velocity and Discharge for Annual Crops

Discharge	**Coef.**	**Robust Std. Err.**	**T**	**P>t**	**[95% Conf.**	**Interval]**
Velocity	0.116659	0.0209998	5.56	0	0.069155	0.164164
_cons	-0.01183	0.0080643	-1.47	0.176	-0.03007	0.006414

Therefore, the model specification along the annual crops is:

$$Discharge= 0.116659velocity +(-0.01183)$$

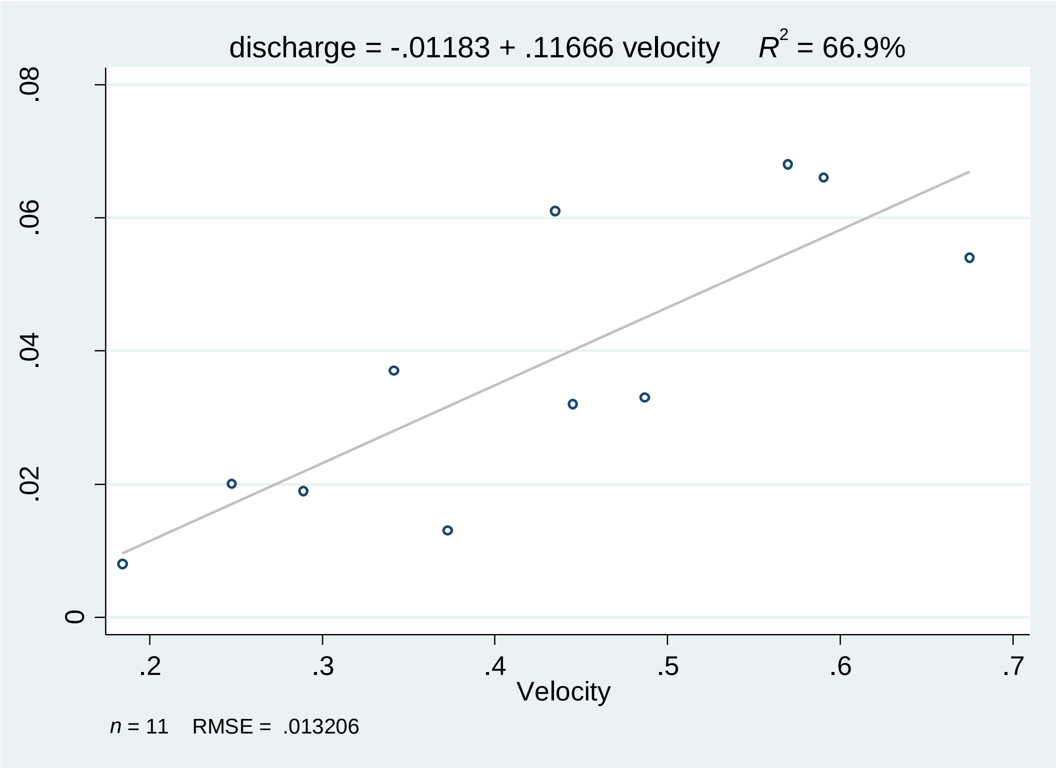

Figure 6: Residual Plot of Discharge (M^3S^{-1}) Against Velocity (MS^{-1}) along the Annual Crops

Source: Researcher 2021

Figure 6 illustrates linear regression model between the independent (Velocity) and predicator variable (Discharge) along the annual crops land-use-land-cover type of Mwache dam site stream

The findings indicate that the predicator variable is well explained by the independent variable as indicated by an r^2 value of 66.86% hence it's a good fit model. There is a reasonable correlation between the explanatory and response variables since the plotted points closely scatter around the line of best fit throughout the flow measurement (Yang, 2022). The coefficient value of the constant is -0.01183 which implies that for every one unit increase in the discharge of water carrying along sediments, the flow velocity decreases by 0.01183 cubic metres. Deductions can also be made that there is a significant relationship between velocity and discharge along the annual crop land since the p-value of 0.0004 is less than 0.05 level of significance.

These findings show the relevance of the study as it proves that annual crops LULC type significantly affects sediment yield in Mwache River basin at 95% confidence level and with a high coefficient of determination of 66.86%, which is the proportion of discharge influenced by the flow velocity.

4.6 Estimated life expectancy of Mwache multi-purpose dam

At the dam site, the discharge in m^3s^{-1} was 0.411 and the total suspended solids in mgl^{-1} was 600

600mg/0.411m3/sec
600mg/1m3/sec =600/0.411 =1459.85mg/m3/sec
Per year =1459.85x31536000=46037829600mgs

The estimated annual sedimentation rate of the dam was **46.038tons/year**. The Mwache multi-purpose dam rests on 250,000 hectares of land, with a 127million m^3 effective storage capacity and reservoir dead storage (DSV) of 9milion m^3 (Mwache RAP 1, 2014), and the sediment volume (SV) was 35,510m^3.

The annual sediment volume of 46,038m^3 implies that the computed sediment volume of 35,510m^3 was accumulated in a duration (T) of 0.8 years. From equation 3.7, sediment deposition (SR) was 44,387.5 and therefore the estimated life expectancy (LE) of the dam was 202.8 years. These results are in sync with findings from the Mwache multi-purpose dam design report of the year 2014 which estimated the sediment deposition rate at 25.8 million m^3 after 50 years, and 43.6 million m^3 after 100 years without any catchment area treatment or reservoir sediment flushing measures. Therefore, with extrapolation that the dam's life expectancy was 291.3 years.

The estimated life expectancy (LE) of 202.8 years indicates that the dam is economically viable. However, with the changes in LULC practices in the basin, coupled with the current ever-increasing adverse effects of climate change, the life expectancy might reduce (Sarwar, 2013). Since various measures have already been initiated to mitigate sediment yield within Mwache River basin (Options study for sustainable management and conservation of Mwache catchment Report, 2017), there is need to increase the sediment yield monitoring frequency specifically along the Mwache dam site stream to establish effectiveness of the mitigation measures as well as enable prompt and proactive review.

4.7 Testing of hypothesis

H_o: Variations in land use and land cover types in Mwache River basin does not affect the overall sediment yield.

The discharge from two LULC types were recorded in table 12 for purposes of conducting a student's t-test

Table 12: Discharge from shrubland and grassland LULC

Shrubland	Grassland
0.003	0.011
0.01	0.017
0.018	0.006
0.028	0.008
0.031	0.02
0.036	0.013
0.043	0.008
0.037	0.002
0.023	0.003
0.005	0.006

Table 13: Student's t-test analysis

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
Shrubland	10	.0234	.0044352	.0140254	.0133669	.0334331
Grassland	10	.0094	.0018511	.0058538	.0052125	.0135875
diff	10	.014	.0049419	.0156276	.0028207	.0251793

mean(diff) = mean (Shrubland - Grassland) t = 2.8329
Ho: mean(diff) = 0 degrees of freedom = 9

Ha: mean(diff) < 0 Ha: mean(diff) != 0 Ha: mean(diff) > 0
Pr (T < t) = 0.9902 **Pr (T > t) = 0.0196** Pr (T > t) = 0.0098

The p-value of 0.0196 is less than 0.05 significance level consequently the null hypothesis is rejected in favour of the mean of the different LULC for both shrubland and grassland are centred around zero. Deductions are thereby made that the means are statistically dissimilar from each other at any level above 1.96%. Therefore land-use-land-cover variations in Mwache River basin affects sediment yield.

4.8 Discussion of Results in relation to the objectives

This section examines the three specific objectives of this study into details while relating them to other similar studies to enable the researcher draw deductions with adequate scientific and academic justifications.

4.8.1 Objective 1 – Analysis of sediment yield from Mwache River basin

The data collected from the three streams displayed that there exists a link between the response and the predictor variables. The strongest relationship from the regression analysis and as depicted by the coefficient of determination r^2 values was from shrub land at 92.65%

followed by annual crops at 72.13% and the least was grass land at 66.86%. From the closeness of plotted points to the line of best fit, shrub land portrayed a robust correlation between response and predictor variables since the plotted points were closest to the regression line. Grass land and annual crops portrayed a moderate relationship since the points in the former LULC type were very close to the line of best fit at the beginning and later on scatter slightly away from it, while the latter had all the points scattered not so close but around the regression line throughout the flow measurements (Yang, 2022).

These results therefore imply that sediment yield is a big issue within Mwache River basin and therefore efforts to control and minimize excessive sediment yield should be intensified. From a study by Gracia-Ruiz *et al*., 1995, such measures for similar land use-land cover types would include, but not limited to reduction of area under annual crops and replacing it with grass land as well as expansion of bushes in areas formally under annual crops.

4.8.2 Objective 2 – Comparative Contribution of different LULC types to sediment yield in Mwache River basin

Results from this study suggests that LULC type affects the overall sediment yield from Mwache River basin. The results show that the highest yield comes from annual crops at 21.306 tons followed by shrubland at 20.235 tons and the least coming out from grass land and 2.782 tons.

The findings are in concurrence with a study by Gashaw *et al*., 2019 on modelling influences of LULC changes on rate of sedimentation in Ethiopia’s Andassa watershed in upper Blue Nile basin. They found out that LULC had a huge contribution to sediment yield. The contribution of cultivated land was 1,199,873 tons, shrubland 66,541 tons and grassland 25,935 tons.

The findings from the current research study are further validated by the adoption of the alternative hypothesis stating that variations in LULC affects the overall sediment yield from Mwache River basin.

The results from these two studies also agree that annual crops, which is similar to cultivated land LULC type, have the highest sediment yield therefore sediment yield mitigation measures and monitoring frequency should be intensified in this land use-land cover type. The second highest yield according to both studies is shrubland and the least was grassland.

4.8.3 Objective 3 -Estimation of the life expectancy of Mwache Multi-purpose dam

As adopted by Gill, (1979), Murthy, (1980) and cited by Froehlich *et al*., 2017, the lifespan of a reservoir is determined based on five approaches; design specifications, project plan, economic viability, usability and full life. The full life stage is when the dam is completely silted up and that all the other four approaches have been satisfied.

From the findings, the life expectancy of the dam meets the economic viability. However, the mitigation measures put in place to address sedimentation should be enhanced and periodically reviewed due to the erratic nature of the rains and the degrading land use practices which expose the soils to erosion. Changes in climatic condition is also projected to cause extreme meteorological events such as extended periods of drought and increased frequency of flush floods. Such like future events coupled with changing land uses within the catchment area, future sediment yield studies are necessary to track the impacts and proactively redesign the mitigation measures to ensure the dam maintains its economic viability for a longer period.

According to Zhao *et al*., 2016, combination of structural and land use change sediment yield mitigation measures produced the best results in terms of the percentage of sediment yield reduction. Structural measures include construction of check dams and other structures like terraces, while land use change measures would include measures such as reduction of area under annual crops and replacing it with grass land as well as expansion of bushes in areas formally under annual crops (Gracia-Ruiz *et al*., 1995).

Zhao et al., 2016, compared sediment yield reduction by employing land use change against the use of structural measures like check dams. They established that land use change without structural measures reduced sediment yield by 31.4% while structural measures without land use change reduced sediment yield by 51.9%. A combination of both measures reduced sediment yield by approximately 80%.

In Mwache River basin, the catchment area under annual crops therefore would require both land use change and structural measures, while catchment under grassland and shrubland would only require the structural measures. However, structural measures need regular monitoring due to accumulation of sediment in the structures making it a costly problem (Zhao *et al*., 2016). Regular monitoring of these control structures is a paramount sustainability measure. It includes monitoring of sediment pass-through, mechanical removal or sediment flushing.

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This section summaries the final deductions of the study. The results arrived at during data collection and analysis have been summarized and tabulated, and at the tail end, recommendations from this research study and suggestions for future studies have also been listed.

5.1 Summary of main research findings

The mean velocity was highest on shrubland followed by annual crops and grass land had the least, while discharge was highest on annual crops followed by shrub land and grass land had the least. On the total suspended solids, the highest amount was recorded from shrub land followed by annual crops and finally grass land. Finally, the estimated sediment yield was highest from annual crops followed by shrub land and finally grass land. The estimated annual sediment yield was 46.038 tons/year while the estimated life expectancy of the Mwache multi-purpose dam was 202.8 years (202 years and 292 days).

Table 14: Summary of research findings

LULC	**Stream cross-section area (m^2)**	**Mean velocity** (m/s)	**Discharge** (m^3/s)	**TSS** (mgl^{-1})	**Sediment Density** (kg/m^3)	**Estimated Sediment volume** (m^3)	**Estimated annual sediment yield** at the dam site (Tons/year)	**Mwache Multi-purpose Dam L.E** (years)
Shrub land (Chigutu stream)	0.354	0.597	0.2342	1000	1	20,235		
Grass land (Maji ya Chumvi stream)	0.336	0.257	0.092	350	0.35	7948.571		
Annual crops (Mwache dam site stream)	0.924	0.422	0.411	600	0.6	35,510	46.038	202.8

Sources**: Researcher 2022**

5.2 Conclusions

The estimated life expectancy of the Mwache multi-purpose dam was 202.8 years, approximately 202 years and 292 days, implying that the project is viable. However, simple linear regression analysis from all the three LULC types under study exhibited strong coefficient of determination, r^2 percentages, i.e., annual crops 66.86%, shrub land 92.65% and grass land 72.13%. This implies that most of the sediment yield from the Mwache River basin was influenced by the various LULC types. The null hypothesis which stated that variations in LULC types within Mwache River basin does not significantly affect the sediment yield, was tested using student's t-test analysis. The null hypothesis was rejected because the p-value of 0.0196 was less than the 0.05 confidence level. This vindicated the supposition that the variations in LULC types within the Mwache River basin had significant effect on the sediment yield.

The mammoth volume of sediments entering the streams from catchment areas under the three LULC types i.e., 35,510m^3 from annual crops, 20,235m^3 from shrub land and 7948.571m^3 from grass land, also implies that sedimentation within Mwache River basin is still a concern albeit the catchment protection and conservation initiatives already installed to address soil loss and sedimentation. With the significant effect the LULC types have on sediment yield, it is imperative to align the sediment yield monitoring plan and frequency of the ongoing sediment yield mitigation measures with the various LULC types. Highest monitoring frequency should be dedicated to annual crops followed by shrub land and finally grass land.

5.3 Recommendations

1. The Water Resources Authority should enhance their periodic data collection at the river gauging stations to gather enough data on Total Suspended Solids analysis which will enable plotting of sediment rating curve that will show the link between discharge and the sedimentation directly without the use of proxy indicators. Although adequate data is required for this, it will aid in sediment monitoring planning and aid in pro-actively reviewing of sediment yield mitigation measures.

2. The Coast Development Authority in their sediment yield mitigation measures monitoring plan, should monitor the ongoing measures according to the LULC types. High monitoring frequency should be dedicated to catchment areas under annual crops followed by shrub land and finally grass land in order of priority.

3. Institutions of learning particularly University of Nairobi's department of geography, population and environmental studies should consider undertaking researches using computer simulation and mathematical models and incorporate elements like soil types, slope and length and intensity of rainfall to establish variations in sediment yield from all the 10 LULC types identified during this study to allow for sediment yield monitoring plan and corrective mitigations measures.

5.4 Suggestions for Further Research

To policy makers

1. Sediment yield monitoring plan and monitoring frequency should be a policy item to ensure that approvals for dam and water pan construction projects include a rider imposing that the proponents develop monitoring plans and optimal monitoring frequency based on estimated sediment volumes and land use-land cover types.

To future researchers

1. Studies to establish the effectiveness of the various sediment control strategies put in place within Mwache river basin
2. Use of mathematical modelling to conduct the comparative sediment yield from the three land use types as well as compute the life expectancy of the dam to compare with findings from the gauging approach.
3. Comparative analysis of sediment volumes from the remaining 7 land use-land cover types identified within Mwache river basin.

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APPENDICES

1. Laboratory results certificate for total suspended solids

FORMF/9/1/3

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Physical-Chemical Laboratory Results Certificate

Report Issue Date:	20-01-2020	Sample No: 2568	Year: 2020
Name of Customer:	WRA Mombasa Sub- Region	Date Received:	07-01-2020
Email Address:	-	Type of Sample:	River
Telephone Number:	-	Date of Sampling:	14-11-2019
Sample submitted by:	Dickens	Source of sample:	Muruhe Bridge
Purpose of sampling:	Domestic	Received by:	Nicky Sitati
County:	Kwale		

PARAMETERS	UNIT	ANALYTICAL METHOD	RESULTS	KS EAS 12:2018 STANDARDS (MAX.)
pH	pH Scale	APHA 4500-H^+ B	7.3	5.5-9.5 (6.5-8.5)*
Colour	$mgPt\ L^{-1}$	APHA 2120 B	125	50(15)*
Turbidity	N.T.U	APHA 2130 B	641	25 (5)*
Conductivity (25°C)	$\mu S\ cm^{-1}$	APHA 2510B	543	2500 (1500)*
Iron	$mg\ L^{-1}$	APHA 3500-Fe B	6.1	0.3
Manganese	mgL^{-1}	APHA 3500 – Mn B	<0.01	0.1
Calcium	$mg\ L^{-1}$	APHA 3500-Ca B	22	150
Magnesium	$mg\ L^{-1}$	APHA 3500-Mg B	10	100
Sodium	$mg\ L^{-1}$	APHA 3500-Na B	70	200
Potassium	$mg\ L^{-1}$	APHA 3500-K B	14	50
Total Hardness	$mgCaCO_3L^{-1}$	APHA 2340 C	96	600 (300)*
Total Alkalinity	$mgCaCO_3L^{-1}$	APHA 2320 B	86	500**
Chloride	$mg\ L^{-1}$	APHA 4500-Cl^- B	99	250
Fluoride	$mg\ L^{-1}$	APHA 4500-F^- C	0.3	1.5
Nitrate	$mgNO_3\ L^{-1}$	APHA 4500-NO_3 D	38	45
Nitrite	$mg\ NO_2^-$-$N\ L^{-1}$	APHA 4500-NO_2^- B	<0.01	0.9
Sulphate	$mg\ L^{-1}$	APHA 4500-SO_4^{2-} E	ND	400
Free Carbon Dioxide	$mg\ L^{-1}$	APHA 4500-CO_2 C	36	-
Total Dissolved Solids	$mg\ L^{-1}$	APHA 2510 A	337	1500 (1000)*
Total Suspended Solids	$mg\ L^{-1}$	APHA 2540 D	1000	-

*Maximum limits for treated potable water; **WHO maximum guideline value; APHA: American Public Health Association (2005) - Standard methods for the examination of water & wastewater; "<": value below method detection limit; ND: Not detectable

Comments:

Turbid and Coloured water with high Iron and TSS content. Treatment is recommended for domestic use.

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Rachel Olonga
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Dr. Kenneth K'oreje
Assistant Technical Coordination Manager

The results contained herein apply to the particular sample(s) tested, whose sample number and tests carried out are as detailed in these results. The information contained here reflects the laboratory's findings as at the time of analysis and based on the samples submitted by the client.

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Physical-Chemical Laboratory Results Certificate

Report Issue Date:	20-01-2020	**Sample No: 2574**	**Year:** 2020
Name of Customer:	WRA Mombasa Sub- Region	**Date Received:**	07-01-2020
Email Address:	-	**Type of Sample:**	River
Telephone Number:	-	**Date of Sampling:**	15-11-2019
Sample submitted by:	Dickens	**Source of sample:**	Mwalhe Bridge
Purpose of sampling:	Domestic	**Received by:**	Nicky Sitati
County:	Kwale		

PARAMETERS	UNIT	ANALYTICAL METHOD	RESULTS	KS EAS 12:2018 STANDARDS (MAX.)
pH	pH Scale	APHA 4500-H^+ B	**7.8**	5.5-9.5 (6.5-8.5)*
Colour	mgPt L^{-1}	APHA 2120 B	**2500**	50(15)*
Turbidity	N.T.U	APHA 2130 B	**351**	25 (5)*
Conductivity (25^{0}C)	µS cm^{-1}	APHA 2510B	**549**	2500 (1500)*
Iron	mg L^{-1}	APHA 3500-Fe B	**5.9**	0.3
Manganese	mgL^{-1}	APHA 3500 – Mn B	**<0.01**	0.1
Calcium	mg L^{-1}	APHA 3500-Ca B	**26**	150
Magnesium	mg L^{-1}	APHA 3500-Mg B	**18**	100
Sodium	mg L^{-1}	APHA 3500-Na B	**60**	200
Potassium	mg L^{-1}	APHA 3500-K B	**7.7**	50
Total Hardness	mg$CaCO_3L^{-1}$	APHA 2340 C	**138**	600 (300)*
Total Alkalinity	mg$CaCO_3L^{-1}$	APHA 2320 B	**130**	500**
Chloride	mg L^{-1}	APHA 4500-Cl^- B	**89**	250
Fluoride	mg L^{-1}	APHA 4500-F^- C	**0.3**	1.5
Nitrate	mgNO_3^- L^{-1}	APHA 4500-NO_3 D	**<0.01**	45
Nitrite	mg NO_2^--N L^{-1}	APHA 4500-NO_2^- B	**<0.01**	0.9
Sulphate	mg L^{-1}	APHA 4500-SO_4^{2-} E	**11**	400
Free Carbon Dioxide	mg L^{-1}	APHA 4500-CO_2 C	**8**	-
Total Dissolved Solids	mg L^{-1}	APHA 2510 A	**360**	1500 (1000)*
Total Suspended Solids	mg L^{-1}	APHA 2540 D	**600**	-

**Maximum limits for treated potable water; **WHO maximum guideline value; APHA: American Public Health Association (2005) - Standard methods for the examination of water & wastewater; "<": value below method detection limit; ND: Not detectable*

Comments:

Coloured and Turbid water with high Iron and Total Suspended Solids content. Treatment is recommended for domestic use.

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The results contained herein apply to the particular sample(s) tested, whose sample number and tests carried out are as detailed in these results. The information contained here reflects the laboratory's findings as at the time of analysis and based on the samples submitted by the client.

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Physical-Chemical Laboratory Results Certificate

Report Issue Date:	20-01-2020	**Sample No: 2566**	**Year:** 2020
Name of Customer:	WRA Mombasa Sub- Region	**Date Received:**	07-01-2020
Email Address:	-	**Type of Sample:**	River
Telephone Number:	-	**Date of Sampling:**	14-11-2019
Sample submitted by:	Dickens	**Source of sample:**	Maji Chumvi
Purpose of sampling:	Domestic	**Received by:**	Nicky Sitati
County:	Kilifi		

PARAMETERS	UNIT	ANALYTICAL METHOD	RESULTS	KS EAS 12:2018 STANDARDS (MAX.)
pH	pH Scale	APHA 4500-H^+ B	**7.4**	5.5-9.5 (6.5-8.5)*
Colour	mgPt L^{-1}	APHA 2120 B	**1250**	50(15)*
Turbidity	N.T.U	APHA 2130 B	**205**	25 (5)*
Conductivity (25^{0}C)	µS cm^{-1}	APHA 2510B	**243**	2500 (1500)*
Iron	mg L^{-1}	APHA 3500-Fe B	**5.4**	0.3
Manganese	mgL^{-1}	APHA 3500 – Mn B	**<0.01**	0.1
Calcium	mg L^{-1}	APHA 3500-Ca B	**16**	150
Magnesium	mg L^{-1}	APHA 3500-Mg B	**215**	100
Sodium	mg L^{-1}	APHA 3500-Na B	**3.0**	200
Potassium	mg L^{-1}	APHA 3500-K B	**10.0**	50
Total Hardness	mg$CaCO_3L^{-1}$	APHA 2340 C	**100**	600 (300)*
Total Alkalinity	mg$CaCO_3L^{-1}$	APHA 2320 B	**90**	500**
Chloride	mg L^{-1}	APHA 4500-Cl^- B	**21**	250
Fluoride	mg L^{-1}	APHA 4500-F^- C	**0.3**	1.5
Nitrate	mgNO_3^- L^{-1}	APHA 4500-NO_3^- D	**<0.01**	45
Nitrite	mg NO_2^--N L^{-1}	APHA 4500-NO_2^- B	**<0.01**	0.9
Sulphate	mg L^{-1}	APHA 4500-SO_4^{2-} E	**ND**	400
Free Carbon Dioxide	mg L^{-1}	APHA 4500-CO_2 C	**20**	-
Total Dissolved Solids	mg L^{-1}	APHA 2510 A	**151**	1500 (1000)*
Total Suspended Solids	mg L^{-1}	APHA 2540 D	**350**	-

**Maximum limits for treated potable water; **WHO maximum guideline value; APHA: American Public Health Association (2005) - Standard methods for the examination of water & wastewater; "<": value below method detection limit; ND: Not detectable*

Comments:

Turbid and Coloured water with high Iron and TSS content. Treatment is recommended for domestic use.

Rachel Olonga
Laboratory Analyst

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Dr. Kenneth K'oreje
Assistant Technical Coordination Manager

The results contained herein apply to the particular sample(s) tested, whose sample number and tests carried out are as detailed in these results. The information contained here reflects the laboratory's findings as at the time of analysis and based on the samples submitted by the client.

2. Flow and discharge measurement sheets

COASTAL-ATHI SUB-REGION DISCHARGE MEASUREMENT SHEET

Name of Observer: WRA CAIRO TEAM / BAKARI Date: 14-11-2019

River: MAJI YA CHUMVI RGS:

GPS: X 542217 Y 9580806 Alt 167 m

GHT at Start: 0.06 M Time at start: 11.13 Am.

GHT at Finish: 0.06 M Time at finish: 11.40AM.

Distance (M)	Depth (M)	Time (sec) Fixed at 30 Sec.	Revolutions (No)	Distance from surface	Remarks
3.7	0.00				WERB
3.4	0.10		40.0	SV	
3.1	0.21		28.0	SV	
2.8	0.10		20.0	SV	
2.5	0.10		29.0	SV	
2.2	0.15		40.0	0.6	
1.9	0.13		35.0	SV	
1.6	0.09		30.0	SV	
1.3	0.04		13.0	SV	
1.0	0.10		10.0	SV	
0.7	0.10		20.0	SV	
0.4	0.00				WELB

Sediment Sample: Taken at 12.10pm
Estimated gauge height → 0.60M
Width at WERB 0.15m
Width at WELB 0.15M
Width at segments 0.30 M

COASTAL-ATHI SUB-REGION DISCHARGE MEASUREMENT SHEET

Name of Observer: WRA CASRO TEAM/ BAKARI Date: 14-11-2019

River: CHIGUTU - MURUVUMU BRIDGE RGS:

GPS: LATITUDE: UTM9563790 LONGITUDE: 37M 5237390 Alt 310 M

GHT at Start: MISC M Time at start: ~~14-0~~ 2:05 pm

GHT at Finish: MISC M Time at finish: 2.41 pm

Distance (M)	Depth (M)	Time (sec) Fixed at 30 Sec.	Revolutions (No)	Distance from surface	Remarks
0	0		0	SV	WELB
0.2	0.05		33	SV	
0.4	0.12		45	SV	
0.6	0.18		56	0.6	
0.8	0.22		59	0.6	
1	0.23		63	0.6	
1.2	0.25		68	0.6	
1.4	0.27		75	0.6	
1.6	0.22		79	0.6	
1.8	0.16		66	0.6	
2	0.07		33	0.6	
2.2	0				WERB

Sediment Sample Taken at 2.30pm
Estimated gauge height → 0.74M
Width at WELB 0.1m
Width at Intermediate Segments 0.2m
Width at WERB 0.1m

COASTAL-ATHI SUB-REGION DISCHARGE MEASUREMENT SHEET

Name of Observer: WRA CASRO TEAM / BAKARI .... Date: 15-11-2019

River: MWACHE - MWACHE BRIDGE .... RGS: ....

GPS: X 556777 Y 9563653 Alt 75m.

GHT at Start: MISC M .... Time at start: 12:21 pm

GHT at Finish: MISC M .... Time at finish: 12:43 pm

Distance (M)	Depth (M)	Time (sec) Fixed at 30 sec.	Revolutions (No)	Distance from surface	Remarks
0.0	0.00				WELB
0.4	0.11		19.0	SV	
0.8	0.20		22.0	0.6	
1.2	0.27		31.0	0.6	
1.6	0.35		40.0	0.6	
2.0	0.30		53.0	0.6	
2.4	0.28		55.0	0.6	
2.8	0.20		63.0	0.6	
3.2	0.16		26.0	0.6	
3.6	0.17		45.0	0.6	
4.0	0.18		41.0	06	
4.4	0.09		34.0	0.6	
4.8	0.00				WERB

Sediment Sample: Taken at 12.40pm

Estimated gauge height → 0.8m

Width at WELB 0.20m

width at Intermediate Segments 0.40m

Width at WERB 0.20m