RESERVOIR SEDIMENTATION IN AN ARID AND SEMI-ARID RIVER BASIN: A CASE STUDY OF KALUNDU DAM IN KITUI COUNTY, KENYA

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DECLARATION

I understand that plagiarism is an offence and I therefore declare that this Master's thesis is my original work and has not been presented to any other institution for any other award.

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ABBREVIATIONS AND ACRONYMS

ADP	**:**	Annual Development Plan
ANOVA	**:**	Analysis of Variance
ASALs	**:**	Arid and Semi-Arid Lands
ASI	**:**	Annual Sediment Load Inflow
ASL	**:**	Annual Sediment Load
ASTM	**:**	American Standards for Testing and Material
ASY	**:**	Area Specific Sediment Yield
CBOs	**:**	Community-based Organizations
CIDP	**:**	County Integrated Development Plan
CGoK	**:**	County Government of Kitui
DEM	**:**	Digital Elevation Model
DMC	**:**	Double Mass Curve
DMCA	**:**	Double Mass Curve Analysis
FAO	**:**	Food and Agriculture Organization
GCM	**:**	Global Climate Model
GIS	**:**	Geographical Information System
GLOVIS	**:**	Global Visualization System
GoK	**:**	Government of Kenya
HDI	**:**	Human Development Index
HEP	**:**	Hydro-Electric Power
ICOLD	**:**	International Commission on Large Dams
IDW	**:**	Inverse Distance Weight
IWRM	**:**	Integrated Water Resources Management
KEWI	**:**	Kenya Water Institute
KMD	**:**	Kenya Meteorological Department
KNBS	**:**	Kenya National Bureau of Statistics
LANDSAT MSS	**:**	Land Soil and Terrain Satellite Multispectral Scanner System
LANDSAT	**:**	Land Soil and Terrain Satellite
LULC	**:**	Land Use Land Cover

MAM	**:**	March, April, May
MJ	**:**	Mega Joule
MODIS	**:**	Moderate Resolution Imaging Spectro-radiometer
MUSLE	**:**	Modified Universal Soil Loss Equation
NACOSTI	**:**	National Commission on Science, Technology and Innovation
NASA	**:**	National Aeronautics and Space Administration
NGOs	**:**	Non-Governmental Organizations
NSE	**:**	Nash Sutcliffe Efficiency
NWCPC	**:**	National Water Conservation and Pipeline Corporation
NWMP	**:**	National Water Master Plan
OND	**:**	October, November, December
PAI	**:**	Population Action International
RGS	**:**	River Gauging Station
RSC	**:**	Reservoir Storage Capacity
RUSLE	**:**	Revised Universal Soil Loss Equation
SWAT	**:**	Soil Water Assessment Tool
TE	**:**	Trap Efficiency
TSSC	**:**	Total Suspended Solids Concentration
USDA-ARS	**:**	United States Department of Agriculture- Agricultural Research Service
USGS	**:**	United States Geological Society
USLE	**:**	Universal Soil Loss Equation
WCD	**:**	World Commission on Dams
WRA	**:**	Water Resource Authority
WRUA	**:**	Water Resources Users Association

ABSTRACT

In Kenya, several water reservoirs located in arid and semi-arid lands (ASALs) are undergo the trouble of accumulation of sediments. Kalundu Dam in Kitui County is a typical reservoir located in ASAL that has been experiencing periodic siltation since 1950s when it was commissioned. However, the patterns of siltation within the dam including the hydrological processes influencing sedimentation processes have not been investigated in this reservoir as with other reservoirs in Kenya's ASALs. Lack of data on the hydrological processes and land use practices has narrowed execution of strategies for controlling sedimentation in ASAL reservoirs. The objective of this study was therefore to determine the hydrological influences and land use practices that have led to silt accumulation in Kalundu reservoir in the period 2000-2021. Datasets used in this study included: (i) hydrological data that was obtained from three (3) sampling stations located along Kalundu River and three (3) stations in the reservoir; (ii) sediment samples from various locations in the reservoir; (iii) reservoir bathymetric survey; (iv) satellite data for land use and land cover (LULC) change and (v) household water uses data that was obtained through questionnaire survey. Remote sensing tools and the Modified Universal Soil Loss Equation (MUSLE) model were used in spatial analysis and estimation of soil loss, respectively. The methods of data analysis that were used in this study included descriptive statistics, regression and correlation analyses. The results of the study showed that the total amount of sediment discharge into the reservoir during both short and long rainy seasons were 43,121.53 m^3/yr (64,360.49 ton/year). The trap efficiency of the reservoir was higher during the long rainy season (55.91%) as compared to the short rainy season (47.73%). This difference was attributed to relatively low river discharge experienced during the long rainy season that leads to limited flushing of sediments out of the reservoir. The analysis of bathymetric data showed that the storage capacity of Kalundu Dam had decreased from 500,000m^3 in 2013 to 149,902m^3 in 2021 with an estimated sedimentation rate of 65,317 tons/yr; and trapping efficiency of 55%. The analysis of particle size distribution of the sediments deposited in the reservoir showed that fine sediments were mostly deposited at the middle section (clay 36%) and coarser sediments before entry into the reservoir (sand 48%). The investigation of soil erosion rates using MUSLE showed that highest rates of soil erosion occurs in the lower parts at 51,450 tons/ha/yr. The analysis of land use and land cover showed that croplands and built-up areas have increased significantly within a period 20 years (2000-2020). Poor farming practices and clearing of natural vegetation have strongly contributed to the increased sedimentation of the dam in the period from 2010 to 2020. This resulted to high water turbidity that subsequently reduces socio-economic benefits and the livelihood of the local community. The study emphasizes the need for implementation of comprehensive soil and water conservation strategies in sub-basins that forms important catchment areas for reservoirs constructed in ASALs and especially for sustainability of Kalundu Dam reservoir.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Reservoir sedimentation as a result of accelerated rates of soil erosion is a great mess influencing water resources development in arid and semi-arid lands (ASALs) of Africa including Kenya. The problem is particularly prevalent in small reservoirs that are important sources of water for irrigation, domestic water and livestock watering. However, little is known about the dynamics of sedimentation in such reservoirs and the extent to which they compromises the goals of providing water to rapidly increasing population particularly in rural areas. The examination of the dynamics and key drivers of sedimentation in such lands is therefore important for sustainable water resources development and management. This is particularly so given that climate change has recently become a major factor affecting rainfall amount and distribution in ASALs which in turn affects spatial temporal distribution of land use and land cover that subsequently determines the rates of soil erosion and therefore volume of sediments that can be transported by seasonal rivers that usually flow for a short period during rainy season (Kitheka, 2017; Kitheka, et al., 2022).

The highest loads of suspended sediment were noted in the sub-basin draining arid and semi zone (Mbagathi and Stony Athi). The zones are characterized by intensive livestock grazing, relatively low mean annual rainfall (568–964 mm) and degraded savannah grasslands. The lowest loads of suspended sediment were measured in the high altitude high rainfall (1210 mm) sub-basins (Ruiru) that is characterized by settlements, dense forest cover and mixed farming. Stony Athi and Mbagathi sub basins draining semi-arid zone with grasslands and livestock grazing showed highest sediment production per unit area (Kitheka, et al., 2022). Increased soil erosion and transfer of silt by seasonal rivers during rainy seasons is a major threat to the long term sustainability of small reservoirs located in ASALs (see also Nishigaki et al., 2017).

The landscapes that are deforested, poorly cultivated and barelands are more susceptible to high rates of soil erosion (Defersha and Melesse, 2012). Agricultural lands located in

ASALs experience reduced productivity due to lose of important nutrients and soils as a result of high rates of soil erosion. Water erosion moves silt to the lower stream via river transfer and these sediments can be deposited in reservoirs constructed across rivers. The sediment load that includes suspended sediment load, is considered to be one of the major causes of water pollution in the streams and reservoirs (Kondolf, et al., 2014). The pollution which is accompanied by high turbidity and high rates of siltation of the reservoirs is usually extra acute in early times of the rainy season (Kitheka, et al., 2022). In a study done by Arthurton, et al, (2008) showed that in the adjoining undammed Athi-Sabaki system, it indicated a marked increase in both water flow and sediment discharge.

Worldwide, the aim of constructing numerous water reservoirs was to offer lots of services such as electric power generation, irrigation, flood control and water supply to serve the ever-growing population and to better communities' livelihoods in areas where normal water supply is not possible due to high operational and infrastructure development costs (WCD, 2000). Accumulation of silt in reservoirs can usher major threats on small water reservoirs where the design capacity is often limited. Steady and rapid accumulation of silt in such small water reservoirs unfavourably influence their usefulness and limits all the benefits associated with them including the supply of water to local communities (Setegn et al., 2010). In addition, the degradation of water quality due to high concentration of suspended sediments and high turbidity often limits the extent to which reservoir can be used for domestic water supply, recreation and sustainability of aquatic ecological systems. This is particularly so in ASALs where surface water sources are usually limited.

Numerous elements are accustomed to supplying of silt in reservoir. Nonetheless, land use and land cover is the greatest contributing element. Land use change that may be driven by cutting down trees, agriculture, mining, industrial, or residential areas development can seriously change the hydrologic response of sub-basins via changing of passageways and rates of water movement in catchment areas (Maloi, 2016). The resulting hydrologic unevenness can usher short and long-term effects including escalated lower stream flooding, minimized durable groundwater regeneration and maximized soil erosion rates that subsequently leads to high sedimentation in surface water bodies (Walling, 2005; cited in Walling, 2009). Therefore, understanding how land use and land cover change affects catchment hydrology, soil erosion processes and reservoir sedimentation is important for enabling policy makers to formulate and implement effective and appropriate response strategies for minimizing undesirable effects of land conversions. Improper land use and ecosystem management practices often contributes to increased land degradation leading to increased soil erosion rates that subsequently leads to reduced reservoir storage capacities (Gebiaw et al., 2017).

Various land use practices meant to increase crop productivity and food security may also enhance soil erosion process which in turn could affect the quality of surface water resources including reservoir storage capacity. Some previous studies have shown that reservoir sedimentation can greatly reduce the storage capacity of surface water reservoirs (White, 2010). For instance, a study on the rates of sedimentation within Masinga dam in Eastern Kenya have shown that reservoir sedimentation is largely attributed to increased agricultural activities upstream particularly on steep slopes in the watersheds. The hydrologic characteristics of the river flow is also important (Bunyasi et al., 2013; Njogu and Kitheka, 2019; Kitheka, et al., 2022, Kitheka, et al., 2002).

A study of soil erosion and reservoir sedimentation was undertaken in Nguu Tatu catchment in the north-east of Mombasa (Kitheka, 1992). This study linked high rates of soil erosion to the rapid rates of sedimentation within the Nguu Tatu reservoirs (Kitheka, 1992). The study identified rainfall amount and intensity, ground cover, length /surface runoff depth, rock /soil type and slope gradient as the factors that influenced soil erosion rate in the catchment. Livestock grazing was found to be the main land use type in the catchment (Kitheka, 1992). The rate of soil erosion was found to depend on the livestock grazing intensity. The study noted high rates of soil erosion to be responsible for siltation of the small reservoirs found in the catchment (Kitheka, 1992).

Within Masinga reservoir, it has been argued that heavy sedimentation is seriously affecting the hydro-electric power generation, water supply and irrigation functions of the dam due to the increasing land use change in the upper Tana Basin (Mutua et al., 2005; Njogu and Kitheka 2017). Other studies undertaken in the Upper Tana Basin have also shown that sediment yield has major implications on the sustainability of Seven Folks Hydro-Electric Power (HEP) dams and water resources development projects (Bunyasi et al., 2013). Changes in sediment yield have been attributed to land use change and rainfall variability in the basin (Njogu and Kitheka 2017). Variability of rainfall is an important factor influencing river discharges in Upper Tana basin which in turn influence the sediment yield in the catchment. The increasing trend in rainfall and sediment yield in the basin have been associated with land use practices and climatic change (Njogu and Kitheka, 2017).

Considering that soil erosion and reservoir sedimentation result from convoluted interlinkages between various elements that are site-distinct and out of site ambience, systemized kinds of reactions have been found to be inadequate. It is therefore important to carryout studies on specific basins so that specific factors determining the association between sediment loads and river discharges can be determined. This is essential for formulating specific recommendations for addressing the problem of reservoir sedimentation, particularly in ASALs where the problem can lead to rapid loss of reservoir design capacity and associated benefits. Overall assertion concerning land/water interlinkages require to be constantly interrogated to find out if they constitute the finest at hand particulars and can brace decision making exercises (FAO, 2002). This study therefore sought to investigate the extent to which the hydrology of Kalundu River has been modified by the land use and land cover changes and how these changes have in turn contributed to increased sedimentation within the Kalundu Dam reservoir. The purpose of the study is generally to provide information on how small water reservoirs in ASALs are rapidly affected by siltation and how this problem can be linked to land use and land cover change in sub-basins to which the reservoirs receives water and sediments. It is expected that this information would inform future processes for planning and construction of small-scale reservoirs in ASALs for water supply, irrigation and livestock watering.

1.2 Statement of the problem

Reservoir sedimentation is a great drawback affecting numerous small-scale reservoirs located in arid and semi-arid lands (ASALs) of Africa and Kenya in particular. High rates of sedimentation have in the past been linked to high rates of soil erosion in catchment area of rivers draining into surface water reservoirs. High rates of reservoir sedimentation can seriously affect the benefits associated with dams. The rapid accumulation of terrigenous sediments can drastically reduce the original design capacity of dams leading to loss of many benefits associated with reservoirs. Many reservoirs in Kenya are experiencing this problem and end up getting filled with sediments rapidly thus shortening their useful life span. This negatively affects their functionality (Oludhe, 2012). Previous studies have shown that reservoir sedimentation can seriously reduce reservoir benefits such hydro-electric power generation capacity, management of lowerstream floods and water supply to urban and rural areas (Oludhe, 2012).

The Kalundu dam reservoir in Kitui County, which is among the many reservoirs situated in the arid and semi-arid lands of Eastern Kenya is experiencing rapid sedimentation due to processes taking place within its catchment. The dam is situated in a semi-arid region and therefore its sustainability is of considerable significance to the neighbourhood people who hinge on it. This dam serves as a source of water for different uses such as watering livestock, irrigation, water for construction of buildings, fishing and domestic use among others. The dam also suffers from eutrophication due to the input of sediment-bound nutrient input originating from the cultivated areas within Kalundu sub-basin, thus reducing the elegant merit linked with it. Increased eutrophication has been attributed to increased inflow of sediment-bound nutrient into surface water reservoirs (Mwaura 2003).

The rapid sedimentation in Kalundu reservoir threatens the functional viability of the dam. The huge costs incurred for rehabilitation of the dam can be minimized if appropriate measures are put in place to minimize sedimentation of the dam. The local community which is dependent on the dam is likely to suffer from socio-economic effects including reduction of water available for irrigation which can lead to increased poverty levels due to reduced income generated from irrigation farming activities, unemployment and conflicts over scarce water resources particularly during dry seasons (see also Terer et al., 2004). There is also possibility of major impacts on recreation since the reservoir is an important recreational ground.

Local communities who also depends on the reservoir for fishing activities will also be affected if the reservoir is completely silted up, a scenario which this study demonstrates is possible in a period of less than 5 years if no interventions are implemented as a matter of urgency. These potential impacts motivated the need for this study to demonstrate how reservoir sedimentation occurs and how it is accelerated by land use and land cover change in the Kalundu River sub-basin. There is also limited data and information on the reservoir sedimentation in ASALs and hence this study fills the existing gaps in as far as information on the linkage between sub-basin soil erosion rates and reservoir sedimentation is concerned. The study also provides information on how reservoir sedimentation in ASALs affects local communities.

1.3 Objectives of the Study

The following were the general and specific objectives of the study.

1.3.1 General Objective

The general objective of the study was to determine the extent to which hydrological dynamics associated with land use and land cover conversions influences siltation of reservoir in Kalundu dam.

1.3.2 Specific objectives

The specific objectives of the study were as follows:

i. Determine the relationship between river discharge and sediment yield in Kalundu River sub- basin for the period 2013-2021.
ii. Establish the relationship between reservoir sedimentation rates and sediment budget in Kalundu dam for the period 2013-2021.
iii. Establish the main sources of sediments deposited in the dam for the period 2013-

2021.

iv. Examine the impact of sedimentation in the dam on water use and abstraction by the local community in the period 2013-2021.

1.4 Hypothesis

The hypothesis of the study are as follows:

H_0: There is no significant relationship between river discharge and sediment yield into Kalundu Dam in the period 2013 and 2021.

H_1: There is significant relationship between river discharge and sediment yield into Kalundu Dam in the period 2013 and 2021.

H_0: There is no significant relationship between reservoir sedimentation rates and sediment budget in Kalundu Dam in the period 2013 to 2021.

H_1: There is significant relationship between reservoir sedimentation rates and sediment budget in Kalundu Dam in the period 2013 to 2021.

H_0: Soil erosion in the Kalundu sub-basin is not the cause of Kalundu Dam sedimentation in the period 2013 and 2021

H_1: Soil erosion in the Kalundu sub-basin is the cause of Kalundu Dam sedimentation in the period 2013 and 2021

H_0: Kalundu Dam sedimentation has not impacted water use and or water abstraction to the local community in the period 2013-2021.

H_1: Kalundu Dam sedimentation has impacted water use and or water abstraction to the local community in the period 2013-2021.

1.5 Justification and Significance of the study

Kenya is categorised as a country short supply of water with less than 1000m^3/person/year and renewable fresh water supply of 647m^3 per person per year

(UNEP, 2018). The surface water resources such as rivers are limited in the country. The scarcity of water is a serious problem in Arid and Semi-Arid Lands (ASALs) that cover more than eighty percent of the entire land area of Kenya (World Bank, 2018). To increase water availability in the ASALs, the government of Kenya has invested heavily in the construction of surface water reservoirs as stipulated in objective 6.1 of the National Water Master Plan 2030 (GoK, 2013). These reservoirs are important sources of water for domestic use, irrigation, and livestock watering among others. However, sedimentation is a major threat that reduces the storage capacity and sustainability of such reservoirs in the ASALs. Therefore, conservation of the available water resources is a matter of great importance.

Water sources including dams, reservoirs and lakes being filled with sediments and losing their useful life span is a matter a great concern. Kalundu Dam is one of the dams that experiences high rates of sedimentation and there is no much that has been done at the catchment to salvage the situation. Soil erosion in the sub basin is thought to be the main source of sediments deposited into the reservoir. This study sought to establish whether the rapid sedimentation in Kalundu Dam reservoir is caused by land use changes in the sub basin and whether land use and land cover changes have modified the basin hydrology and sediment yield. The sought to also establish how local communities are affected by high rates of reservoir sedimentation.

Soil conservation practices carried out in Kalundu basin have been inadequate because sources of sediments were unknown and soil erosion control measures have not been directed to appropriate sites. Kalundu sub-basin is a water tower for the Tiva River to which Kalundu River drains into. Under the social pillar of the Kenya Vision 2030 which champions for conservation and recovery of water towers in Kenya to ascertain liveable of water resources in the time ahead, there is need to have sufficient data and information in order to design strategies and or interventions for the protection and rehabilitation of the catchment areas in order to minimize soil erosion and therefore sediment deposition in the reservoirs.

The National Water Master Plan (NWMP) (GoK, 2014) and Vision 2030 have the aim of increasing water availability upto year 2030. Kalundu Dam, by its location in an ASAL area and given that it serves a local community, needs to be given top priority because rapid sedimentation is a major threat to various benefits associated with the reservoir. The management of sedimentation in the dam requires robust management practices that are only possible if data and information is generated to determine the sources and causes of the high sedimentation and also to design appropriate measures. The dam was erected in the 1950's with an initial design volume of 300,000m^3. However, by 1970, the dam had completely silted up due to heavy sedimentation. However, the causes of heavy and rapid siltation of the reservoir have not been investigated. The rehabilitation of the dam was carried out in 2013 mainly through excavation of the deposited sediments and improvement of the spillway.

Rehabilitation of the dam was however not accompanied by comprehensive soil and water management strategies in the sub-basin with the implication that the reservoir continued to receive huge volume of sediments from highly settled Kalundu sub-basin in Kitui Central sub-county. This study is therefore important in that it provides data and information on how land use and land cover changes in the basin have intensified soil erosion process which in turn has led to increased input of sediments into the Kalundu Dam reservoir. The NWMP (GoK, 2014) acknowledges that conversions on land use activities in many of the water towers has brought about changed hydrology and morphology of water sources. There have been no past researches in the study area to determine the factors responsible for high rates of sedimentation in the dam. Understanding these factors is important for designing suitable mediation initiatives to counter the problem and save the useful life span of the dam (Begueria et al., 2003; Walling, 1999).

Surface water reservoirs are important sources of water in Arid and Semi-Arid Lands (ASALs) of Africa and other parts of the world. Small surface water reservoirs are important sources of water for various uses and especially so by the local communities where conventional piped water supply is not possible. The sustainability of such reservoirs is therefore of great importance as they contribute immensely to socio-economic development in rural areas. Studies on reservoir sedimentation are therefore necessary for generating data and information on the potential sources and impacts of sediments deposited in reservoirs. Such studies are also important for determining or formulating strategies for enhancing the long-term sustainability of surface water reservoirs in ASALs. This study will hence be of great importance to many institutions and contributors in Kenya.

First and foremost, the study will be useful to the Government of Kenya and the Government of Kitui County in view of the need to provide data and information on the sustainability of dams constructed in arid and semi-arid lands and mitigation measures that can be implemented to counter the impacts of rapid reservoir sedimentation. Also, the study will establish the specific areas and tributaries within the Kalundu sub-basin that are producing high quantities of sediments leading to rapid sedimentation of the dam. The study will allow the government to channel soil and water management exercises to appropriate sites in the sub-basin. In addition, the government will be in a position to use this study to design and or review policies on the construction of dam ins ASAL regions. It will also enable enforcement of policies governing land use and land cover change including governance of reservoirs in arid and semi-arid areas of the country. Thirdly, the outcome of this research work will contribute to the anatomy of understanding by keeping investors, future researchers, farmers, the public and any other interested party informed on the effects of land use and land cover change on siltation of reservoirs that can be relied upon for decision making. The dam is depended upon by the local community for several uses and therefore its sustainability is imperative in providing water to people to meet the goals of Kenya's Vision 2030.

The outcome of this research work will also help to tell on the upcoming exercises of selecting locations for erecting dams in Kitui County and other water supply projects with the identical characteristics. Also, agencies that formulate policies on sustainable water and land management can rely on the data and information provided by this study. The past rehabilitation of the dam costed the government of Kenya USD 2,470,092.89

(NWCPC (2014), funds which could have been channelled to other development projects in the county. it is expected that present costs of rehabilitating the reservoir would be in terms of billions of Kenya shillings. Therefore, recommendation of this study will help to reduce high costs of desilting the reservoir allowing funds to be channelled to other beneficial development projects in the County. Information and data generated in this study will also enable soil and water management exercises to be directed to appropriate areas of the sub-basin so as to reduce the soil erosion rates in those areas. Targeted soil erosion control measures in the basin have a high possibility of reducing sediment production and discharge into Kalundu Dam reservoir, hence increasing the sustainability of the reservoir.

1.6 Limitations

The researcher encountered some limitations while carrying out the research work. The first limitation was that the study employed satellite images which demanded for powerful computer and access to the internet which increased the cost of data acquisition. Another challenge was the rapid changes in the flow of Kalundu River during rainfall storms. To counter this limitation, more refined sampling frequency was employed during the rainy seasons. However, lengthy tracking of river discharge, sediment load, and sedimentation rates would have been more ideal for a study of this nature.

1.7 Scope of the study

The scope of this research work is limited to the examination of the dynamics of land use and land cover changes and how these changes modifies the stream flow dynamics which in turn affects reservoir sedimentation in Kalundu Dam. Specifically, the overall goal was to find out the hydrological characteristics of Kalundu River, find out the trend of land use practices contributing to soil erosion, and generation of sediments which eventually cause sedimentation of Kalundu Dam. This study did not consider the downstream area of the dam which forms part of the larger Tiva river basin. This study will rely on historical data especially rainfall data from the Kenya Meteorological Department (KMD) for the period from 2013-2022. Satellite images for 2000, 2010 and 2020 of the study area were sourced from online data.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter describes scrutiny of past researches that have been undertaken on sedimentation processes in surface water reservoirs at global, regional, national and at local levels. The information used to prepare this chapter was retrieved from books, published journals, technical reports and government reports. Literature review was done to identify methodologies of studies done elsewhere, establish main findings and conclusions of other similar studies and also to establish gaps in knowledge in as far as reservoir sedimentation studies is concerned.

2.2 Relationship between River Discharge and Sediment Yield

The relationship between river discharge and sediment transport in rivers has been a subject of many studies. Most of the studies have been carried out in the North and South America and Europe (Zhang, 2008, Setegn et al., 2010 Miao et al, 2010, Chen et al., 2001; Subramanian, 1993). These studies have shown that understanding the recent variations of water discharge and sediment load in the global change scenarios is important. A study done for Yellow River basin in China considered annual hydrologic series of the water discharge and sediment load obtained from 15 gauging stations (10 mainstream, 5 tributaries). The method used was Mann-Kendall test to detect both gradual and abrupt change of hydrological series since the 1950s. The results indicated significant decrease for both water discharge and sediment load with $p<0.05$ (Miao et al, 2010). The declining trend was found to be greater with distance downstream. Drainage area was found to have a significant positive effect on the rate of decline (Miao et al, 2010). These studies have shown that sediment load distribution along the Yangtze River was found to be against that observed for the river discharge.

Upper basin was found to produce most of the sediment (Chen et al., 2001). Indian rivers have an annual sediment load that is a little more than 1.2 billions tons (Subramanian, 1993). This is roughly 10% of the global sediment flux to the world oceans. Sediment discharge of Indian rivers have shown pronounced seasonal and spartial variability. Very high yields of sediment discharge have been witnessed in the Himalayan rivers draining the tectonically active belts. The current estimates of sediment yield of the Ganga and Brahmaputra together is about a billion tons/yr[2] compared to the global annual sediment flux of about 15 billions tons/yr[3] (Subramanian, 1993).

Sediment load was found to reduce dramatically by approximately 0.8x108 tons/year in the middle of Yangtze in China. This was as a result of a marked decrease in slope and the change of the river to a meandering pattern running from the upper Yangtze rock sections (Chen et al., 2001). The study revealed that during the dry season, a strong correlation exists between the river discharge and sediment load along the Yangtze drainage basin due to lower flow that carry lower concentration of sediment. A strong correlation was found to exist in the upper Yangtze during the wet season, due to high flows with high velocity that suspends sand on the bed. The Middle and lower Yangtze River sections were noted to have a negative to poor correlation owing to the flow velocity that is unable to keep sand in suspension in these reaches, transporting only fine-grained particles downstream.

The study considered hydrological data for 30 years' period, 1950 – 1980, when many dams were constructed in the upper Yangtze drainage basin. The trend of annual sediment load was found to be decreasing along with slightly reduced annual river discharge at Yichang and Hankou hydrological stations. Sediment load was observed to be quite stable at Datong further lower stream, and not affected by a little lessened discharge. Additionally, the Accumulation of silt at the three hydrological stations registered an increase, which can be associated to silt deprivation on land attributed to escalating human exertion, principally in the upper drainage basin, like cutting down of trees and erection of many dams. Monthly average silt load of these 30 years' throbbed nearly two months behind discharge, insinuating dam-released sediment movement along the whole River basin at the time of high-water stage (Chen et al., 2001).

Following the research done to identify switches in the time series of water and sediment discharge of the Zhujiang (Pearl River), China, water discharge and sediment load series (from the 1950s to 2004) was collected from 9 locations (Zhang, 2008). Annual water discharges were found to be influenced mainly by variability in precipitation. Reservoirs/dams construction was noted to have little influence on water discharge in the Zhujiang Basin. Significant lessening drifts of sediment load was noted at a number of locations in the principal arm of the Xijiang and Dongjiang tributaries. It was revealed that since 1990s, many stations had significant lessening drifts. The lessening sediment load in the Zhujiang results from effects of constructing reservoirs in the watershed. The estimated yearly sediment load from the Zhujiang (in exemption of the delta region) to the estuary has dwindled from 80.4×10^6 tons averaged for the interval 1957–1995 to 54.0×10^6 tons for the interval 1996–2004. The research concluded that, the sediment load dwindled uniformly since the early 1990s in that in 2004 it was nearly 1/3 of the average level of before-90s. The study concluded that discharge of water and sediment load of the Zhujiang in future was going to be greatly influenced by people's activities with a greater extent reservoir advancement, particularly the finishing of the Datengxia hydroelectric project, and an escalation of tree planning policy in the watershed (Zhang, 2008). Water flowing in a river can contain sediments eroded from different places of the Earth. When the quantity of sediments is greater than the river movement capacity, only the quantity that can be transportable will be transported downstream. The rest of the sediments will be settled on the segment (Foster and Meyer, 1977). It is critical to estimate the sediment movement by assessing river discharge at the time of rainfall occcurence for the calculation of lengthy sediment yields from river basins, as a single rainfall occurence may potray the movement of numerous 'normal' years (Wolman and Gerson, 1978). The association between rainfall, runoff and soil deprivation are knotty in nature. Runoff is the medium that carries sediment particles. Intermittent and highest value of runoff influence the peak sediment load in rivers (Shen et al., 2003). Using Global Climate Model (GCM) in Apalachiola basin revealed that during the rainy seasons, highest river flow in the basin ends up producing peak sediment yield (Hovenga, 2015).

Walling (2017) argues that in most tropical basins, when the stream flow increases it leads to an increase in sediment yield. The sediment yield was noted to associate positively with stream flow greatly at the time of rainy seasons (Picouet et al., 2001), (Setegn et al., 2010). However, in the case of Africa and Kenya in particular, only few studies have been undertaken to establish how stream flow influences sediment transport (Setegn et al., 2010; Kitheka et al., 2022; Onyando et al., 2005; Mango et al., 2011). This studies have shown that in Ethiopia, sediment yield associated significantly with stream flow having a coefficient of determination (R^2) that was above 0.5 (Setegn et al., 2010). Studies conducted in Mara River in Kenya established that in an increased stream flow, there is a corresponding increase in the sediments transportation ability of the river (Mango et al., 2011; Baker and Miller, 2013). Another study conducted in Lake Baringo showed that sedimentation of the lake had contributed to lose of its depth by 6.5m in 2003 due to high water yields and high sediment yield generated from the Perkerra basin (Onyando et al., 2005; Mango et al., 2011). Thus, there is urge for proper soil and management practices to safe the situation.

2.3 Relationship between Reservoir Sedimentation and River Sediment Supply

The relationship between reservoir sedimentation and river sediment supply has been a subject of numerous studies globally (Alam, 1999; Alemu, 2016; Schleiss and De Cesare, 2010; Minear and Kondolf, 2009; SedNet, 2004, Setegn et al., 2009; Morris and Fan, 1998). These studies have shown that there is a likelihood that Statewide reservoirs have filled with 2.1 billion m^3 of sediment to date. This has decreased total reservoir capacity by 4.5%. It was estimated that about 200 reservoirs have lost more than half of their initial capacity to sedimentation (Minear and Kondolf, 2009). Loss of reservoir capacity from sedimentation was noted to be difficult to offset by constructing new reservoirs. This is because reservoirs have already been built at most suitable sites in the developed world (Morris and Fan, 1998). Sedimentation of reservoirs has been noted as a serious problem in many regions having high sediment yield. In particular, regions that are geologically active like California (Morris and Fan, 1998). Reservoirs of small-capacity in mountain regions that are eroding rapidly, are most vulnerable to problems of sedimentation. It can be prohibitively expensive to deal with accumulated sediments. For some dam removals, this has been the greatest component of dam decommissioning costs (U.S. Bureau of Reclamation, 2006). Even before reservoirs fill completely with sediment, accumulation of sediments within the reservoir reduces the usable capacity, interfere with outlet works, damage turbines and cause backwater flooding upstream (Morris and Fan, 1998).

Sedimentation of reservoirs reduces their water storage capacity (Alam, 1999; Alemu, 2016) and with time eradicates the ability for flow monitoring which is important for reservoir functionality like flood control, water supply, energy production and navigation (Graf, 1984; Morris and Fan, 1998). A good example is when siltation of a reservoir turns out to be theatrics, the generation of beneficial highhest energy in hydropower resrevoirs is jeopardized (Schleiss and De Cesare, 2010). The way out construction may also get obstructed hinged on the rate of siltation. Other structures not made for sediment travel may be blocked or damaged and hence generate security problems. Also, excess reservoir sedimentation can cause wearing of hydraulic machinery thus leading to their decreased productivity and increased maintenance costs (Faghihirad et al., 2015).

Improper sediment management in water can majorly increase the activity of growth of aquatic plants and lead to entry of the organisms at amounts that accommodate the purpose of the reservoir. Silt fasten or demean contaminants, lessening their bioavailability. But if harmful stuff entangled in the silt are kept in a reservoir, they are likely to form a likelihood hazard to the lower stream valley (SedNet, 2004). Polluted sediments live to be a possible spring of contamination to surface and groundwater, and it is hard to deal with them during sediment withdrawal or lower stream express.

Recently, there has been improvements in data availability. This improved data can now give a meaningful basis for establishing the global pattern of sediment yield and its major controls. The absence of long-term data records for most rivers limits detailed evaluation of the role of anthropogenic activity in modifying the global denudation system. Currently, there is a wide range of evidence to show the importance of such changes, in regard to both increases and decreases in sediment flux. Availability of longer-term data records allows for analysis that provides an important way of assessing the sensitivity of sediment yields to changes in the environmental. This in turn requires the impact of both human activity and climate change to be considered (Walling and Webb, 1996).

In Africa, a number of studies on the relationship between reservoir sedimentation and river sediment supply (Mitchell, 1987; Setegn et al., 2009 Chitata, 2014; Alemaw, 2013). These studies noted that the impacts of silt accumulation in a dam is the reduction of water stocking ability which reduces the yield both in quantity and reliability. In a country like Zimbabwe, the association between reservoir sediment yields exposed to certain risk levels, water storage ratios and the reliability of water inflow, have been well found out by Mitchell (1987). Agricultural activities have severely degraded and transformed Alemaya Lake located in the Eastern highlands of Ethiopia during the last few decades (Setegn et al., 2009). A study carried out by Setegn et al., (2009) used aerial photographs for the years 1965, 1996 and 2002 to quantify and spatially characterize the spatial and thematic information on the major land use and land cover types of the Alemaya watershed. The results revealed permanent decrease of the lake surface area during the period 1965 –2002. The surface area of the lake that was around 393.6 ha in the year 1965 was noted to have reduced to 226 ha within a span of 37 years (Setegn et al., 2009).

Small surface dams/reservoirs in semi-arid areas with erratic and low rainfall perform a principal duty of giving ready and convenient source of water. Management of surface reservoirs require current data and information on loss of reservoir capacity caused by sedimentation. Lack of this data/information pauses challenges to the sustainable surface reservoir management. Chitata (2014) carried out a study to investigate Mutangi reservoir storage deprivation caused by accumulation of silt from 2000-2012 located in Chivi, a semi-arid area in Southern of Zimbabwe. The study employed hydrographic surveys, water depth-capacity and grab sampling methods to estimate the capacity of the dam as of 2012. Trap efficiency was computed using a set of empirical models that relate trap efficiency to the capacity-watershed area ratio and capacity-inflow ratio. It was found that Mutangi reservoir had a trap efficiency of 95% - 98% (av = 96.4%).

The Mutangi reservoir had also lost 37% of its storage capacity caused by accumulation of sediments in 12 years (2000 and 2012). Sedimentation rate was found to be 8539 tons

yr^{-1}, 8265 tons $yr^{-1}$and 9110 tons $yr^{-1}$for the hydrographic survey, water depth-capacity and grab sampling method respectively. The study concluded that the figures had little difference thus any method can be used to compute the rate of sedimentation. The area specific sediment yield (ASY) ranged from 14 -15.5 tons $ha^{-1}yr^{-1}$ (av = 14.956 tons $ha^{-1}yr^{-1}$). It was revealed that with the sedimentation rate observed, the designed reservoir dead level was going to be deprived via siltation in eight years. The useful life span of Mutangi reservoir was projected to be 30 years. The results revealed that conservation exercises that reduce soil erosion, hence sedimentation in these small reservoirs need to be exercised so as to lengthen their lifespan (Chitata, 2014).

Alemaw (2013) assessed the impacts of siltation on small dams and used a small reservoir in the Lotsane Catchment located within the Limpopo Basin of Botswana for the study. The study argues that accumulation of sediments is a great challenge for agricultural dams in Botswana, because it minimizes the storage volume and liveable duration of the reservoirs. The actual activity of siltation begins from the first day of storing water in a reservoir. During design, allowance is created for each reservoir to have a given storage volume, particularly for sediment settlement, called dead storage. A large fraction of the sediment gets settled for numerous years of the reservoir's life in regions other than the dead storage, and this scenario cannot be unwound at an cheaper cost Alemaw (2013). The research focused on assessing annual sedimentation rate by analysing the ongoing siltation activities in a number of dams within Lotsane catchment.

Spatial analysis and modelling researches were done pegged on the Revised Universal Soil Loss Equation and GIS to find out sediment yield and the level of effects of every reservoir for a particular landscape, rainfall and catchment heterogeneity Alemaw (2013). Similarly, ground observations and soil sampling were done so as to find out the elements that caused to accumulation of sediments into the reservoir in the study area. In Lotsane catchment, spatial data on the dams were also gathered from the Ministry of Agriculture, which were used for ground-truthing, GIS-based calculations and model validation (Alemaw, 2013). The findings revealed that the mean sediment rate and sediment delivery ratio were 1.74 t/ha/year and 81%, respectively. These parameters are helpful in estimating lifespan of the dams and have rehabilitation practices associated to siltation challanges (Alemaw, 2013).

A study conducted by Godwin (2011) to investigate the impacts of sedimentation on a reservoir brought about by land use in the time 2009-2010 rainfall season used hydrographic surveys and grab sampling methods at Chesa Causeway Dam in the Upper Ruya sub-catchment of Zimbabwe. The study noted that sediment specific yields at the dam were 774 tons $km^{-2}yr^{-1}$ employing the grab sampling method and 503 tons $km^{-2}yr^{-1}$ using hydrographic survey. The study predicted that the dam will be completely filled up with sediments in the next eleven years and will have a liveable duration of 30 years. It was noted that alluvial gold panning exercises ongoing on the upper region of the stream of the dam could be the ones aggravating the problem. The research concluded that both hydrographic surveys and the grab sampling methods can be employed for estimating sedimentation rates in reservoirs. It also summed up that the liveable duration of reservoirs is majorly depended on the land uses carried out in the upper regions of the stream (Godwin, 2011). This study analysed land use during only one rainfall season, leaving out much information on land use during dry season. It also did not analyse for a lengthy of time to detect any changes on the land use with time thus leaving out crucial information to inform the land use change and sediment production, which will be done in this study. This study employed MUSLE method to evaluate soil erosion in the Kalundu River sub-basin.

In Kenya, only few studies have been undertaken to establish how river sediment supply influences reservoir sedimentation (Mutua et al., 2005) predicted sediment loading into Masinga reservoir and its loss of storage volume. It was roughly calculated that the yearly deprivation of storage volume of the world's reservoirs caused by reservoir siltation was about 0.5 – 1.0% (White, 2000). The sedimentation process proceeds with different trends that depends on characteristics of the river basin and hydrology. The study discussed annual depletion rates for many reservoirs to be greater and sometimes can rise up to 4% or 5%. Consequently, they deprive much of their volume after only 25 – 30 years. The reservoir was noted to face severe sedimentation endangering its functionality which includes hydropower generation, public water supply and irrigation.

The designed sediment load entering this reservoir had been noted to be 3.0 x 10^6 m^3 per year in 1981 (about 1% per annum reservoir reduction). By 2000, annual sediment loading had increased to over 11.0 x 10^6 m^3, nearly 4 times. This increase in sediment load was found to have reduced the designed capacity by more than 15%. The study noted that land degradation had turned out to be more visible with maximized land use change in Masinga catchment over the years, thus endangering the functionality and liveable duration of Masinga reservoir due to erosion and sedimentation Mutua et al., (2005). The study recommended that a study to be done to quantify spatially soil erosion and sediment yield being deposited into the reservoir with a aim to minimize the sediment transport, which will be done in this study for Kalundu Dam.

2.4 Soil Erosion and Sediments Sources in river basins

Researches on soil erosion and sediment production areas including agricultural firms, barelands and built up areas have been carried out in USA, China and Ethiopia (Morris et al., 1998; Verstraeten et al, 2003; Temene et al, 2006; Hurni, 1993). These studies have shown the rate of sedimentation in 1105 U.S. reservoirs has an inverse relationship between pool volume and sedimentation rate. Six percent of the reservoirs with capacities exceeding 12 m^3 had annual storage loss rates exceeding 1 percent, whereas no reservoir larger than 1200 Mm (1 x 106 acre. ft) had an annual rate of storage loss exceeding 0.5 percent (Morris, et al., 1998). There are no accurate data on the rates of reservoir sedimentation worldwide, but, from the available data, Mahmood, (1987) estimated that about 1 percent of the worldwide reservoir water storage capacity is lost annually, equivalent to about 50 km^3 of annual water storage capacity loss. As of 1986, the capacity-weighted average age of world storage was estimated at only 22 years, with about 1100 km^3 of gross storage capacity having been sedimented.

Soil erosion and sediment related problems were noted to affect sustainability of land management and water resource development in many developing countries (Temene et al, 2006). In a study done by Hurni (1993), estimated that soil loss caused by water erosion from cultivated fields amounts to huge tonnage. Although it is believed that catchment erosion is responsible for the loss of valuable nutrients in the soil and rapid storage capacity loss of water in dams, very few studies have been carried out to quantify erosion rates as well as understand the spatial dynamics of erosion – sedimentations and/or siltation processes in relation to dams on a catchment scale (Verstraeten et al, 2003).

Hidayat and Sulistyo (2019) researched on the impacts of land use changes on soil erosion and sediment movement. Soil Water Assessment Tool (SWAT) which is a hydrological model was applied for simulation in this research. The model simulated land use changes, pegged on Land Cover Index Changes, permanent and production scenarios, on soil erosion and sediment transported (Sed-out), in 101,027.250 hectares of the upper stream of Mrica reservoir watershed in Banjarnegara in Indonesia. The results indicated that quantitatively, the rise in land cover index permanent, then a drop in land cover index production had the ability to reduce the value of soil erosion (ton/hectares/year) of around 5.77 to 82.37% and from 5.15 to 75.12% of sedimentary trans-ported (mm/year). Qualitatively, the results showed that positive Extreme scenario could rise the worthness of soil erosion in a number of sub-catchments and the upper stream of Mrica reservoir watershed, from poor condition on the living quality to reasonable, and even acceptable.

According to Hidayat and Sulistyo (2019), other than land use adjustments, water and soil conservation measures, catchment basin governance techniques should be used to lower the rate of soil erosion and sediment transport on rivers. On the other hand, the research never examined the socio-economic effects of the reservoir sedimentation. This information is critical to inform on how the users and the people living around the dam are being affected by the reservoir sedimentation. Also, sedimentation association between the river discharge and sediment load was not done. This calls for a need for it to be done as it will inform on how much sediment load is being carried by the river flow and if there are any mechanisms that can be put in place to reduce sediments being transported to the river as well as water holding practices to reduce high run-off.

A number of studies on soil erosion and sources of sediments in river basins have been carried out in Africa (Wang, 2009; Bruijnzeel, 1990; Jensen, 2005; Meyer and Turner, 1994). These studies have shown that Lushi basin in Lushi County, China, is one of the sub-basins of the Yellow River basin. The basin was noted to be experiencing severe problems associated with soil erosion, especially during the “wet” season. The study employed BTOPMC model to estimate the soil erosion and sediment yield during single rainfall events. Model structure of a modified form of the Universal Soil Loss Equation (USLE) was incorporated in the BTOPMC model structure as a core module of the erosion component. River discharges and sediment yields were simulated using BTOPMC for 29 events in the Lushi basin. The river discharges were found to increase with sediment yield (Wang, 2009).

Land cover can be defined as the physical and biophysical cover over the surface of Earth. This includes how vegetation, water, bare soil and artificial structures are distributed in space. On the other hand, land use is how human beings use or intend to use or manage land cover type through practices like agriculture, forestry and building construction among others. Meyer and Turner (1994), categorized land use and land cover change in to two large groups. First category being changes where it’s a conversion from one cover or use group to another, for instance from forest to grassland. Second category is modification where the change occurs within a single land use and land cover group. For instance, from rain fed cultivated area to irrigated cultivated area caused by conversions in its physical or functional characteristics. Population growth has been the most contributing factor to changes in land use and land cover than other forces particularly in the developing countries like Kenya.

The exact soil loss on an area hinge on the land use after the land is cleared. Bruijnzeel (1990), argues that surface erosion from grassland that has been kept well, forests whose grazing has taken reasonably and soil-conserving agriculture are low to reasonable. Impacts of erosion management practices on sediment yield will be greatly easily detected on the spot. There is a reverse association between basin size and sediment delivery ratio. Thus, the higher the sediments delivered in the dam, the more the dam decreased in size. It is observed that for catchments of many hundred km^2, upgrading may only be observed after a reasonable time lag (decades), caused storage effects (Bruijnzeel, 1990).

Conversion of land from natural forest into agricultural cultivation (Hidayat and Sulistyo, 2019) is an issue that ought to be put into consideration to inform the action to be taken in the future. The art of remote sensing has brought clear understanding of urban growth, land degradation, crops, soils, forests and among other globe characteristics and activities. With Geographical Information Systems, the utilization of helpful secure particulars including digital elevation models (DEM), soil maps and hydrology have also become important (Jensen, 2005). The information is provided by extracting particulars from remotely sensed images into Geographical Information Systems (GIS) platforms. Therefore, the assimilation of data acquired through remote sensing and that from GIS has the ability of improving the correctness of the outcome. According to Murayama (2009), remote sensing and GIS are commonly assimilated recently for analysing and mapping changes in land cover and land use. Satellite image can be used to map and classify land use and land cover (Baker et al., 1991). In remote sensing, supervised classification algorithms are used to derive maps for land use and land cover change into GIS (Tripathi and Kumar, 2012). This study adopted this approach to derive land use and land cover maps for the area under study.

Gimba et al., (2018) assessed the impacts of land use and land cover changes on Kusala Reservoir in Kano state Nigeria for the period of four decades. GIS was used to obtain and analyze satellite imageries such as Landsat MSS 30m resolution for 1973, 1990, 1999 and 2009. The study found that the reservoir had reduced by 44.46 ha (70% drop) and vegetation cover had dropped by 2955.87 ha (46% drop). Built-up area had rose by 630.81 ha (98% rise) while cultivated area had rose by 5042.11 ha (84% rise). Bare land had decreased by 2683.98 ha (61% drop) between 1970s and 2010s (Gimba et al., 2018). The research concluded that effects of land use and land cover changes over the years were the major cause of siltation and decrease in the volume of the reservoir. The study recommended that catchment basin governance; desilting and correct project tracking and many others should be embraced. However, the study did not determine the sedimentation rate of the reservoir to inform the liveable duration of the reservoir, which will be done in this study for Kalundu dam. This information is critical to the water sector to employ mechanisms of salvaging the Kalundu Dam in order to maintain its designed use.

The study recommended planting of trees and agroforestry to increase the forest cover in the catchment to consequently reduce sediment yield. However, Kalundu Dam being a dam that is experiencing serious sedimentation and with a few methods of soil conservation around the dam being carried out, no such studies have been done. Therefore, lack of knowledge exists on how land use and land cover change around the sub-basin is impacting the sedimentation of the dam (Oludhe, 2012). Such a study needs to be done to identify the areas that are contributing high sediment load to the dam. This will provide valuable information on focused yield reduction efforts in erosion prone areas. Also, it will help reduce the amount of silt getting in to the dam (Chitata, 2014).

Reservoir sedimentation results from soil erosion. It is used as an indicator to inform on erosion challanges and sediment transport within a watershed (Juhar, 2018). Estimated length sediment yield data has been utilized for a long time to determine the life span of a reservoir. However, these estimates have contradicted the designed sediment storage pool and reservoir liveable duration as many reservoirs are rapidly filled with sediment (Juhar, 2018). Comparatively, short periods of flood discharge export most sediment from watersheds. Accurate monitoring of these events is crucial to inform on the long-term yield and variation of load with time to examine sediment routing methods. Spatial changes of sediment yield is also needed in order to lay down sediment yield decrement practices on the areas that greatly release sediment to the reservoir (Juhar, 2018).

Although the mean rate of sedimentation in reservoirs can be shown in volumetric units like millions of cubic meters (m^3) or acre-feet per year, for relating reservoirs of contrasting sizes it is appropriate to show the rate of sediment accummulation as the percent of the original storage capacity lost per year (Juhar, 2018). Sediment accumulation rate can also be showed in terms of the reservoir half-life, the years needed to completely sediment half the original volume. Because the capability of sediment ntangling reduces as reservoir volume is decrease, the half-life does not show half the time needed to completely deprive all storage volume. The potential of a storage reservoir to fulfil its design function will by then be adversely affected by the time half the storage storage has been deprived (Verstraeten, 2000).

In the case of Kenya, a few studies have been on soil erosion and sediment production (Kitheka, et al, 2008; Kogo et al, 2020). These studies have established that land-use change are the main cause of response to a range of socio-economic pressures such as population growth. The studies further indicated that mainly system without dams of the Rufiji and Athi-Sabaki respectively were indicating proof of alter in water run-off and sediment load due in large part to land-use change (Kitheka, et al, 2008). Studies into establishing the impacts of the land use and land cover changes on water and sediment yield on Thika River Catchment in Kenya, it was found out that the forest cover in the Thika River watershed in Kenya had reduced by 36% (Kigira, et al, 2000). The SWAT model was calibrated and employed to fairly predict the stream flow in the Thika River. Considering kinds of land use and land cover scenarios it showed that rising forest cover would considerably decrease sediment yield and regulate stream flow (Kigira et al., 2000). Therefore, a 100% forest cover would reduce the present sediment yield by 30%, while a reduction in forest cover of 20% would rise sediment yield by 40% (Kigira et al., 2000). Murera reservoir in Kenya showed that sediment settlement was higher in the southern part than northern part of the reservoir. Thickness of the sediment layer ranged from 0 m up to 0.8 m (maximum). The total sediment storage volume was 117,683.39 m^3. This meant that the reservoir had lost 14% of its actual storage capacity. Since no previous sedimentation study has been done for Kalundu Dam, this study will be helpful in providing information on whether the dam is getting filled up with silt and the expected lifespan of the dam.

Kogo et al, (2020) studied the effect of land use and land cover changes on soil erosion in western Kenya in the years 1995 and 2017. GIS-based Revised Universal Soil Loss Equation (RUSLE) modelling method and remote sensing methods were employed to do the examination. The research proved that the mean soil loss through soil erosion activities such as sheet, rill and inter-rill was 0.3 t/ha/y and 0.5 t/ha/y, in the years 1995 and 2017, respectively. Farms contributed more than 50% of the total soil loss both in 1995 and 2017. Grass/shrub had (7.9% in 1995 and 11.9% in 2017), forest (16% in 1995 and 11.4% in 2017). Built-up areas had the little donating element to soil erosion. Areas where trees had been cut down for farming reasons were found to have highest soil erosion (0.84 tons/ha). This was followed by farms converted from grass/shrub areas (0.52 tons/ha). The soil erosion rate was to rise with slope because of high velocity and erosivity of the runoff. Slopes of more than 30 degrees had high erodibility in the region, particularly in Mt. Elgon, Chereng'anyi hills and Elgeyo escarpments. (Kogo et al, 2020)

2.5 Impact of Reservoir Sedimentation on Community Water Use

Reservoir sedimentation affects community water uses and several relevant studies have been undertaken in South Africa, Ethiopia, Ghana (Antwi-Agyei et al., 2019; Tundu et al., 2018; Lawson, 2011; Jember, 2017). These studies have shown that socio-economic activities of people who live around reservoirs/dams are greatly impacted by sedimentation of the reservoirs/dams. This is majorly evident in a research done by Tomasson and Allanson (1983), which showed that the growth rates of Barbus and Labeo species in Lake LeRoux, South Africa decreased majorly because of risen sediment inflow into the lake that resulted to reduced clarity. Also, rise in turbidity was noted to reduce the beauty value of water, reservoir recreational activities and human enjoyment of the lake. Reservoir/dam sedimentation was also noted to interfere negatively with the activities of disinfecting the water before it is pumped to the end users.

Jember (2017), assessed land use and land cover dynamics in Ribb catchment and its impacts to the continual of Ribb dam, South Gondar, Ethiopia. The study noted that changes in land use and land cover influence the upgrading of catchment and the ecosystem in many ways. Catchments in the country were noted to be threatened because of unceasing menaces they were facing. Data on socio-economic and perception on watershed changes on land use and land cover was collected from 100 sample households. The results revealed that a number of socio-economic activities were the main contributors of land use and land cover change. They included population pressure, weak policy, poverty, lack of institutional enforcement, and tenure insecurity. Great consequences of changes in land use and land cover were noted to be soil erosion, lack of fuel wood and effect on livelihoods. The study concluded that population pressure was the main driver of alterations in land use and land cover in the catchment.

Recently, reservoir catcment in Ghana were noted to have suffered major alterations with great impacts on socio-economic upgrading and community livelihoods (Antwi-Agyei et al., 2019). A study on changes in land use and land cover and their effects on livelihoods in the Owabi reservoir watershed were carried out by Antwi-Agyei et al., (2019). The study covered information from 1970 to 2014. It employed Landsat, ERDAS Imaging and Arc Geographic Information System (ArcGIS 10.2) softwares augment with collaborative processes such as focus group discussions, key informant interviews and questionnaire surveys with 400 households. The outcome proved that since 1970, 24.6% of high-density forests and 15.8% of sparse forests had decreased; built-up area had risen from 9.8 to 56.6%. The part of bare soil had increased and areas of water bodies had declined. Urbanisation and absence of local participation in the governance of the catchment was identified as the key elements that were bringing changes in land cover that had severely impacted the livelihoods of the neighbouring communities. The research recommended for more active involvement of the neighbouring communities in the decision-making exercise for successful and continual governance of natural resources.

All anthropogenic activities need water. Water bodies have been polluted with direct or indirect impinging of humans via anthropogenic activities polluting water bodies with numerous contaminants causing worse effect on people health and aquatic life (Lawson, 2011). The condition of water is becoming extremely degraded because of incorrect land conservation as well as ignorance to the environment causing quick degradation of water condition. Land degradation and sheet erosion leads to transportation of the top soil into the water bodies leading to in excess levels of turbidity (Tundu et al, 2018).

Impounding structures do also entangle nutrients attached to the sediments. High concentration of nutrients like phosphates and nitrates have led to changes in the upper stream ecosystem by the proliferation of vegetation and other living organisms (Sumi and Hirose, 2009). Eutrophication and organisms' dissemination can be greatly accelerated by inadequate sediment management to levels that compromise reservoir functions. (Sumi and Hirose, 2009). On the other hand, sediments can fix or degrade pollutants. This reduces their bio-availability. Sediments that are contaminated remain a potential source of pollution to surface water. Sediment removal or downstream releases cannot easily handle the contaminated sediments (SedNet, 2004).

2.6 Research Gaps

In Kenya, a few studies on reservoir sedimentation have been undertaken and those that have focused on small surface water reservoirs located in arid and semi-arid lands are very few indeed. The examination of previous researches has shown that very few studies have also been undertaken in Africa. While several studies have established the association between river discharge and sediment loads, studies on the impacts of sediment loads discharged by rivers into surface water reservoirs are still scarce in Africa. This research strives to close this aperture by investigating the impacts of river discharge and sediment loads on the sedimentation rate of surface water reservoir.

The few studies done in Kenya have addressed the association between river discharge and sediment yield including the patterns of sedimentation inflow and outflow. The studies have not exhaustively examined the extent to which land use and land cover changes impact on accumulation of silt in reservoirs. Also most of the previous studies have not examined the socio-economic impacts, type of sediments deposited in reservoirs, and spatial distribution of sedimentation in the reservoirs located in ASALs. This study attempts to address these gaps by also examining the effects of land use and land cover change on sedimentation of a small surface water reservoirs located in arid and semi-arid region of Kenya.

Although Kitui County is located in an arid and semi-arid area in Kenya with water scarcity problem, no reservoir sedimentation studies have been undertaken. Also, there was no evidence that a study on reservoir sedimentation has been undertaken in Kalundu Dam which is one of the main dams in Kitui County experiencing serious sedimentation problems. There is also lack of information on the association between river discharge and sediment loads in most of the seasonal rivers emptying into arid and semi-arid lands of Africa including Kenya. There is also lack of information on the patterns and rates of reservoir sedimentation in most of the reservoirs constructed in arid and semi-arid lands. Absence of this particulars has limited the formulation of appropriate strategies for management of reservoir sedimentation in ASALs. This research strives to bridge this aperture by investigating the impacts of different rainy seasons of the year in the siltation of Kalundu dam.

2.7 Conceptual Framework

In this research, land use and land cover and climatic factors impacting Kalundu Dam sedimentation were identified. Hydrological, environmental and socio-economic impacts associated with Kalundu dam sedimentation were also identified (see Figure 2.1). The independent variables in this study were pegged on two categories of factors influencing the rate of sedimentation in surface water reservoirs. First, the climatic factors were examined. These factors include rainfall intensity which influences the extent of soil erosion that generate sediments from the land, stream flow variability and rainfall variability. All these factors are associated with the amount of sediment load that is generated from the sub-basin and moved by the rivers and finally is settled in the reservoir. The other category of independent variables is linked with anthropogenic factors which include land use and land cover changes resulting from disturbance of soil and land terrain due to human activities.

The intervening variables include human interventions med at controlling soil erosion and conserve loss of water and soils from the mainland. These interventions can be community-based or programmes initiated by the government and other stakeholders in an effort to control land degradation particularly soil erosion as a result of land use in a given area.

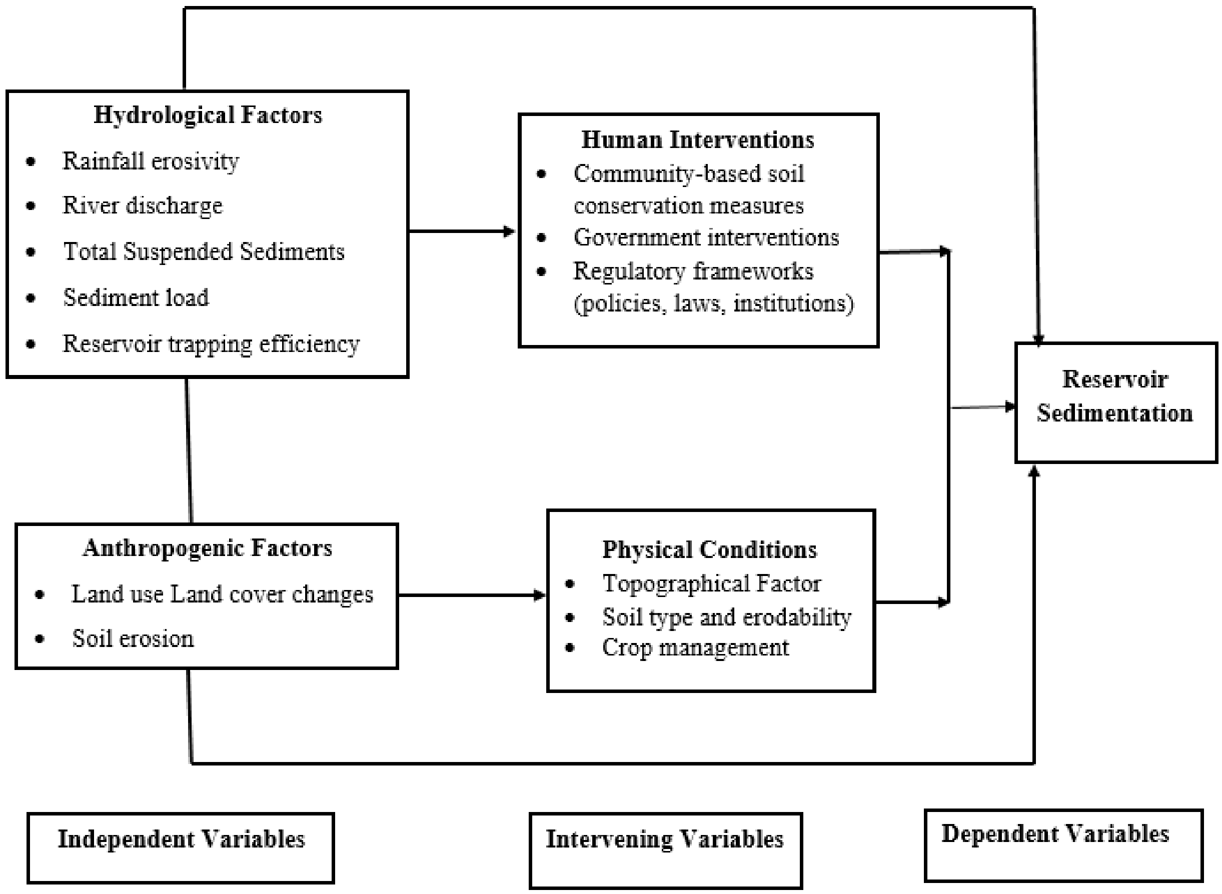


Figure 2.1: Conceptual Frame work of the Study (Source: Kasuki, 2022)

Implementation of the appropriate regulatory frameworks can also influence how land use practices can contribute to loss or conservation of water and soil in a given area. The aim of this study is to establish whether the rapid sedimentation in Kalundu Dam reservoir is due to land use changes in the sub basin and whether land use and land cover have modified the basin hydrology and sediment yield. The physical conditions of the lands can also influence to some extent the rate which soil erosion occurs. These conditions may not directly cause soil erosion, but they are thought to have some influence on the rate at which soil erosion and transportation of sediments occur. These conditions are defined by the change in stream flow patterns, infiltration, run-off generation mechanism, base flow and soil erosion dynamics (Figure 2.1). To achieve integrated water resource management in Kitui County, environmental impacts including soil and water conservation, influence ground water recharge, flood control and variability in surface run-off were found to play a great role. Social-economic impacts including WRUA's participation, reduced sedimentation, reduced water conflict, improved food production, increased water availability, improved health and improved decision making by all stakeholders were found to contribute towards achieving integrated water resource management (Figure 2.1).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

This chapter gives information on the methodology employed in this study. The main items described in this chapter include information of the study area, details of datasets and the procedures applied to collect them, fieldwork procedures and steps undertaken in the data analysis. Data and information used in this study are obtained from various sources including published materials and technical reports.

3.2 Description of the Study Area

The study area is located in the upper part of the Kalundu sub- basin which is found in Kitui Central Sub-County in Kitui County. The county is one of the 47 (counties located) in the South Eastern parts of Kenya (see Figure 3.1). The total spatial extent of the study area determined through GIS analysis is 24km^2. The Kalundu Dam was constructed in the 1950's across the seasonal Kalundu River approximately 11 km from the confluence with the Tiva River. The dam was the main source of domestic water for Kitui Town and its environs in the period between 1950 and 1970. According to the National Water Conservation and Pipeline Corporation, the dam had an initial design capacity of 300,000 m^3 (NWCPC, 2014). However, the reservoir was filled with sediments in the 1970s and therefore could not serve the intended purpose.

The NWCPC rehabilitated the dam in 2013 at a cost of USD 2,470,092.89. Kalundu Dam Rehabilitation Project entailed breach repair of a 13.5m high Dam and its auxiliaries (NWCPC, 2014). On completion, the capacity of the dam was increased to 500,000m^3 of water, with a surface area of 48,500m^2. The reservoir provides 1800m^3/day of irrigation water to local farmers in Wii, Unyaa, Tungutu and Mbusyani locations and KARI Kitui when it is filled with water. Rehabilitation works started in August 2011 and ended in September 2013 (NWCPC, 2014). The total volume of sediments that were excavated from the dam was 310,000m^3. The estimated useful life span of the reservoir after rehabilitation was 15 years (King'ori, 2014). By the time this study was undertaken, high rates of sedimentation in the reservoir were still evident.

According to Figure 3.2, the geography of the study area is marked by steep slopes to the east, where the elevation increases to 1700 m above sea level. Kalundu River sub-basin is part of the large Tiva River basin that drains into the Tana River basin. It is a seasonal river that only flows during the long and short wet seasons, which last from March to May and from October to December, respectively. Kalundu River drains its water into Kalundu Dam (see Figure 3.1) that is located in Kitui Central Sub-County. The Kalundu River drains through an expansive Tiva River basin before joining Tiva River. From the upper catchment region to the confluence with the Tiva River, the river is about 17 kilometres long.

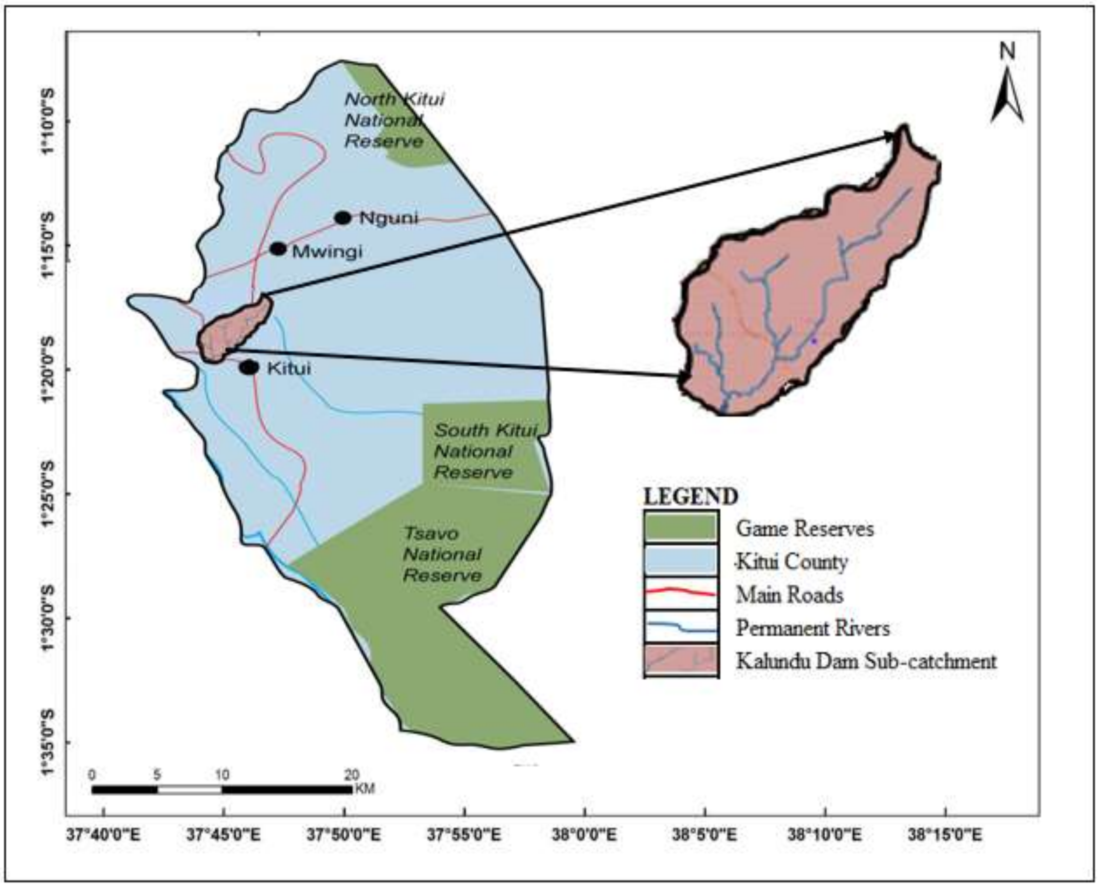


Figure 3.1: Location of the study area in Kitui County, Kenya (Source: Kasuki, 2022)

3.2.1 Topography

The study area is located in the central Kitui hills. The area is comprised of undulating hills differentiated by wide low lying areas. The undulating topography grants way to plains heading to the east and the Kitui hills. The elevation of Kalundu sub-basin ranges from 1043 to 1221m above sea level (Figure 3.3). The southern region of Kalundu sub-basin has the lowest elevation of 1040m above sea level. The rate of soil erosion is quite high in the hilly areas with high elevation. Soil erosion rates are relatively lower in low-lying areas (Mian Li et al, 2019). The topography of the area is rugged with steep slopes rising from Kalundu River valley (Figure 3.4). The steepest areas are characterized by 89% slope while the lowland slope ranges from 0-25%. The highest slopes of 70- 85% rise are found around Kalundu Dam while the low slopes of 0-30% rise are found at the upper parts of the Kalundu sub-basin (Figure 3.4). The lower and middle parts of the basin are more susceptible to soil erosion than the upper parts of the basin which has low slope percentage rise.

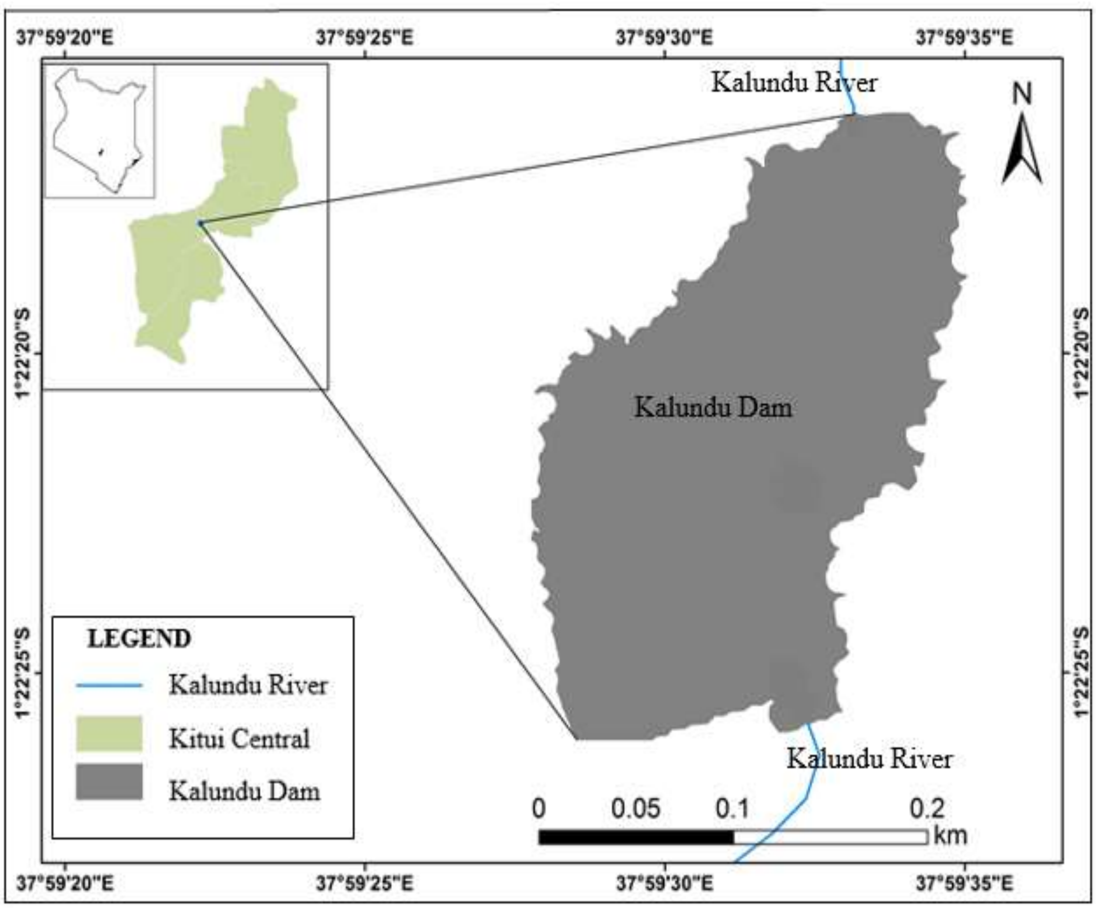


Figure 3.2: Location of Kalundu Dam in Kitui central, Kitui County (Source: Kasuki, 2022)

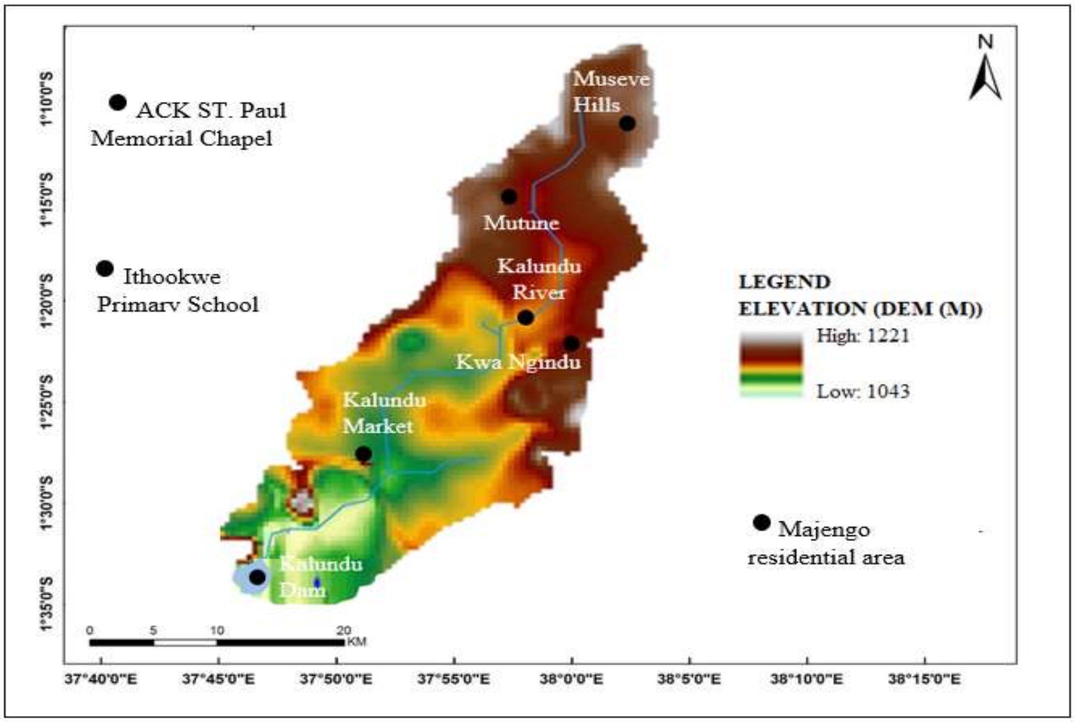


Figure 3.3: Digital Eelevation Model of Kalundu sub-basin (Source: Kasuki, 2022)

3.2.2 Climatic Characteristics

Kalundu sub-basin experiences a bi-modal rainfall pattern with two rainy seasons per year (Figure 3.4). The two rainy seasons are short and long seasons. The long rain season occurs in the period between March and May with usually very erratic and unreliable rainfall. The short rains season occurs in the period between the months of October to December but with more reliable rainfall (Kitui CIDP, 2018). The other months which include January to March and June to September are usually dry. The annual rainfall in the sub-basin ranges between 250-1050 mm per annum with 40% reliability during the long rains and 66% reliability during the short rains (Kitui CIDP, 2018). In addition to seasonal variations, rainfall also shows significant inter-annual variations (ADP, 2015). Rainfall experienced in the sub-basin is associated with the impacts of Inter-Tropical Convergence Zone where orographic lifting of moist air occurs over Kitui hills that rise to 1700m above sea level. The study area experiences hot and dry climatic conditions. High temperatures are experienced in most periods of the year. Mean daily temperature ranges from 20˚C to 24˚C. The hottest months are usually the months of September and October and also between January and March.

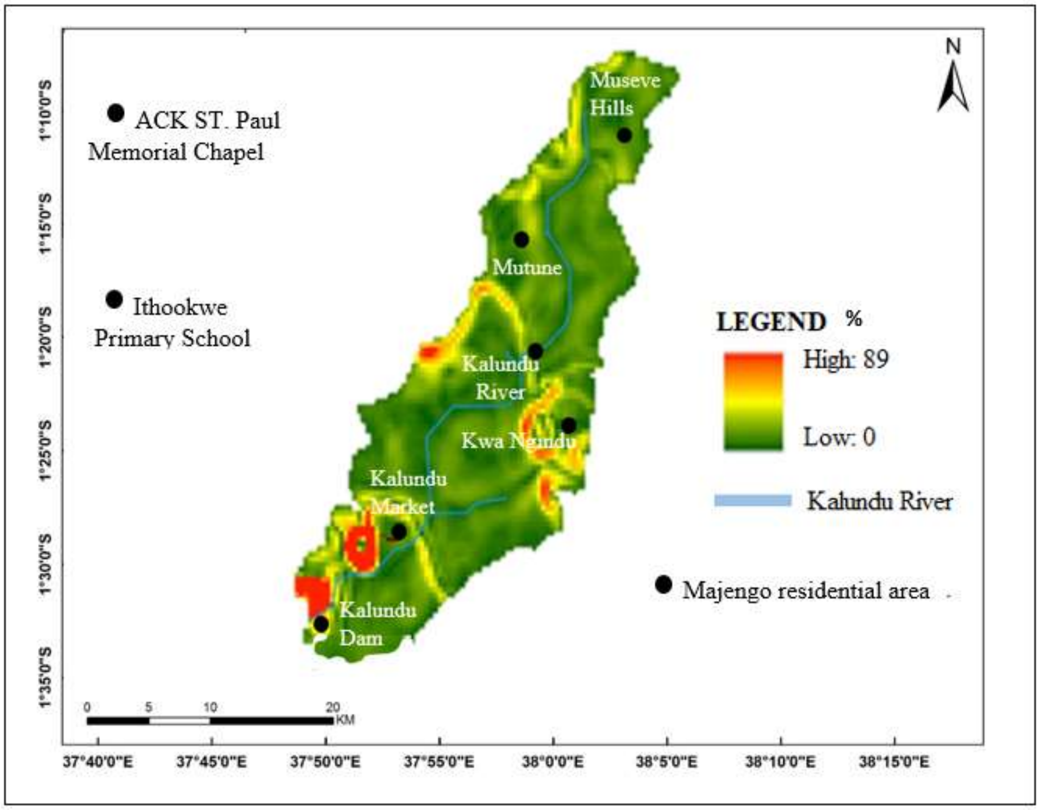


Figure 3.4: The distribution of slopes (%) in the Kalundu sub-basin (Source: Kasuki, 2022)

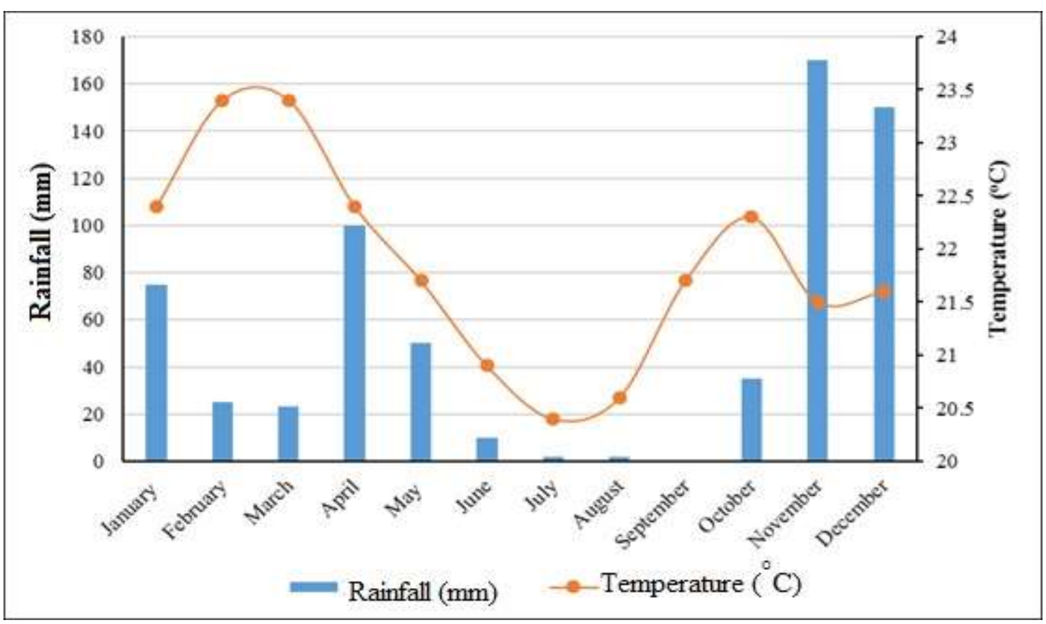


Figure 3.5: Mean monthly rainfall and temperature in Kalundu sub-basin (Source: Kitui CIDP, 2018).

The maximum temperature rises to as high as 28.5°C (Kitui CIDP, 2018). Maximum mean annual temperature ranges between 26°C and 29°C, and the minimum mean annual temperature ranges between 14°C and 22°C (Figure 3.5). The coldest month is July with temperatures dropping to as low as 14-20°C (ADP, 2015). The high temperatures during the day times are associated with high rates of evaporation with a average annual potential evaporation ranging between 1800 to 2000mm (ADP, 2015).

3.2.3 Geology and Soils

The geology of the area is comprised of the pre-Cambrian basement complex system (Mozambique belt rocks) overlaid by the tertiary rocks that includes the outcrops of sedimentary rocks. The Mozambique belt is made of high-grade metamorphic rocks.

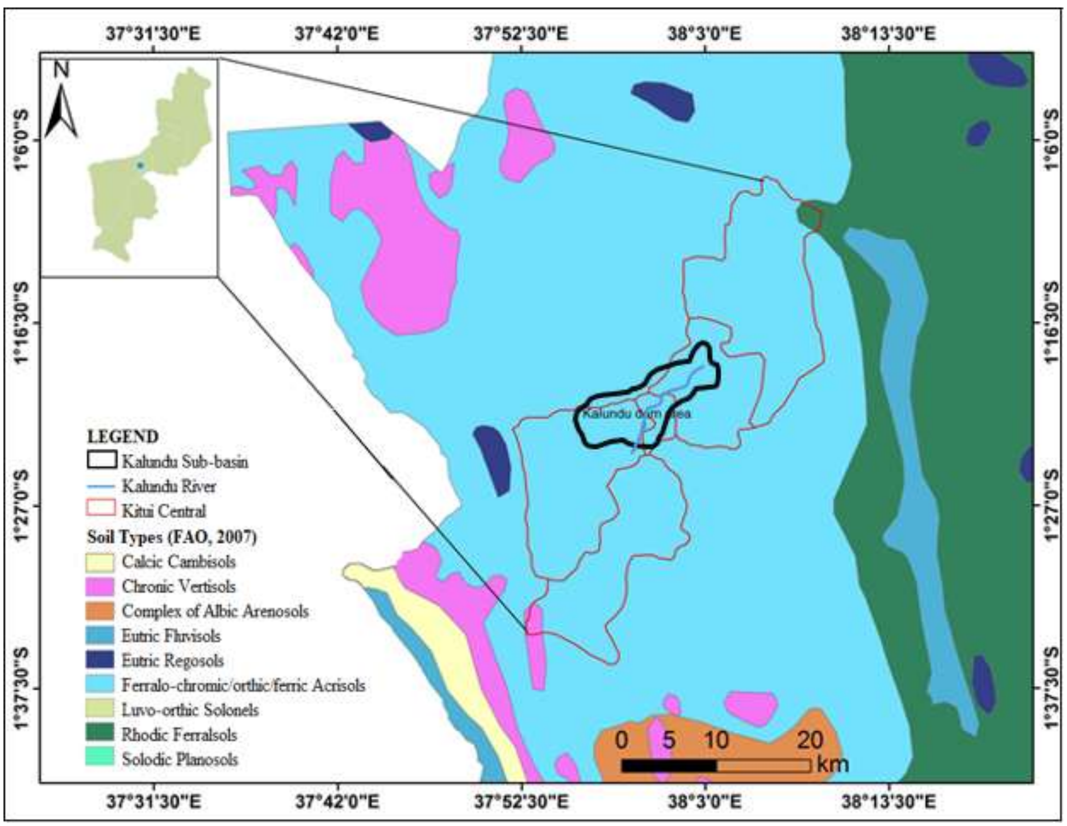


Figure 3.6: Distribution of soils in Kalundu River sub-basin (Source: FAO, 2020).

The belt trends from Ethiopia through Eastern Kenya to Mozambique (Holmes, 1951). Metamorphic evolutions are well uncovered in the study area, where active seasonal streams have made great gorges presenting nearly undisturbed progression in the metamorphic rocks. The most dominant rock types include granitoid gneisses, migmatites, pegmatites, biotite gneisses among others (Nyamai et al., 2003). The soils reflect greatly metamorphic parent rock material and the rainfall regimes that donate to their evolution (Figure 3.6). The soils are generally of low fertility and many are highly erodible. The study area is covered with the red sandy soils that are well distributed and cover most of the area while the black montmorillonitic cotton soils are confined to river valleys. Lateritic soils are also recurrent, although in some areas, provide way to sandy soils and black cotton soils. Generally, the red soils in the area are well drained while the black cotton soils are poorly drained (Sanders, 2007).

3.2.4 Drainage

The drainage of the study area is characterized by presence of seasonal rivers that flow in a south westwards direction. The main river in the study area is Kalundu River that

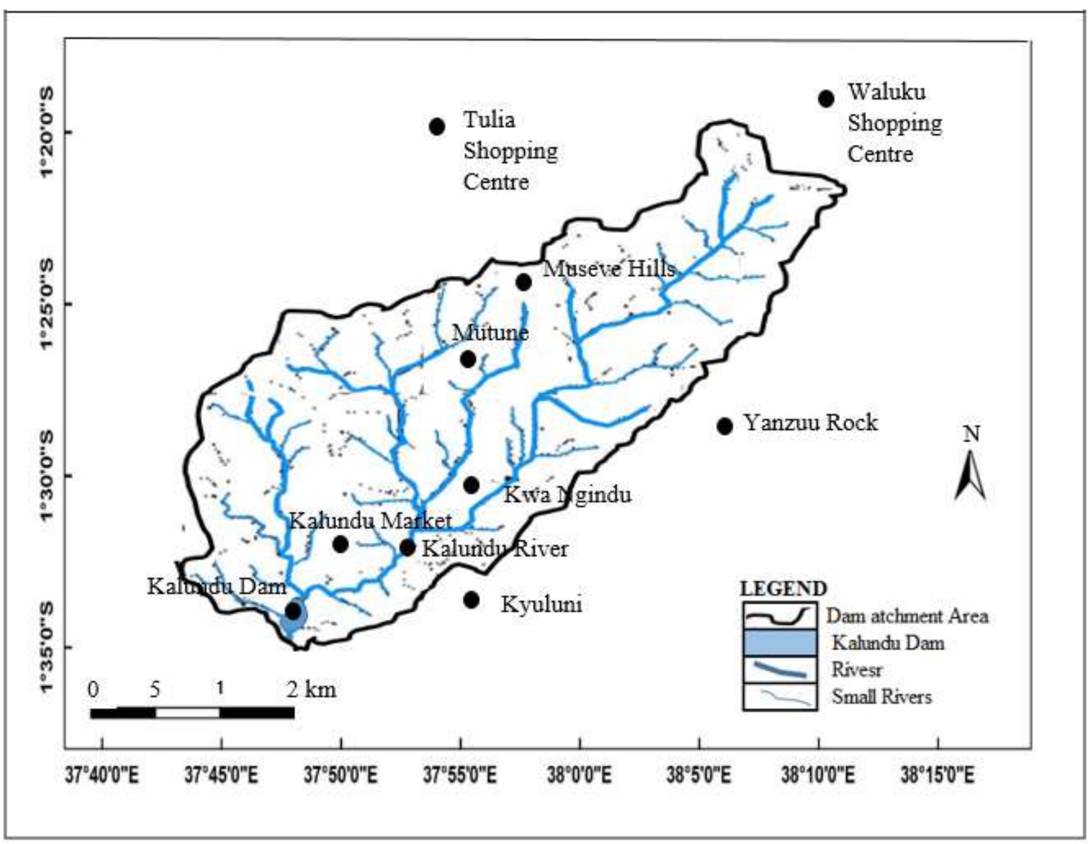


Figure 3.7: Drainage pattern of Kalundu Sub-Basin (Source: Kasuki, 2022)

generally flows from north east to the south west of the area and eventually discharges into Tiva River (Sanders, 2007) (Figure 3.7). River Tiva and River Mwitasyano join further south to form the larger Tiva River that flows into the Tana River. Other rivers that drain the study area include River Ngoni which flows from North-Western part of the area. All the rivers found in the study area are seasonal and intermittent, flowing only in the time of rainy seasons and are dry in most times of the year (Sanders, 2007). The direction of flow of the seasonal rivers and streams is mainly dictated by the topography hence majority of the rivers flow in the North Eastern – South Western direction (Figure 3.7). The direction of flow of rivers can also be attributed to the tectonism in the area (Sanders, 2007). The study area is occupied by high-grade granulite faces consisting of rocks which are resistant to weathering. Hence the flow is dictated by the major joints in the rock units. This explains why there is a sharp change in the direction of flow of the rivers (trellis pattern) in the northern parts of the sub-basin where some small streams join the main river perpendicularly (Sanders, 2007). The drainage pattern of the rivers at the central and lower sections of the sub-basin is dendritic where tributaries meet the main River at an angle (Figure 3.7).

3.2.5 Population

The population within Kalundu sub-basin area has been growing rapidly and is pressurizing the natural and environmental resources including forests, land, and water (PAI, 2020). The main population concentration centres are Kitui Town, Kalundu market and Liani shopping centre with a total of more than 16000 households and calculated population density of 224 persons per square kilometre within the trading town centres (CGoK, 2019). The study area experiences a high population density ranging from 60 - 130 people per square kilometre. Kalundu dam sub-basin lies within Kitui County whose total fertility rate is 5.1 compared to the fertility rate of Kenya 4.6 (PAI, 2020). The area is currently dominated by a youthful population with about half of the population being under 15 years. Almost three quarters of the population is under 30 years (Kitui CIDP, 2018). Youthful population and high unemployment rate has been identified as a threat to upgrading in the County. It is anticipated that the county's population will continue to grow rapidly in the coming years (PAI, 2020).

3.2.6 Agriculture and Land Use

The main land use activities in Kalundu sub-basin include mixed farming where rain-fed small-scale cultivation of crops in less than 3acre farms and livestock keeping is common in the lower areas of the sub-basin (Kitheka, 2017). In the upper areas of the sub-basin, large scale cropping activities and livestock keeping is common. The challenge of intermittent and low amount of rainfall in this area is also experienced particularly in growing of crops. Annual crops like maize, sorghum, millet and beans are grown in the area (Kitui CIDP, 2018). Perennial crops such as bananas and mangoes are also common. Agricultural lands and forests are found in the upper zone of the sub-basin. The natural vegetation in the sub-basin is characterized by scrubs and bushlands. Kitui hilltops are in the same zone dominated with Drypetes, Combretum, Vepris and Croton tree species (PAI, 2020). Other species such as Acacia-Commiphora and strychnos-Combretum bushlands are found in the lower parts of the Kitui hills. Mixed land uses are observed in the lower parts of the sub-basin towards Kitui town characterized by settlements, institutional and agricultural lands. Degradation of the land is also observed in areas due to growing population, abandoned crop lands and poor waste management especially near Kitui town (PAI, 2020).

3.2.7 Socio-Economic Activities

The Kalundu River sub-basin occurs in a region that is characterized by a low Human Development Index (HDI) of 0.53 which is yet to attain the country’s mean of 0.56. Poverty is also noted in the study area and duplicates itself in other socio-economic outcomes including inaccessibility to basic services, education, poor nutrition and health (KNBS, 2019). The estimated level of absolute poverty is at 47.5% which is alittle higher than the country’s mean of 36.1% in 2016 (GoK, 2019). A larger segment of the population engages in casual labor especially in the construction projects, business activities and employment in the government and Non-government offices in Kitui Town. However, due to urban development and new businesses, there is anticipation that new jobs and opportunities demanding for services will be created in Kitui Town in the near future. The newly constructed Kibwezi-Isiolo highway that runs through Kitui Town will also open up new avenues and market for farm products.

3.3 Research Methodology

This study employed a standard methodology in the study of the relationship between river discharge of sediment loads and sedimentation in Kalundu dam reservoir. The datasets employed in this research were topographic data (DEM), land use and land cover data, soil, rainfall, river discharge and sediment fluxes data. Field work was carried out in the study area to collect data such as river discharge, TSS, turbidity, including collection of sediment samples for particle size analysis. For the purpose of monitoring river discharge and sediment loads, sampling stations were established as shown in Figure 3.8. The fieldwork was undertaken in the period between long rainy season (April-June 2021) and short rainy season (October- 2020–February 2021). The frequency of sampling depended on the parameter to be tested. The dam water samples for testing turbidity and TSSC were taken on weekly basis during the rainy seasons. Samples of sediments from the reservoir were collected during the dry season for analysis of particle sizes of soils. Triplicate dam water samples of 1 litre were taken on weekly basis during long and short rainy seasons at three sampling stations located at the upper, middle and lower parts of the Kalundu Dam reservoirs (see Figure 3.9). Water samples were collected using a depth integrated sampler for the determination of the Total Suspended Sediment Concentration (TSSC). The water samples were taken to Kenya Water Institute Water Quality Laboratory in Nairobi for analysis on TSSC. Particle size analysis was done at the Ministry of transport, infrastructure, housing and urban development in Nairobi County. A turbidity meter was used to measure the turbidity.

3.4 Determination of the Relationship between River Discharge and Sediment Yield

Three sampling stations for river gauging and sediment load monitoring were established. One of the stations was located upstream near Kalundu bridge (RGS 1), the other one located near Intellect College (RGS 2) and another one below the spillway (RGS 3) (see Figure 3.8).These sampling stations were selected because of the following: straightness of the river section, the accuracy with which observations can be made, stability of the stream channel, accessibility to the station under all condition particularly during floods, ability of the station to cover the full range of discharge that may occur, and where the stage and discharge remains reasonably stable.

3.4.1 Measurement of River discharge

Monitoring of river discharge and TSSC along Kalundu River was done during the short rains in (October-November-December 2020 and January- February 2021) and during the long rains (April-May-June 2021). River discharge measurements involved determination of velocity and the cross-sectional area of the river at the two sampling stations located upstream of the dam. A straight and uniform river reach was identified for measurements of water level, width, velocity and cross-sectional area, to ensure least surface disturbances (Raghunath, 2006). The velocity of flow (*V*) was determined by using surface floats made of wood and 15cm in diameter. The time (*t*) taken by the float to travel a certain distance (*L*) was measured using a stopwatch.

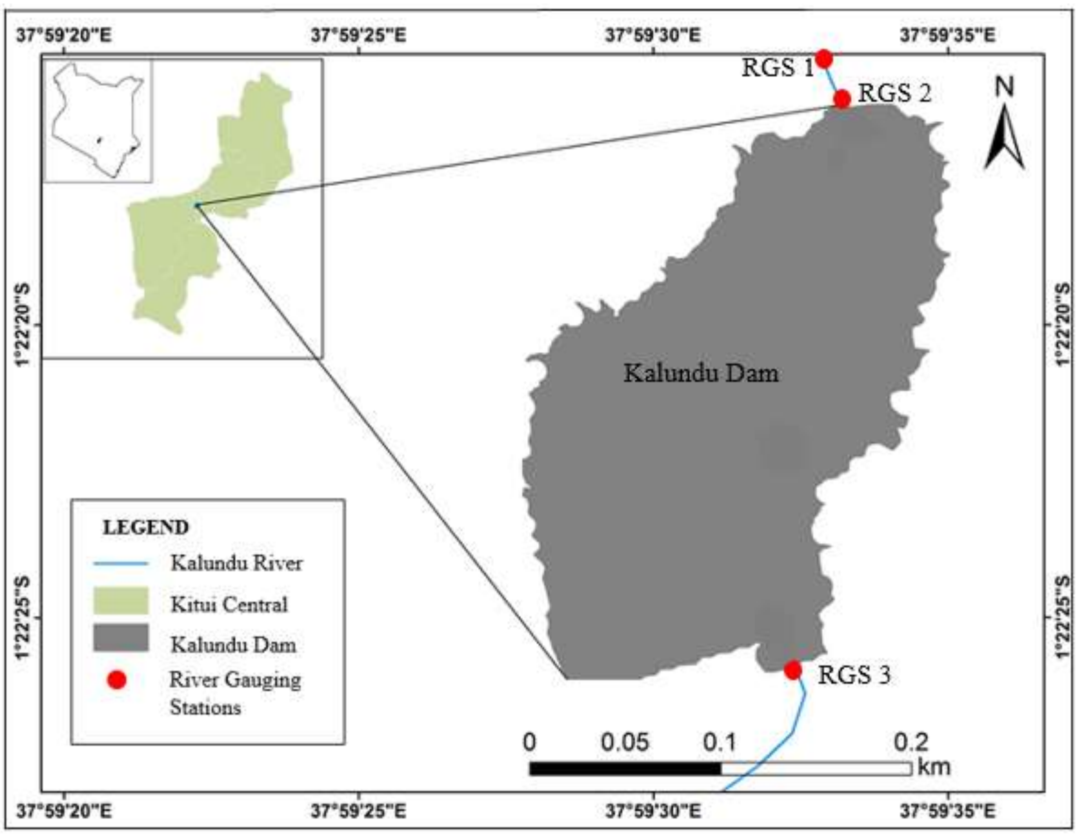


Figure 3.8: RGS locations along Kalundu River (Source: Kasuki, 2020)

A graduated staff gauge was utilized to compute the depth of the river in meters at each of the equally spaced points along the cross section. A profile of the river cross-section was then plotted and a high water surface level drawn. A tape measure was utilized to compute the width of the river (Raghunath, 2006). Area-Velocity method was applied to determine the river discharge. From two stations, measurements of river discharges were taken using cross-sectional area velocity method. The surface velocity *vs* was obtained using float and mean velocity *V* was calculated using the equation 2 below (Raghunath, 2006).

$vs = L/t$ ……………………………………………………………………………equation 1

$V \approx 0.85\ vs$……………………………………………………………………equation 2

Where L is the distance travelled by the surface float, t is the time taken by the surface float to cover L distance, vs is the surface velocity, V is the velocity of the river flow

The cross-sectional area (A) of the channel was then calculated using the equation 3 below (Raghunath, 2006).

$A = b.d\ (m^2)$ ………………………………………………………………equation 3

Where b is the breadth (m), d is the depth (m)

Therefore the instantaneous discharge (*Q*) of Kalundu River was obtained by multiplying the cross-sectional area (*A*) with the mean flow velocity (*V*) as shown in Equation 4 (Raghunath, 2006).

$Q = V * A$ ……………………………………………………………… Equation 4

Where V is the velocity of flow ($m.s^{-1}$) and *A* is the cross-sectional Area (m^2).

3.4.2 Measurement of Sediment Yield

This section presents the methodology that was used to measure sediment yield in the Kalundu River sub-basin that is the important source of water that enters into the Kalundu dam reservoir.

3.4.2.1 Measurement of Total Suspended Solids Concentration (TSSC)

TSSC was determined for three sampling stations where water samples of 1 litre were collected three times daily along Kalundu River during rainy seasons. To obtain the sample, the sampler was lowered into the flowing river water. A valve mechanism enclosed in the head was electronically operated by the observer to start and stop the sampling process. Water samples were analysed at the Kenya Water Institute Water Quality Laboratory. The sampling was done in the time of the long rainy season (April-May-June in 2021) and short rainy season (October-November-December 2020 and January- February 2021. Due to lack of flow in the river, no sampling was done during the dry season. Sampling of the upper and lower zones of the dam aided in establishing sediment fluxes into and out of the dam. This data was used to compute sediment fluxes as well as the sediment trapping efficiency of the dam.

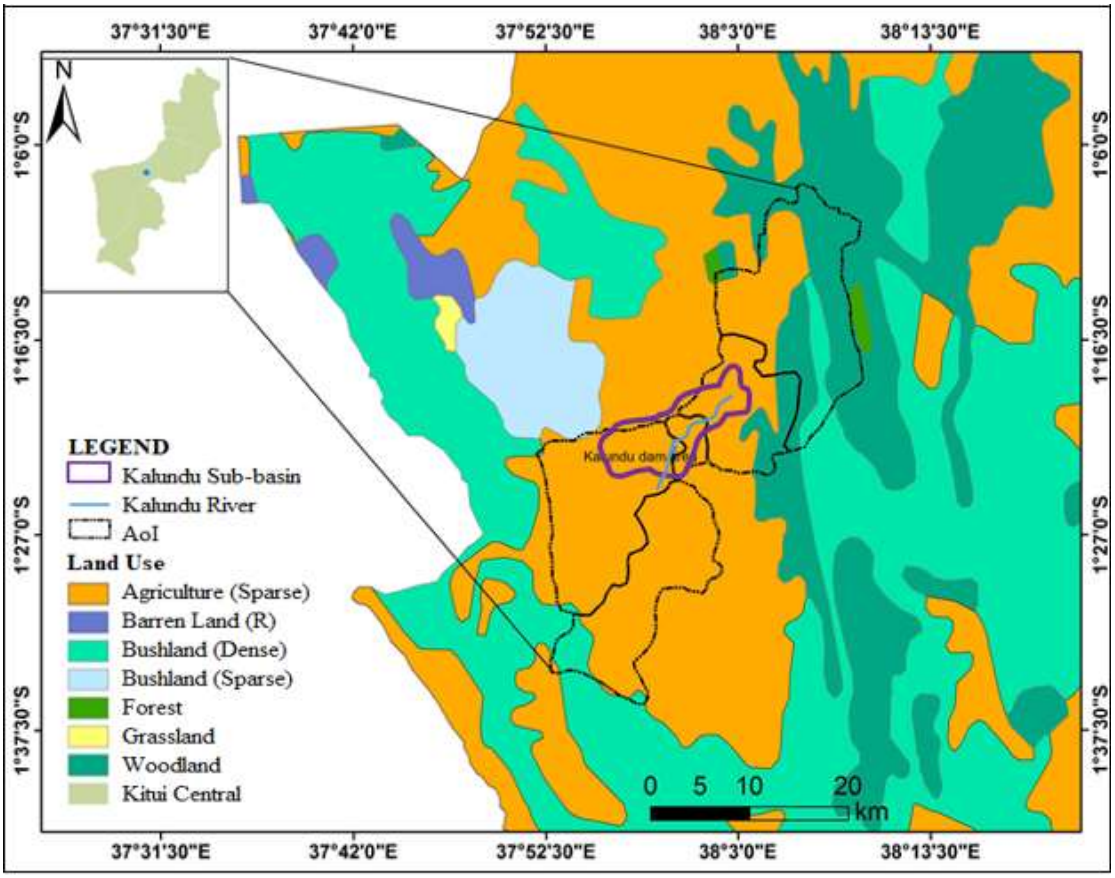


Figure 3.9: Kalundu sub-basin Land use and Land cover (Source: Kasuki, 2021)

The total suspended sediments concentration (TSSC) was determined using gravimetric method according to Kamarudin et al., (2018) and American Public Health Association (APHA, 2005) methods. The TSSC was expressed in mg/L while the water samples were filtered using a 45 mm glass fibre filter and the residue dried in an oven at a temperature of 120^{o}C. The TSSC was then computed using Equation 5 (Kamarudin et al., 2018; APHA, 2005).

$$TSS = \{(WBF + DR) - WBF\}\,(mg)\ x\,\frac{1000}{VFW}\,(mL) = mg/L \ldots\ldots \text{ Equation 5}$$

Where WBF = Weight of membrane filter, DR = Dry residue, VFW = Volume of filtered water

3.4.2.2 Determination of Instantaneous Sediment Load

The total annual sediment load inflow into Kalundu dam was determined by considering the annual water inflow into the dam using equation 6.

$$ASI = Q_i * Q_L \ldots\ldots \text{ Equation 6}$$

Where ASI is the annual sediment load inflow, Q_i is the instantaneous river discharge upstream of the dam (m^3/month), and Q_L is the instantaneous monthly sediment load (kg/m^3)

The Total Suspended Sediment Concentration (TSSC) and instantaneous river discharge (Q) data for each of the established sampling stations were used to determine instantaneous sediment fluxes. This was determined by using Equation 7 (Simons et al., 2017; Geeraert et al., 2015)

$$Q_s = C * Q \ldots\ldots \text{Equation 7}$$

Where C is the Total Suspended Sediment Concentration (kg/m^3), Q_s is the sediment flux (kg/month) and Q is the river discharge (m^3/month)

The annual TSSC was determined by summing the monthly sediment loads using Equation 8.

$$Q_L = \sum_{i=1}^{n} = Q_i * C_i$$
………………………………………………….….……….Equation 8

Where Q_L is the annual Sediment load (tons/year), the volume of sediments were converted from cubic metre to tons by diving by 0.67m^3 (1tone of sediment = 0.67m^3) (Hufschmidt. and Srivardhana, 1986), Q_i is the monthly instantaneous river discharge (m^3/month), and C_i is the monthly TSSC (kg/m^3).

3.5 Determination of Sedimentation Rates and Sediment Budget

Determination of sedimentation rates and sediment budget of Kalundu dam was done by estimating the reservoir trapping efficiency, reservoir sedimentation survey, volume of deposited sediments in the reservoir and useful life span of the reservoir. These methods are as presented in the section below.

3.5.1 Trap Efficiency Determination

The sediments trap efficiency (TE) of Kalundu dam was determined by computing the volume of sediments that enters and leaves the dam according to the method of Verstraeten and Poesen (2000). To compute the average sediment yield generated from the contributing watersheds, adjustments of the weight of the deposited sediment was done for the reservoir sediment trapping efficiency.

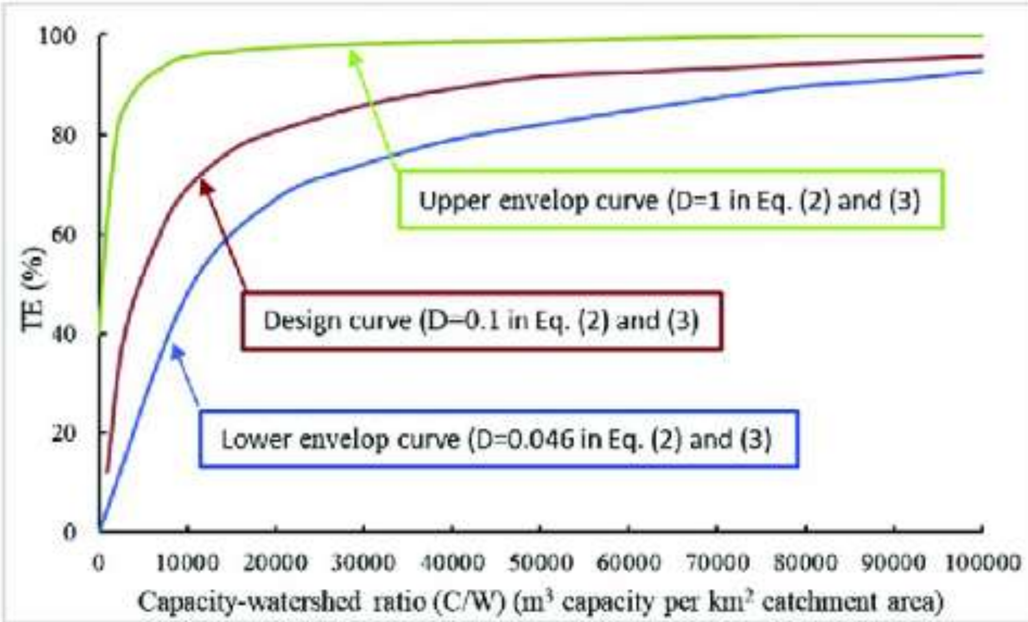


Figure 3.10: Capacity-watershed ratio (C/W) curve (Source: Brown, 1943)

This study employed calculation proposed by Brown (1943) to compute the TE of the Kalundu dam as shown in Equation 9.

$$TE = 100\left[1 - \frac{1}{1+0.0021D\frac{C}{W}}\right] \quad \text{Equation 9}$$

Where; D is a coefficient and has a range of 0.046 to 1. It has an average value of 0.1 (Brown 1943). Trapping Efficiency hinge on D. D hinges on a reservoir's attributes. The D value in this research work will be computed using a curve established by Brown (1943) that associates trapping efficiency to a capacity–watershed area ratio $\frac{C}{W}$. Brown (1943) proposed that values for D are near to 1 for reservoirs in areas with little and great varying run off and those that hold back and store flood flows.

3.5.2 Reservoir Sedimentation Survey

The bathymetric survey of Kalundu Dam reservoir was taken through measurement of water depth along transects established in the reservoir (Figure 3.11). Bathymetric survey enabled determination of the capacity of water and sediments stored in the dam (ICOLD, 1989). The depth measurements were taken at established points marked using a GPS through echo-sounding method using Navigational Encho Sounder JFE-360. The transects were established from the lower to the upper zone of the reservoir at an interval of 10 m. Measurements of depths along the transects was undertaken at an interval of 10m using a boat. The amount of settled sediments was determined by lessing the original storage capacity from the current storage capacity. Bathymetric survey was done in December 2021 when the dam was at full capacity. The current surface area of the reservoir was delineated using ArcGIS. A bathymetric map was generated using Inverse Distance Weight (IDW) tool in ArcGIS. The current reservoir storage capacity (RSC) for Kalundu Dam was computed using Equation 10 shown below according to (Adwubi et al., 2009; Aynekulu et al., 2009).

$RSC = A_r * h\ (m^3)$…………………...………………………………………..Equation 10

Where A_r is water Surface Area (m^2), h is mean depth of the reservoir (m)

Figure 3.11: Kalundu Dam Water depth measurement in December 2021 (Source: Kasuki, 2022)

3.5.3 Computation of the Volume of Deposited Sediments

The volume of accumulated sediments in a reservoir is assumed to represent the reservoir storage capacity lost (see also Adongo et. al, 2019). The sediment volume for Kalundu dam was computed using Equation 11 according to Ferrari and Collins (2006). The volume of sediments were converted from cubic metre to tones by diving by 0.67m^3 according to Hufschmidt and Srivardhana (1986).

$$\mathrm{SCL} = \mathrm{ISCR} - \mathrm{CSCR} \quad \text{Equation 11}$$

Where SCL is the reservoir storage capacity lost (m^3), ISCR is initial (Original) reservoir storage capacity (m^3) and CSCR is the current reservoir storage capacity (m^3). It is important to note that the accumulated sediment volume (SV) in a dam is equivalent to the reservoir storage capacity lost (SCL).

3.5.4 Determination of Sedimentation Rates

The sedimentation rate for Kalundu Dam was determined using Equation 12 below according to (Aynekulu et al., 2009).

$$\mathrm{MASR} = \frac{\mathrm{SCL}}{\mathrm{A_gR}} \quad \text{Equation 12}$$

Where MASR is the mean annual rate of sedimentation (m^3/yr), SCL is the reservoir storage capacity loss (m^3), and $\mathrm{A_gR}$ is the age of the reservoir (yr).

3.5.5 Determination of Useful Life Span of the Reservoir

The useful life span of the dam was computed using Equation 13 according to (Gill, 1979).

$$UL = 0.5\left(\frac{ISCR - SCL}{MASR}\right) \quad \text{Equation 13}$$

Where UL is the useful life of the reservoir in years when the initial storage capacity will have been reduced to 50%, $ISCR$ is the initial (original) storage capacity of the reservoir (m^3), SCL is the storage capacity loss (m^3), and $MASR$ is the mean annual rate of sedimentation (m^3/yr). The water surface area loss of the dam was computed using Equation 14 according to (Gill, 1979).

$$WSAL = IWSA - CWSA \quad \text{Equation 14}$$

Where $WSAL$ is the water surface area loss due to sedimentation (ha), $IWSA$ is the initial water surface area at full supply level (ha), and $CWSA$ is the current water surface area at full supply level (ha).

3.5.6 Determination of Sediment Budget

The sediment budget of the reservoir was estimated by determining the sediment load at the inlet and outlet of the dam. The difference between sediment input and sediment output is equivalent to the amount of settled sediments in the reservoir. Thus, sediment budget can be determined using Equation 15.

$$I = O + ds \quad \text{Equation 15}$$

Where $ds = I - O$ ....Equation 16

Where I is sediment input in the reservoir and O is sediment output in the reservoir, ds is the change in sediment storage where positive (+ve) value indicates trapping of sediments and negative (-ve) value indicates exports of sediments out of the reservoir.

3.6 Establishment of Sediments Sources

The determination of sources of sediments deposited in Kalundu reservoir was achieved by establishing the land use and land cover changes using remote sensing approach and simulation of soil loss in Kalundu sub-basin using Modified Universal Soil Loss Equation (MUSLE) model. Soil erosion is a naturally occurring activity which is majorly impacted by people activities (Dragicevic and Milevski, 2010). In this research, land use and land cover changes and soil loss were determined to provide insights on the specific areas which are contributing the highest amount of sediments into the reservoir.

3.6.1 Determination of Soil Erosion in the Kalundu Sub-basin

The rate of soil erosion in the Kalundu sub-basin was determined by use of Modified Universal Soil Loss Equation (MUSLE) as provided in Equation 17. MUSLE formula is an advanced version of the USLE formula (Wischmeier and Smith 1978). This formula made use of the rainfall factor (R) in place of instantaneous peak river discharge and total runoff factor to project soil erosion. The mean soil loss for a flood is a product of the volume of the flood (Q in m^3), the peak discharge of the flood (q_p in m^3/s), the erodibility of the soil (K), the index slope (S), the slope length (L), the crop management (C) and the conservation support practice (P).

$A_{MUSLE} = 11.8(Q * q_p)^{0.56} * K * LS * C * P$………………………………...… Equation 17

This method was selected because it can provide a reliable estimate of the sediment yield resulting from each individual rainfall storm event. A study done by Djoukbala et al., (2018) on comparing the erosion projection models from USLE, MUSLE and RUSLE in a Mediterranean catchment, showed that MUSLE provided a greater spatial distribution of erosion resulting from a better productivity of rainfall factor. This study applied ArcGIS software to compute the six MUSLE factors including R factor, K factor, LS factor, C and P factor. These were then processed through overlay analysis to produce a soil erosion map of the Kalundu Dam sub-basin. The MUSLE model factors were computed as explained in the following sections.

3.6.1.1 Calculation of Soil Erodibility Factor

The Soil Erodibility Factor (K) factor value was computed by utilizing digital soil map of the study area. Kalundu sub-basin soil map shape file was generated from hydrological processing of DEM and using Arc GIS, then K value was determined. Soil Erodibility factor was computed by utilizing the expression indicated in Equation 18.

$\text{Erodibility} = \text{Sand} + \text{Silt/Clay})/100$……………………………………..… Equation 18

3.6.1.2 Calculation of Slope Length and Steepness

Digital elevation model (DEM) with ground revolution of 30 m x 30 m was obtained from United State Geological survey (USGS) website. Each of the Slope Length and Steepness (LS) parameters were derived independently from a Digital Elevation Model (DEM) using hydrology tool in spatial analyst tool of ArcGIS. LS factor was computed based on Equation 19 (Wischmeier and Smith 1978):

$$LS = \left(\frac{l}{22.13}\right)^{m} (0.43 + 0.30s + 0.043s^{2})/6.574 \quad \text{Equation 19}$$

where LS is the slope length and steepness factor, S is the field slope (%), l is the slope length (m), and m is the dimensionless exponential which varies from 0.2 for slope less than 1% to 0.6 for slope greater than 10% (Renard et al., 1997; Sadeghi et al,. 2007a).

3.6.1.3 Crop Management Factors

Using Landsat satellite images from United State Geological survey (USGS) website, the land use and land cover classification of the study area was done to derive different classes of LULC. These LULC classes were used to define the coresponding crop management factors (C) in each LULC class.

3.6.1.4 Conservation Support Practice Factor

The Conservation Support Practice Factor (P) is the ratio of soil loss by a support practice to that of straight row farming up and down the slope. This factor is utilized to account for control practice that reduce the erosion potential. The P factor gradient ranges from 0 to 1 (Godone and Stanchi, 2011). In this research, P factor was estimated using the land use practices in the study area according to Morgan (1994) and Ali and Hagos (2016). The P-factor expresses the effects of the conservation practices that reduce the amount and rate of runoff, and consequently, reduce soil erosion.

3.6.2 Soil Particle Analysis

The sizes of the sediments particles deposited in the dam were determined according to standard method (ASTM-D2487) for gradation test (ASTM International, 2018). Soil samples were collected by coring from three points located at the upper, middle and lower zone of the reservoir. Particle size analysis was undertaken at the Ministry of transport, infrastructure, housing and urban development in Nairobi. The samples were dried and 1kg of each sample was used for sieve analysis to determine the sizes of the sediments. The sediments were categorized pegged on the percentage composition of clay, silt and sands in a sample. The particle size distribution in the reservoir was determined to give insights on the sources of silt accumulated in the reservoir.

3.6.3 Land Use and Land Cover Change Analysis

The analysis of land use and land cover change in the Kalundu sub-basin was undertaken using the Landsat images. Cloud free satellite images were obtained from the Global Visualization Viewer (Glovis) archive (https://earthexplorer.usgs.gov/). All the images were best acquired during the dry periods before the end of year short rains between August and October for the year 2000, 2010, and 2020 (Table 3.1).

Table 3.1: Landsat imagery for Kalundu sub-basin from 2000-2020 (Source: Kasuki, 2021)

Year	Date/Month	Path	Row	Name of scene
2020	10/10	167	061	LC08_L2SP_167061_20201010_20201016_02_T1
2010	30/09	167	061	LT05_L1TP_167061_20100930_20161008_01_T1
2000	25/10	167	061	LE07_L1TP_167061_20001025_20170216_01_T1

Glovis allowed the examination of images from different series of Landsat program since 1972. Glovis has the advantage of having the longest free continuous satellite data source. Kalundu River sub-basin has an area of 24 km^2. The area covered by one Landsat scene is 185 x 185km, with images having spatial resolution of 30m captured from an altitude of about 170km above sea level. Thus, objects with less than 30m may not be clearly observed on Landsat imagery (Tripathi and Kumar, 2012). The archived images used in the study were captured after every 16 days. This interval determines the observable characteristics of the land features. Land use and land cover change analysis in this study was done at intervals of 10 years between 2000 and 2010 between 2010 and 2020. The images used in the analysis had been captured in the period between September and October in the respective study years.

3.7 Determination of Impacts of Reservoir Sedimentation on Water Uses

The determination of effects of siltation of reservoir on the local community was done through questionnaire survey, field observations and review of reports and focused group discussions with the local community. Questionnaires were administered to the residents and beneficiaries of the water from the Kalundu dam. A semi-structured questionnaire was administered through face-to-face method of collecting data (Gall and Borg, (2006). This study employed a descriptive research design where both qualitative and quantitative data were collected in order to establish how Kalundu reservoir sedimentation influenced water uses in the local community. A descriptive research design was used to ascertain facts not to test theory (Pinsonneaut and Kraemer, 1993). The descriptive research design was also used in the field survey to obtain information on how the local community was been impacted by sedimentation of Kalundu dam (Mugenda and Mugenda, 2003).

3.7.1 Target Population and Sample Size

The target population of this research work were derived from the households in Kalundu Dam sub-basin. A simple random sampling approach was applied in the selection of respondents to be subjected to the questionnaire interviews. The sample size was 102 households from a total population of 1020 households which represent 10% (Table 3.2). This according to Mugenda and Mugenda (2003) is a sufficient sample size to facilitate an objective study. Only one respondent was considered for each household.

Table 3.2: Target Population and Sample Size (Source: Kasuki, 2021)

Zone	Population Size	Sample size
Museve area	250	25

Kitui town	350	35
Kalundu village	260	26
Mutune area	60	6
Kwangindu area	100	10
Total	**1020**	**102**

3.7.2 Pilot Study

The questionnaire was pretested by conducting a pilot test to establish its validity and reliability. Ten (10) respondents were selected randomly for the pilot study but were not involved in the main study, hence the response that were considered for this study were 92 households. The aim of the pilot assessment was to determine consistency and logic of the questionnaire.

3.7.3 Validity and Reliability of Questionnaire

The validity and reliability of questionnaire was determined through the pilot study. The reliability of the questionnaire was tested by computing the Cronbach's Alpha coefficient from the results of pilot study with the help of the SPSS program. When Cronbach's Alpha coefficient is above 0.7, the questionnaire is considered reliable but if it is less than 0.7, the questionnaire is treated unreliable (Santos and Haubrich, 1999). The same questionnaire was then administered to the target population of this study within a time interval of one week and had an Alpha value of 0.83.

3.8 Methods of Data Analysis

The data collected in this study was subjected to both hydrological and statistical analysis as discussed in the section below.

3.8.1 Hydrological Data Analysis

The section below discusses the methods used in this study to analyse hydrological data to determine the patterns and consistency of different data variables including river discharge, sediment yield and Total Suspended Sediment Concentration.

3.8.1.1 Time-Series Analysis

The time series analysis was undertaken to reveal the trend on river discharge, sediment yield and Total Suspended Sediment Concentration (TSSC) for long rainy season March-April-May (MAM) and short rainy season October-November-December (OND). This study also employed hydrographs analysis to determine the patterns of river discharge and sediment loads (Wei, 2006 and Tong, 2012).

3.8.2 Statistical Analysis

The study employed various statistical methods to analyze the data. These methods were; measure of central tendency, correlation analysis, regression analysis and analysis of variance (ANOVA). These methods are explained in more particulars below.

3.8.2.1 Measures of Central Tendency

The measures of central tendency that were used in this study are mean, mode, minimum and maximum values. Mean is used to get averages of different data sets. Mode is used to know the frequency of a variable. The arithmetic mean was established by adding the values of a variable and then dividing by the number of values (Gupta and Gupta, 2009) as shown in Equation 20.

$$\bar{X} = \frac{\Sigma X}{N} \quad \text{............ Equation 20}$$

Where: $\bar{X}$= Arithmetic mean, ΣX = Sum of values in the series, N = Number of values in the series

The arithmetic mean was used to quantify different quantitative indicators like the average annual rainfall in a number of years, river discharge, land use change and average sediment yield (Richter et al., 1996). The mode was determined according to Equation 21 and was utilized to determine the range of the rainfall in which most values by (Gholba, 2012).

$$Z = L_i + \frac{f_i - f_o}{2f_i - f_o - f_2} * i \quad \text{............ Equation 21}$$

Where: Z = value of mode, L_i= lower of modal class, f_o= frequency of the preceding modal class, f_2= frequency of the subsequent modal class and post modal class, i= class interval of the modal class

The Median was used to calculate the amount of rainfall in which the rainfall data collected falls between and calculated using Equation 22 according to Gholba, (2012).

$$\text{Median} = Bm + I * \left[\frac{\frac{n}{2} - (\sum f_i)o}{f_m}\right] \quad \text{.. Equation 22}$$

Where: Bm = lower boundary of the median class, $(\sum f_i)o$ = the sum of the frequencies from the classes, f_m= frequency of the median class, n= number of the observations and I = interval of the median class

3.8.2.2 Regression Analysis

Regression analysis was applied to determine association between variables. Both linear and multiple regression analysis methods were used in this study. The simple regression analysis was utilized to establish the association between stream flow and sediment load or land use and land cover change (Seber and Lee, 2012). Simple regression analysis enables the dependent variable to be calculated once the independent variable is known (Montgomery et al., 2012). A simple linear regression equation generated for the association between river discharge and sediment yield (rainfall and river discharge or sediment yield) is shown in Equation 2 3.

$$Y = a + bX + e \quad \text{.. Equation 23}$$

Where: X- Independent variable (rainfall), Y - Dependent variable (river discharge, sediment yield or land-use change), b – Slope of the line, a- Intercept and e- error term.

3.8.2.3 Multiple Linear Regression Analysis

Multiple linear regression analysis was used to establish the dependency level between multiple independent variables and a dependent variable (Yevjevich, 1972). In this research, the sediment yield was taken as the dependent variable (Y) and the independent variables included river discharge (X_1), land use change (X_2) and sediment yield (X_3). The p-value was examined to give the magnitude of the association between independent and dependent variables in the regression equation (Katz et al., 2002). The smaller the p-value the more magnitude the association and the regression equation (Katz et al., 2002). The regression equation is magnitude if the p-value is less or equal to 0.05 (Katz et al., 2002). This research employed the multiple regression model shown in Equation 24.

$$Y = aX_1{}^2 + bX_2 + c$$ …………………………………………………........… Equation 24

Where Y = Sediment Yield (tons/month), a and b = the coefficient values of X variables, X_1= River discharge (m^3/month), X_2= Rainfall (mm/month) and c= Constant.

3.8.2.4 Correlation Analysis

Correlation analysis was utilized to measure the strength of the association between the independent and the dependent variables (Kothari, 2004). The correlation coefficient (r) was computed using Equation 25. The correlation coefficient (r) ranges from −1 to 1 and is utilized as an index of the degree of linear association between stream flow and sediment yield data (Lee and Nicewander, 1988). If r = 0, no linear relationship exists. If r = 1 or −1, a perfect positive or negative linear association exists (Taylor, 1990).

$$r = \frac{n\sum xy - (\sum x)(y)}{\left(\sqrt{n(\sum x^2) - (\sum x)^2}\right) - \left(\sqrt{n(\sum y^2) - (\sum y)^2}\right)}$$ ……………………………………...…. Equation 25

Where r is the correlation coefficient, x- Dependent variable (e.g. sediment yield), y- Independent variable (e.g. river discharge) and n -Total number of values/variables.

3.8.2.5 Coefficient of Determination (R^2)

The coefficient of determination (R^2) was utilized to determine the proportion of variance in the data obtained from established gauging stations. Coefficient of determination (R^2) refers to the amount of variation described by the independent variable (Legates and

McCabe, 1999). Coefficient of determination (R^2) ranges from 0 to 1, with greater values showing less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001; Van Liew et al., 2003). The R^2 was calculated using Equation 26.

$$\sqrt{R^2} = r \quad \text{Equation 26}$$

Where R^2 is the coefficient of determination, r is the correlation coefficient

3.8.2.6 Analysis of Variance (ANOVA)

ANOVA is a parametric test that assumes the populations used follow a normal distribution, each sample is an independent random sample and population variances are equal across responses for the group levels. It uses an F test statistic to test the significance of the difference between and within the means of two related samples (Park, 2009). One-way ANOVA was computed and F ratio obtained which provided information about the variability between and within groups (Armstrong et al., 2002). In of this research, the independent variable was the rainfall which was compared with the sediment yield and river discharge the dependent variables under a 95% level of confidence.

The hypothesis was tested at a 95% level of confidence. To test the hypothesis, the F distribution that varies depending on degrees of freedom was used. The F table only gives values for α =0.05. The statistical decision was made if the p-value was less than or greater than 0.05. There is an inverse relationship between F and p value. If the F statistic was less than critical F, then $p>0.05$, if the F statistic is greater than F Critical, then $p<0.05$ (Wei, 2006). In order to be statistically significant at the 0.05 alpha level, an F test statistic of greater than the alpha value was needed. In other words, if $p \leq \alpha$, it means that there is no sedimentation in the dam (that is, values of observations are identically distributed) hence reject the null hypothesis.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter discusses the outcomes of the research pegged on each of the specific objectives of the study. The first section provides the results on the association between river discharge and sediment yield. The second part gives the outcomes on the association between reservoir sedimentation rates and sediment budget. The third section provides the results on soil erosion and sources of sediments deposited in Kalundu Reservoir. The fourth part of this chapter provides outcomes on the impacts of reservoir sedimentation on community water uses.

4.2 The Relationship between River Discharge and Sediment Yield

This section presents the results of the analysis of the association between river discharge and sediment yield in the Kalundu River system.

4.2.1 River Discharge Variability

The data on the variability of Kalundu River indicated that stream flow exhibits significant seasonal variability. The variability is essentially due to variability of rainfall occurrence in the basin.

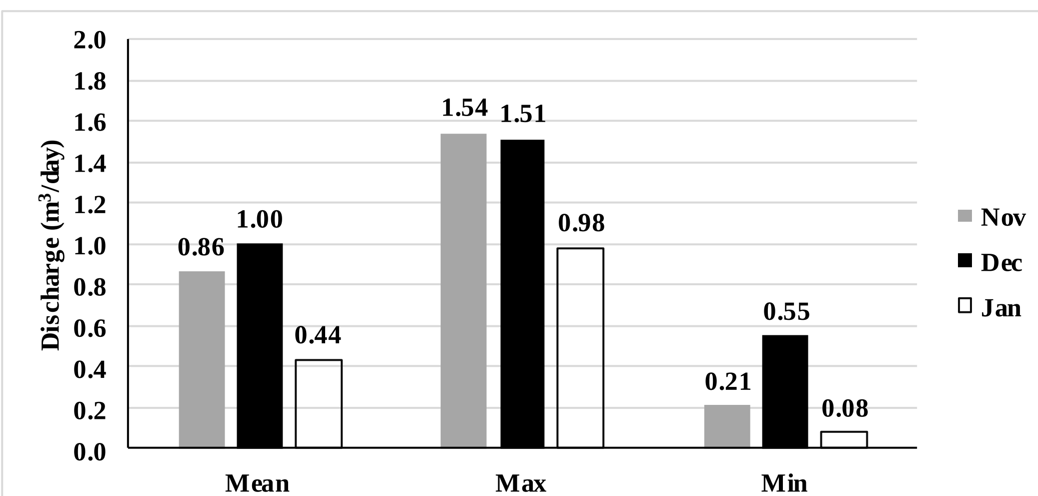


Figure 4.1: Variability of river discharge at station 1 and 2 (upstream) during the

short rains (November 2020- January 2021) (Source: Kasuki, 2022)

During the short rains (November-January) in 2020, the maximum river discharge in Kalundu River ranged from 0.98-1.54 m^3/day with a mean range of 0.44-1.00 m^3/day (Figure 4.1).

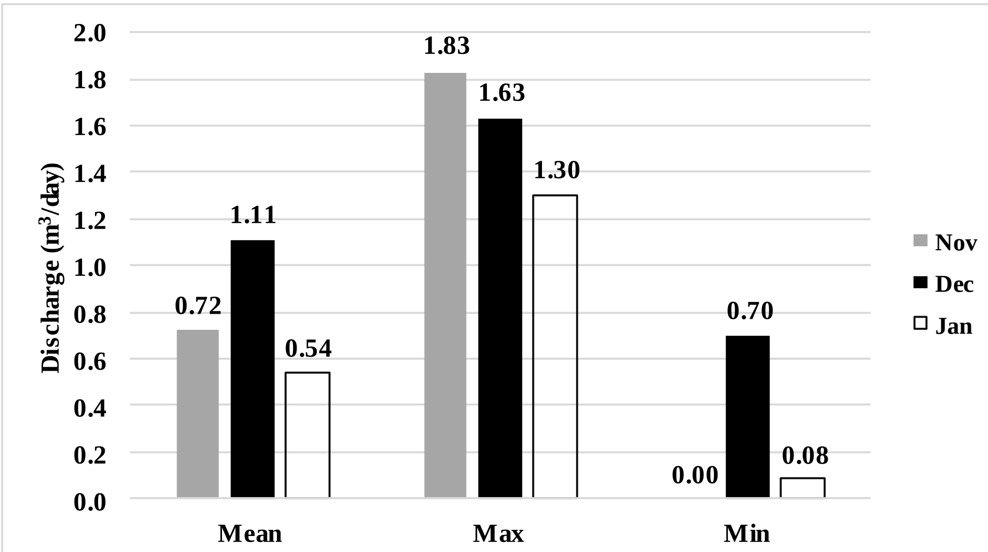


Figure 4.2: Variability of river discharge at station 3 (downstream) during the short rains, (November 2020- January 2021) (Source: Kasuki, 2022)

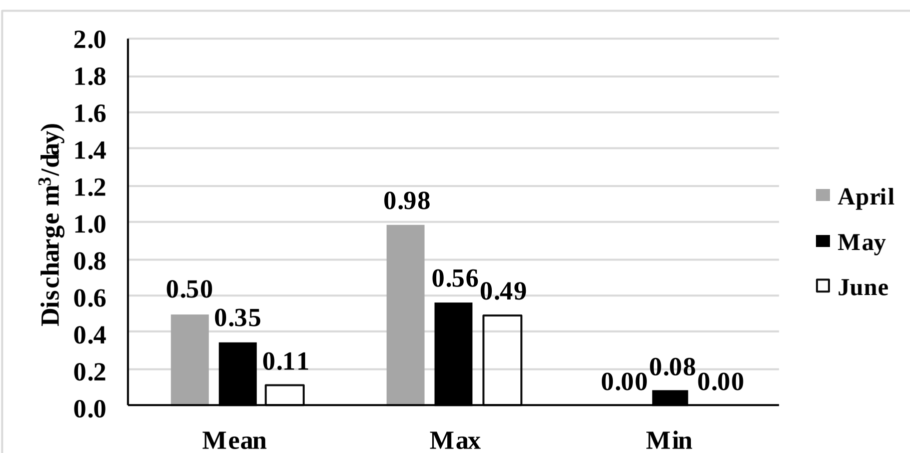


Figure 4.3: Upstream Kalundu River discharge variability during the long rains (April– June 2021) (Source: Kasuki, 2022)

During the long rains (April-June 2021), the river discharge was highest in mid-April and in the beginning of May but reduced consistently towards June 2021. This is the reason why the maximum value of $0.98m^3$/day in Kalundu River (upstream at the entrance to the reservoir) was recorded in April. The discharge from the reservoir ranged from 0.13-$0.41m^3$/day (Figure 4.4). The minimum discharge from the reservoir ranged from 0-$0.08m^3$/day while the minimum discharge ranged from 0-$0.10m^3$/day. There was no river flow in April and June because of lack of rainfall during this period (Figure 4.4). The maximum river discharge was observed between April and May ranging from 0.49-$0.98m^3$/day while the maximum dam discharge in the same period ranged from 0.55-$1.35m^3$/day. Few days in April and June recorded no river flow hence zero river discharge along the river and subsequently there was no discharge from the dam for several days in April and June.

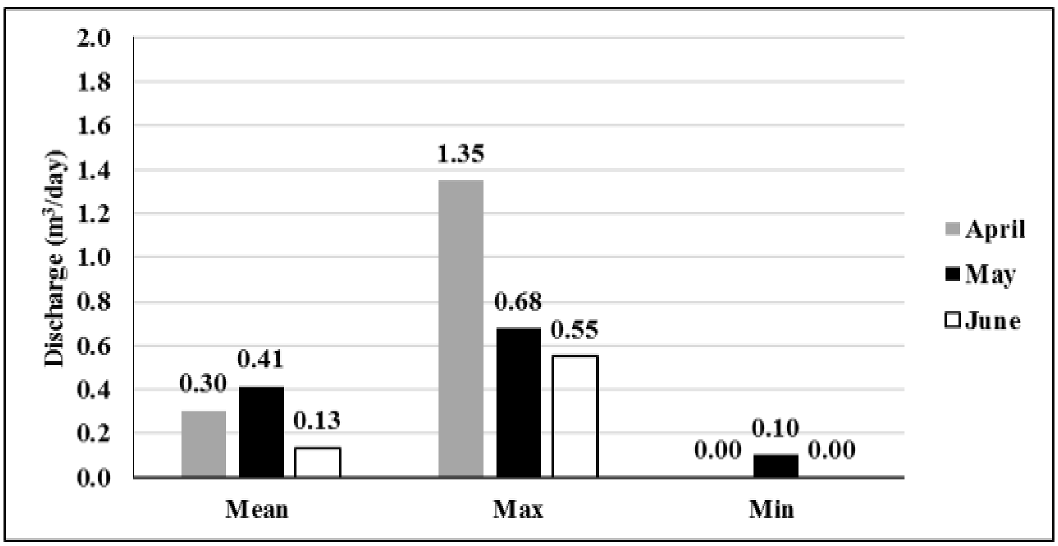


Figure 4.4: Downstream Kalundu River variability of river discharge during the long rains (April-June, 2021) (Source: Kasuki, 2022)

Generally, the outcome of the research indicated that the peak river discharge in the time of short rainy season was relatively higher than during the long rainy season. During the short rains, the peak river discharge was more than one and a half times (1.57) higher than during the long rains. The minimum river discharge was 10 times higher during the short rains than during the long rains. Correspondingly, it was noted that the total river discharge was 2.6-times higher during the short rains than during the long rains season.

The total river discharge during the short rainy season was $70.3m^3$/day with a mean value of $23.4m^3$/day while during the long rainy season the total river discharge was $27.5m^3$/day with a mean value of $9.2m^3$/day. These findings suggest that more sediments were likely to be deposited into the Kalundu Dam reservoir during the short rainy season than during the long rains season corresponding with the total river discharge getting into the reservoir.

During the long rains, the total inflow into the Kalundu reservoir was 21% higher than the outflow while during the short rains the inflow was greater than the outflow by 3%. During the period before the long rains (April-June) a lot of water from the reservoir is abstracted and used in various domestic uses by the community living near the reservoir. This means that when the rains come, the inflow fills back the abstracted water before any spill-over occurs. This makes sense when the inflow during the long rains is much greater than the discharge from the dam. It is also suggested that before the short rains season, the reservoir has limited capacity to hold a substantial amount of water. As a result of that, the amount of inflow during the short rainy season does not significantly differ from the outflow during that time of year. This explains the low percentage difference between the inflow and outflow during the short rains season. These results are also confirmed when the sediment load that gets into the reservoir is compared with the sediment load discharged from the reservoir during the short rains season. The inflow sediment load corresponds well with the outflow sediment load during that season (see Figure 4.6).

The examination of patterns of variability of river discharge during the short and long rainy season showed that the recession periods tend to be relatively long as compared to flooding (rising) period of the hydrograph. The increase in river discharge during the flood period was more rapid while the recession period was more gentle. These patterns are attributed to the nature of hydrology of Kalundu River basin. There is also a strong relationship between river discharge measured upstream and river discharge downstream given that the correlation coefficient (r=0.93, p-value=0.01) during the short rains and (r=0.98, p-value=0.01) during the long rains respectively (Figure 4.3 - 4.4). Kalundu

River also exhibited significant inter-annual variability in the stream flow which can be attributed to inter-annual variability of rainfall.

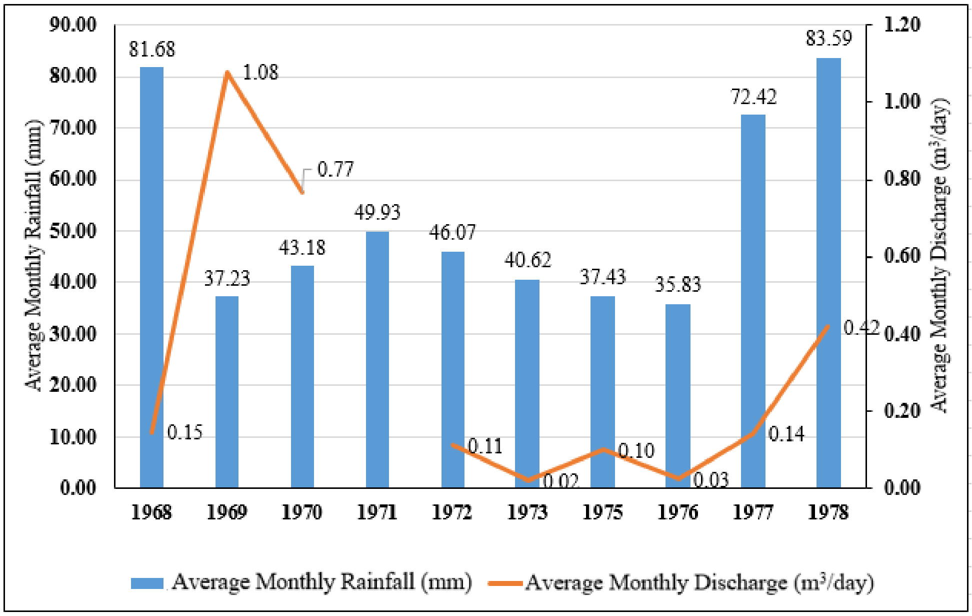


Figure 4.5: Variability of Kalundu River discharge in the period 1968-1978 (Source: Kasuki, 2022)

The available historical data shows that river discharge during the long rains (March-June) in the period 1966-1970 had reached a peak of 3.5-4.3m^3/day with a mean value of 1.5-2.06m^3/day. During the short rains (November-January), the peak river discharge ranged from 2.5-2.8m^3/day with a mean value of 0.02-1.08m^3/day (Figure 4.5). In the period between 1976 and 1978, the river discharge increased significantly. The mean river discharge ranged from 0.14-0.66m^3/day during the long rains and decreased further during the short rains to 0-0.55m^3/day. However, the river discharge data from WRA for the period 1968 – 1978 is not accurate as demonstrated in Figure 4.5.

4.2.2 Variability of Sediment Loads

Variability of sediment load in this research indicated that there is a significant association between sediment load inflow and sediment load outflow (Figure 4.6). Sediment load was derived from the product of the river discharge and TSSC which were measured within the month of October 2020 to February 2021. Figure 4.6 shows that during the short rains season variability of sediment load deposited into the reservoir was significantly associated with the sediment load discharged out of the reservoir (P-value=0.0001, R^2=0.9322, r= 0.67) (Figure 4.6). The mean sediment load deposited into the dam during the short rains was 98.3m^3/day while the outflow was 79.3m^3/day resulting to about 19% decrease in the mean sediment load. The graph implies that a significant amount of sediment load that gets into the reservoir correspondingly flows out of the reservoir but slightly less than the inflow.

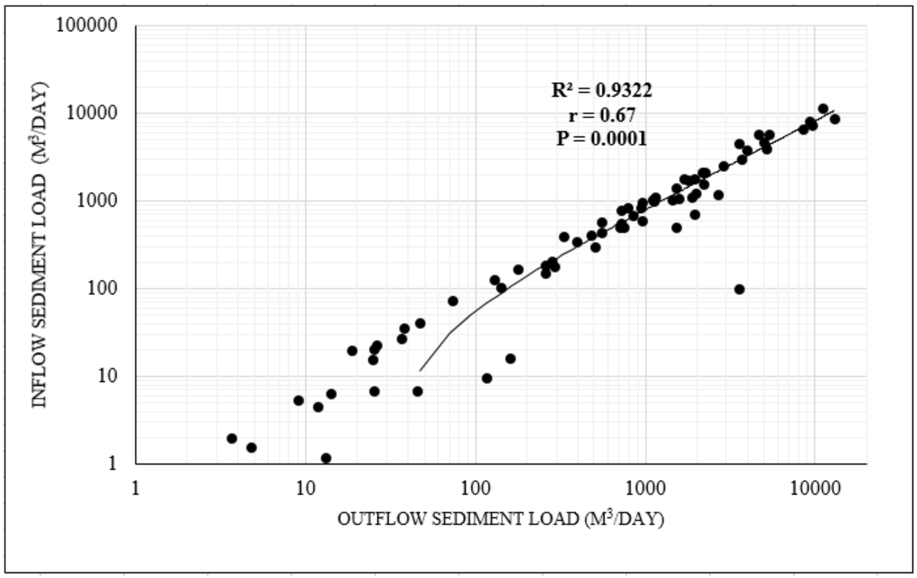


Figure 4.6: Relationship between sediment inflow and outflow in the Kalundu Reservoir during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

Figure 4.7 shows that during the long rainy season, variability of sediment load that gets discharged into the Kalundu reservoir was not significantly related to the outflow (P-value=0.79, R^2=0.295, r= 0.54) (Figure 4.7). The mean sediment load discharged into the reservoir during long rains was 30m^3/day and a mean outflow of 12m^3/day which imply about 61% decrease in the mean. These results imply that sediment inflow was not likely to give a significant amount of sediment outflow from the reservoir. The outflow was much less than the inflow. A comparison of these results confirms that less amount of sediments was likely to be deposited into the reservoir during the short rain season than during the long rainy season.

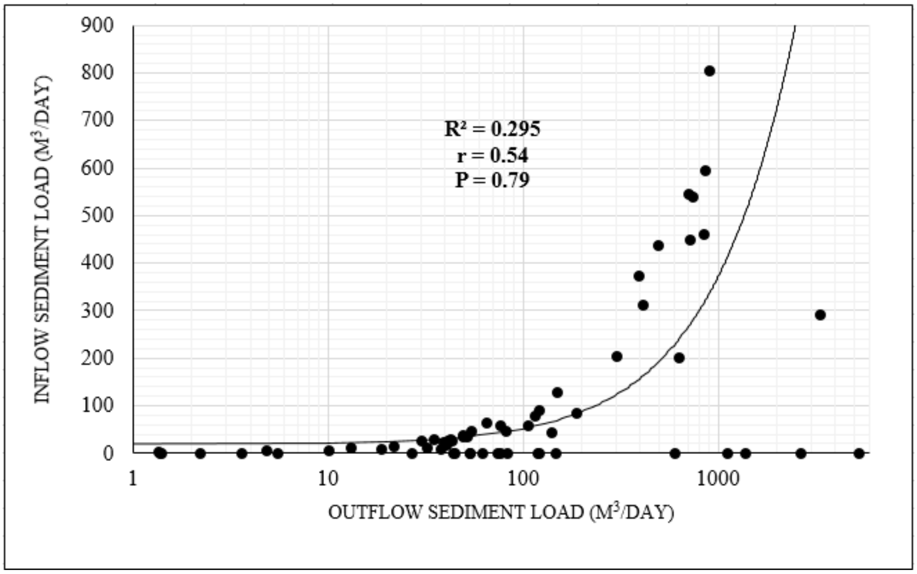


Figure 4.7: Relationship between sediment inflow and outflow in the Kalundu Reservoir during the long rainy season (April-June 2021) (Source: Kasuki, 2022)

4.2.3 Variability of Total Suspended Sediments Concentration

There is a significant variation between TSSC in the Kalundu River and TSSC values after the reservoir (downstream).

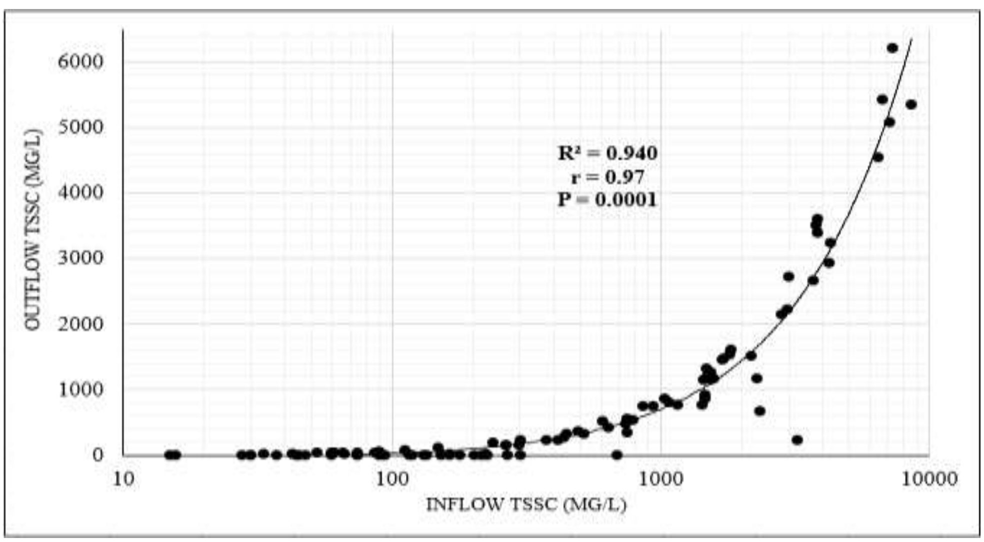


Figure 4.8: Relationship between inflow TSSC and outflow TSSC in the Kalundu Reservoir during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

During the short rainy season, the TSSC in Kalundu River ranged from a minimum of 1 mg/L to a maximum of 8,593.06 mg/L with a mean value of 1,131.565 mg/L. In the same season, the TSSC downstream ranged from 0 - 6227.66 mg/L with a mean value of 796.22 mg/L. The average TSSC recorded downstream was 21.3% lower than the TSSC upstream. This is equivalent to the amount of TSS that gets deposition into the reservoir. From the analysis, the total suspended sediments concentration inflow and the TSSC outflow showed a significant positive correlation whereby; R^2=0.940, r= 0.97, and P-value=0.0001 which signifies a relative balanced flow of TSSC in and out of the reservoir (Figure 4.8).

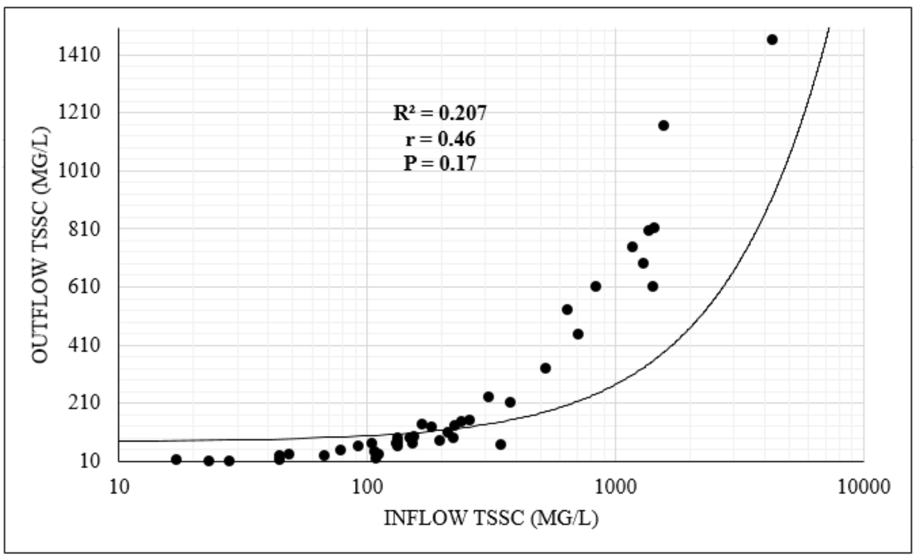


Figure 4.9: Relationship between inflow TSSC and outflow TSSC in the Kalundu Reservoir during the long rainy season (April- June 2021) (Source: Kasuki, 2022)

During the long rainy season, the TSSC in Kalundu River ranged from 0.002mg/L to a maximum of 7,405.77 mg/L with a mean value of 592.812 mg/L. In the same season, the TSSC downstream ranged from 0 – 3,727.682 mg/L with a mean value of 190.549 mg/L. The average TSSC recorded downstream was significantly lower by about 61% compared to TSSC upstream. Figure 4.9 shows that there was no significant relationship between TSSC inflow and the TSSC outflow during long rainy season (R^2=0.207, r= 0.46, and P-value=0.17) (Figure 4.9). By comparing the two seasons, the results show that the mean TSSC deposited into the reservoir during the short rainy season was less than the TSSC discharged during the long rainy season.

4.2.4 Relationship between River Discharge and Total Suspended Sediments Concentration

The relationship between river discharge and total suspended sediments concentration during the short rainy season showed a significant relationship between river discharge and total suspended sediments (R^2=0.39, r=0.63, P-value=0.03) (Figure 4.10). The results presented in Figure 4.10 imply that an increase in the river discharge is likely to cause an increase in TSSC. The mean value for river discharge in Kalundu River during the short rainy season was 0.69m^3/day while that for TSSC was 1,131.565 mg/L. The results also show that relatively higher TSSC were measured during the periods of high flows. Relatively lower TSSC was measured during periods of lower river discharge. The TSSC were very low when river discharge was less than 0.4 m^3/day. Figure 4.11 shows a relationship between river discharge and Total Suspended Sediment Concentration in Kalundu River during the long rains (April- June 2021).

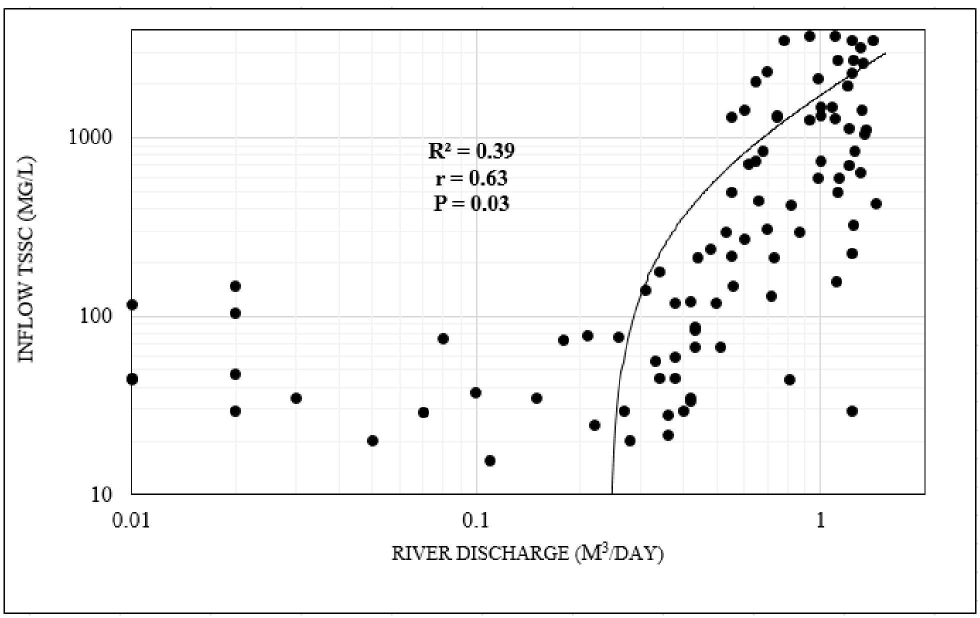


Figure 4.10: Relationship between river discharge and TSSC in the Kalundu River during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

The results show that there was no significant relationship between river discharge and total suspended sediments during the long rainy season (R^2=0.24, r=0.49, P-value=0.08) (Figure 4.11). However, an increase in the river discharge contributed to a slight increase in TSSC. Relatively higher TSSC were measured during the periods of high flows while relatively lower TSSC was measured during periods of lower river discharge.

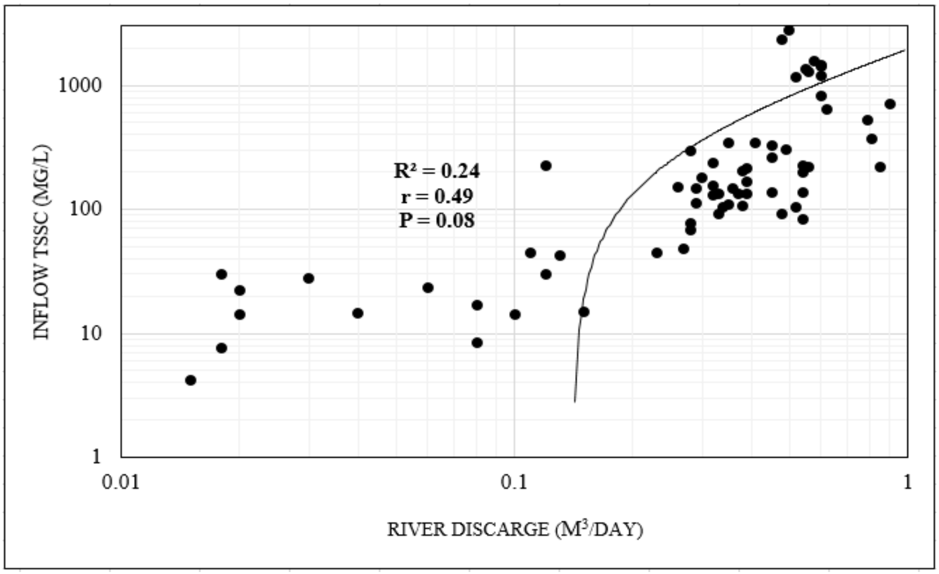


Figure 4.11: Relationship between river discharge and TSSC in the Kalundu River during the long rainy season (April- June 2021) (Source: Kasuki, 2022)

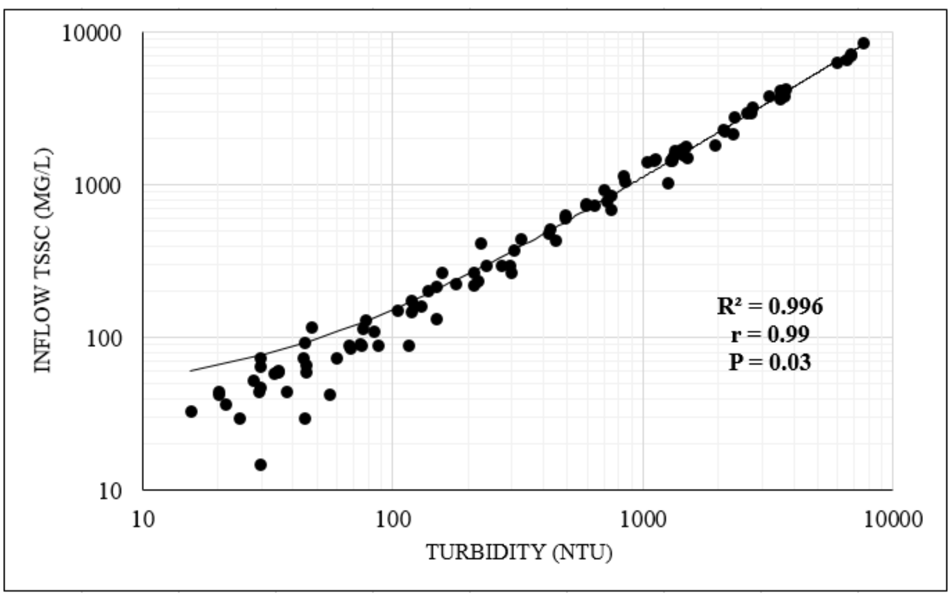


Figure 4.12: Relationship between turbidity and TSSC in Kalundu River during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

During the long rainy season, the TSSC in Kalundu River ranged from 0.002mg/L to a maximum of 7,405.77 mg/L with a mean value of 592.812 mg/L. In the same season, the TSSC downstream ranged from 0 – 3,727.682 mg/L with a mean value of 190.549 mg/L. This study established a significant relationship between turbidity and TSSC given (r=0.99, R^2=0.996, P-value=0.03) (Figure 4.12). These results imply that an increase in the TSSC contributed to significant increase in turbidity of water in the river flow.

4.2.5 Relationship between River Discharge and Sediment Load

The association between river discharge and sediment load was established as shown in Figure 4.13. The results showed a significant relationship between river discharge and sediment load given that (R^2=0.36, r=0.61, p-value=0.001). This results imply that an increase in the river discharge during high river flow contributes to an increase in the sediment load. This is due to increased capacity of the river to transport sediment. The supply of significant amount of sediments into the Kalundu dam is greater during periods of river flows higher than about 0.6m^3/day. Figure 4.13 shows that below a river discharge of 0.6m^3/day the river does not transport significant amount of sediment load.

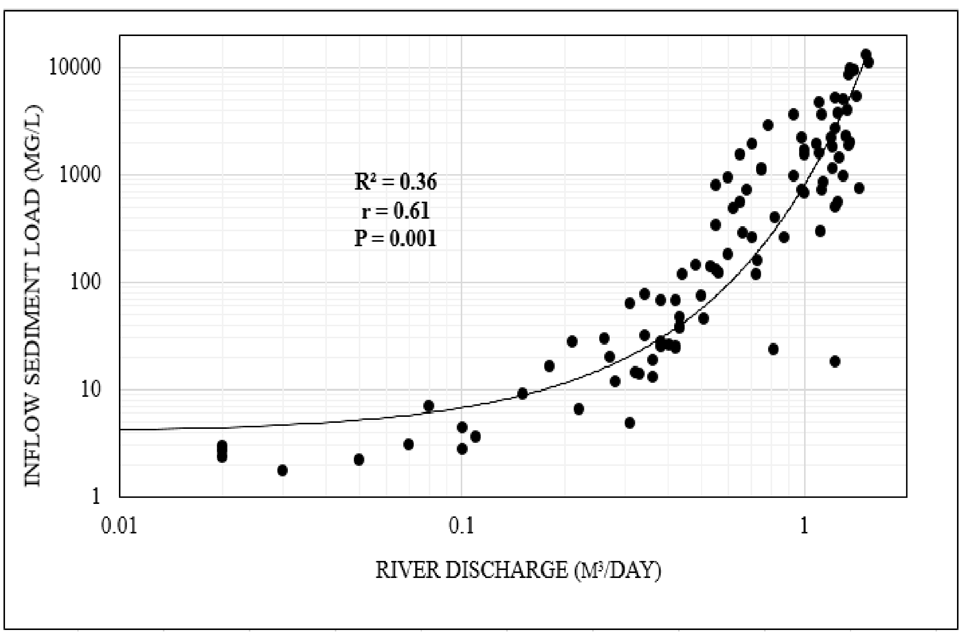


Figure 4.13: Relationship between river discharge and sediment load in Kalundu River during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

It is likely that there is no discharge of sediments into the dam when river discharge is less than 0.5m^3/day due to low river velocities. The results presented in Figure 4.14 show that there is a significant relationship between river discharge and sediment load during long rain season given that (R^2=0.24, r=0.49, P-value=0.02). Similar to the observation made in Figure 4.13, the results indicate that there is a significant relationship between river discharge and sediment yield that gets into the Kalundu reservoir. The study therefore rejects the null hypothesis that there is no significant relationship between river discharge and sediment yield. Relatively higher sediment loads and sediments transportation into the Kalundu reservoir is likely to occur during high river flows (>0.5m^3/day) during the long rains and when the river discharge is below f 0.4m^3/day the river does not transport a significant sediment load (Figure 4.14).

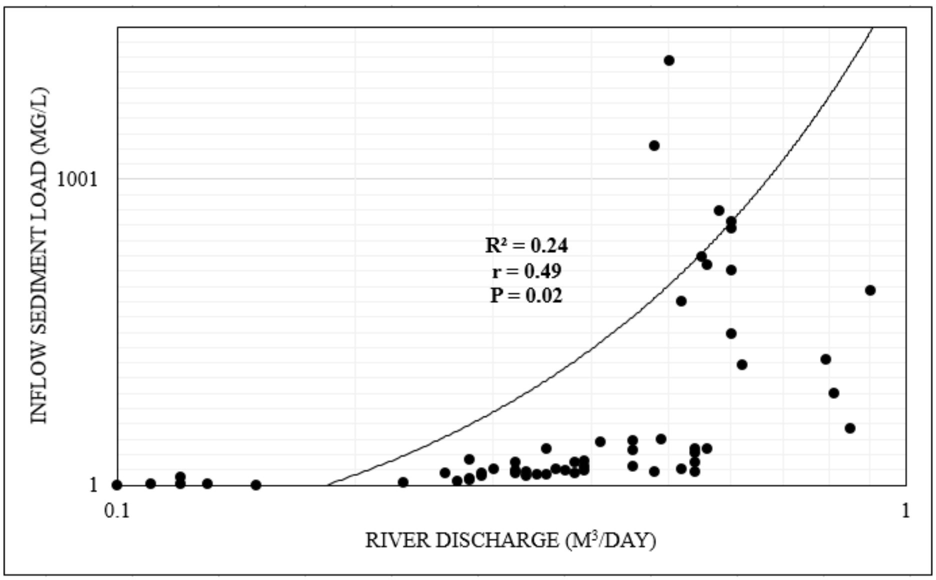


Figure 4.14: Relationship between river discharge and sediment load in Kalundu River during the long rainy season (April-June 2021) (Source: Kasuki, 2022).

Figure 4.15 shows the association between river discharge and water turbidity in Kalundu River. The mean turbidity was found to be 1003.499 NTU. There is a significant relationship between river discharge and turbidity (r=0.67, R^2=0.45, P-value=0.001). The results imply that high turbidity in the river is experienced during periods of high flows. However, when river discharge is below 0.4m^3/day, water is very clear and turbidity is very low.

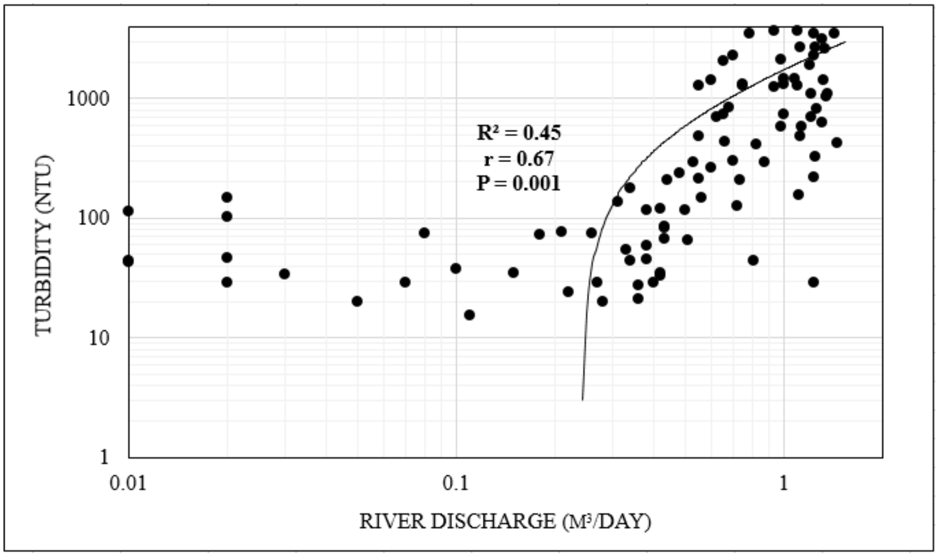


Figure 4.15: Relationship between river discharge and turbidity in the Kalundu River during the short rainy season (October 2020 – February 2021) (Source: Kasuki, 2022)

Figure 4.16 shows a positive relationship between river discharge and turbidity. The highest river discharge reached during the long rainy season was 0.98m^3/day and lowest of 0.001m^3/day.

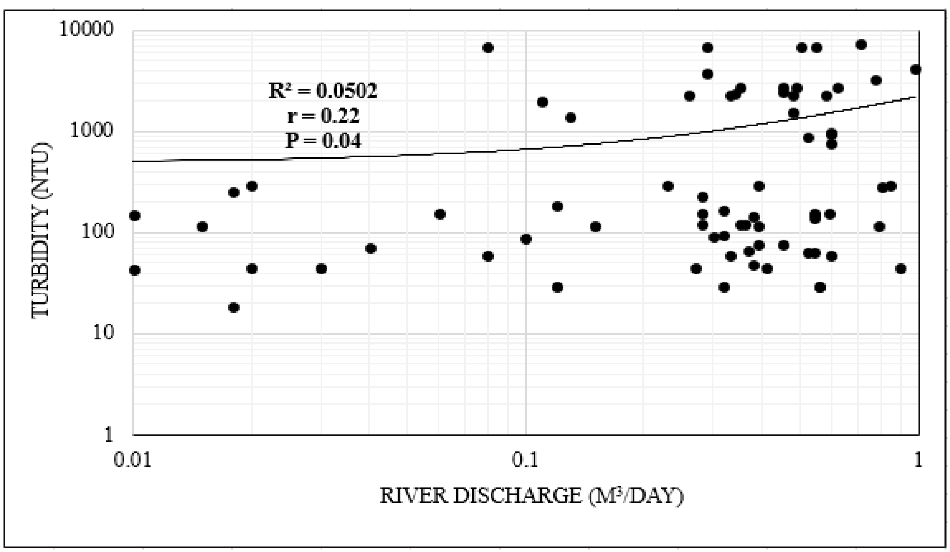


Figure 4.16: Relationship between river discharge and turbidity in the Kalundu River during the long rainy season (April-June 2021) (Source: Kasuki, 2022)

The mean river discharge was $0.35m^3$/day while the mean turbidity was 1,123.284 NTU. There is a significant relationship between river discharge and turbidity (r=0.22, R^2=0.0502, P-value=0.04). The results presented in Figure 4.16 show that high turbidity is experienced in the times of high flows in the time of the long rains.

4.3 Reservoir Sedimentation and Sediment Supply

The accumulation of sediments in the Kalundu dam reservoir depends on the quantity of sediment moved by the river and sediment trapping efficiency of the reservoir. The trapping of sediments can be assumed to be the difference between sediment inflow and outflow.

4.3.1 Relationship between Water Level at the Spillway and River discharge

The relationship between water level at the spillway and river discharge was established by taking measurements of water levels at the spillway in the period between April and June in 2021 and between October 2020 and February in 2021. The results showed a significant variability of reservoir water levels. This variability was due to changes in the river discharge. Figure 4.17 shows the negative water levels at the spillway against the river discharge measured in Kalundu River.

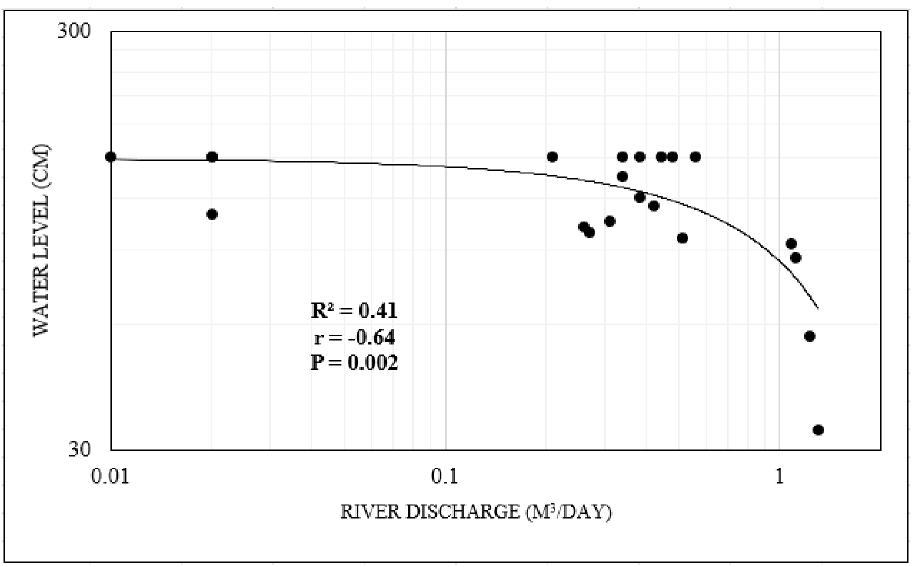


Figure 4.17: Relationship between spillway dam water levels and Kalundu River discharge (Source: Kasuki, 2022)

The zero (0) mark of dam water level was measured when the spillway was completely full. The dam water level increased as the water in the spillway dropped. During the short rainy season, the water levels ranged from 0.86 to 1.5m with a mean value of 1.2m. The maximum dam water level at the spillway was 1.5m. There was a significant relationship between river discharge and dam water level at the spillway (R^2=0.41, r=-0.64, P-value=0.002) (Figure 4.17). The water level at the spillway decreased as the river discharge increased.

4.3.2 Sediment budget

The analysis on sediment budget was derived from the measurements taken for Kalundu River discharge (Q) and TSSC during both the short and long rain seasons in 2020 and 2021 respectively. During mid-November 2020 and towards the end of that month, a significant quantity of sediment load got trapped in the reservoir 97.28% and 24.86%, respectively (Annex VII). TSSC played a major role in the sedimentation of the reservoir since large proportions of TSS got trapped in the reservoir. During the short rainy season, the volume of sediments supplied into the reservoir was defined by the overall load transported by Kalundu River. Sediments load resulting from erosion and runoff in the land surface were not included in this study.

Deposition of sediments into the reservoir ranged from 0.03-12,975.74 m^3/day with an average of 1,288.74 m^3/day. During the short rains season, a total of 134,028.84 m^3 (200,043tons) of sediments were deposited into the reservoir. The total sediment outflow was 108,074.10 m^3 (161,304.478 tons) with an average of 1,038.17 m^3/day (1,549.51 tons/day). The sediments inflow was greater than the outflow as a result of trapping of 25,954.74 m^3 (38,738.418 tons) of sediments in the reservoir. Trapping of sediments occurred at an average rate of 251.99 m^3/day (376.104 tons/day) during the short rainy season giving a trapping efficiency of 47.73%.

During the long rain season, a total of 28,448.87 m^3 (42,461 tons) of sediments were deposited into the reservoir. The total sediment outflow was 11,282.08 m^3 (16,838.925

tons) at an average of 150.43 m^3/day (224.522 tons/day). The sediments inflow was greater than the outflow as a result of trapping of 17,166.79 m^3 (25,622 tons) of sediments in the reservoir (Annex VIII). Trap efficiency of Kalundu reservoir during the short rains was 47.73% compared to 55.91% during the long rain season. These findings affirm that more deposition of sediments into the reservoir likely occurred during the long rain season than in during the short rain season.

The analysis showed that at 95% confidence interval, there is a significant relationship between the rate at which sediments get deposited into the Kalundu reservoir and the sediment budget given that during the short rainy season, R^2= 0.38, r= 0.61, p-value= 0.000, F=61.05, Sig. F value=0.000 while during the long rainy season; R^2= 0.59, r= 0.77, p-value= 0.000, F=101.06, Sig. F value=0.000. This implies that the increasing amount of sediments that get deposited into the reservoir has a significant influence in the increasing sediment budget. With these results the study rejects reject the null hypothesis that stated that; there is no significant relationship between reservoir sedimentation rates and sediment budget in Kalundu Dam in the period 2013 to 2021.

4.3.3 Estimation of Reservoir Sedimentation Rates

Estimation of reservoir sedimentation rates was done by conducting a fieldwork exercise in December 2021 to measure the current water depth in Kalundu dam. Figure 4.18 shows the pattern followed during the measurement of water depth in Kalundu reservoir. The current storage capacity of Kalundu dam was obtained from the product of mean water depth and the total surface area of the water in the dam. The results of bathymetric survey showed that there is a significant variation in water depth in the dam. In the upper zones of the reservoir, the water depth ranged from 1.1-2m. In the middle zone of the reservoir, the water depth ranged from 2.8-3.5m. In the lower zone of the reservoir, the water depth ranged from 2.2-2.8m. The survey showed that the lower and middle zone of the reservoir was relatively deeper compared to the upper zone (Figure 4.19). From the bathymetric analysis, more accumulation of sediments occurred at the upper and lower parts of the reservoir which contributed to decrease in the water depth. Less significant accumulation of sediments occurred in the middle section of the reservoir.

The mean water depth in the dam as of December 2021 was 2.1m. The total surface area of the dam (A_r) was found to be 43,199.53m^2. The estimated reservoir storage capacity of the dam as at December 2021 was 149,902m^3. The design capacity of Kalundu Dam after it was rehabilitated in 2013 was 500,000m^3 with original surface area (A_r) of 48,500m^2 and a depth of 13.5m. These results show that the total storage volume of the reservoir had decreased by 350,098m^3 from 500,000m^3 to 149,902m^3.

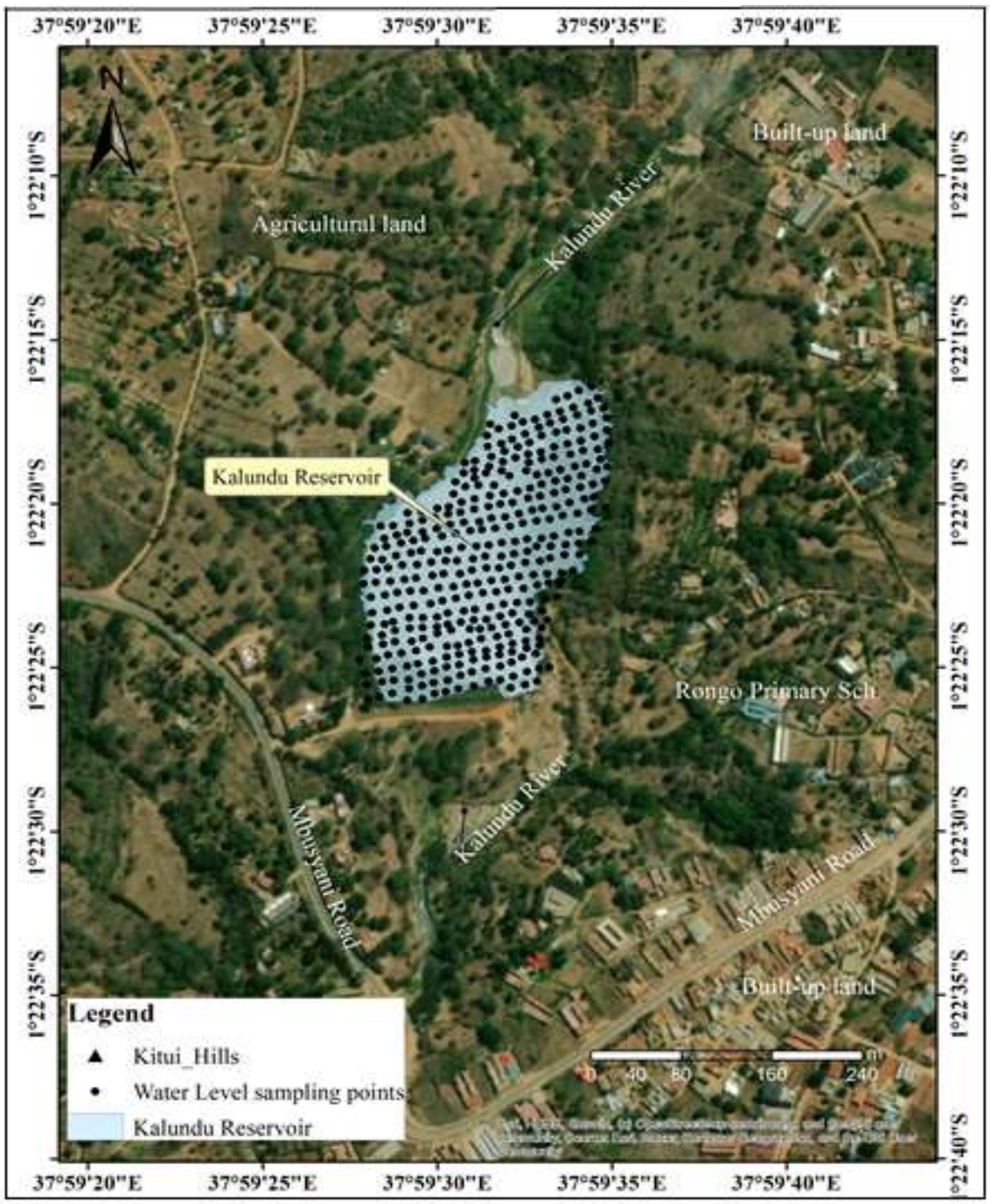


Figure 4.18: Water level sampling points in the Kalundu reservoir and land use and land cover patterns in the surrounding area (Source: Kasuki, 2022)

This is equivalent to approximately 70% loss in reservoir storage capacity which can be attributed to sediment deposition. The total surface area of the reservoir decreased from 48,500m^2 to 43,199.53m^2 which is a decrease of 5,300.47m^2, equivalent to 11%. The design water depth reduced from 13.5m in 2013 to 3m in December 2021 which is approximately 70% decrease.

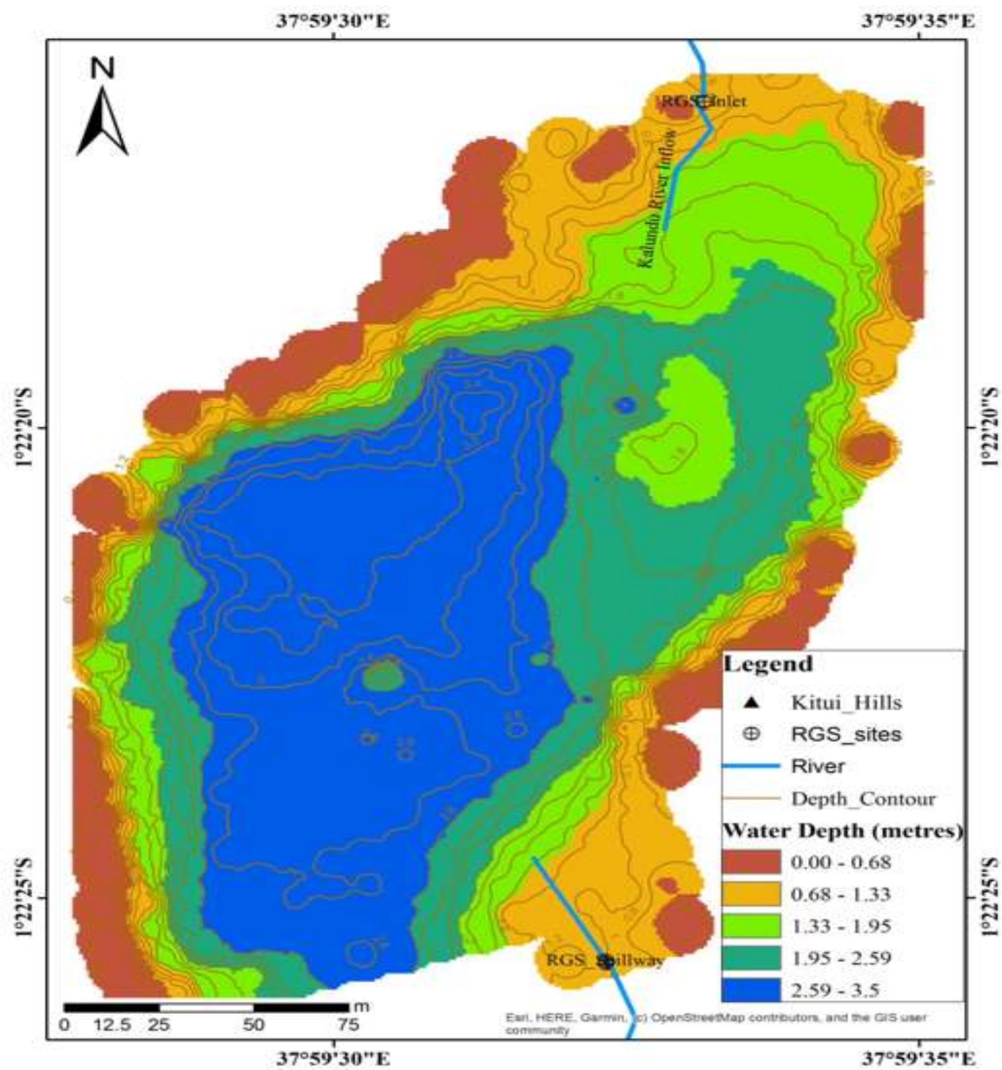


Figure 4.19: Bathymetry of Kalundu reservoir based on measurements carried out in December 2021 (Source: Kasuki, 2022)

These results show that since 2014, the lost storage capacity of the reservoir is equivalent to the volume of sediments that had accumulated. This was calculated by subtracting the original reservoir storage capacity (500,000m^3) from the current reservoir storage capacity (149,902 m^3). Therefore the dam has lost 350,098m^3 which is equivalent to 522,534 tons of sediments. This yields a mean annual sedimentation rate of 65,317tons/yr for a period of 8 years. The same translates to a rate of 2,722 tons/km^2/yr.

4.3.4 Estimation of Useful Life Span of the Reservoir (UL)

Estimation of useful life span of the reservoir (UL) was determined using equation 10 presented in chapter three. The useful life span of the reservoir (UL) is the number of years needed for the reservoir storage volume to be reduced by 50%. The volume of the water in the reservoir was 149,902m^3 and the initial storage capacity of the reservoir immediately after rehabilitation in 2013, was 500,000m^3. The total amount of accumulated sediments by December 2021 was obtained by getting the difference between the initial reservoir storage capacity and the correct volume of water. This resulted to 350,098m^3 of accumulated sediments. Using Equation 13 in section 3.5.5 the Useful Life Span (UL) of Kalundu reservoir was found to be about 3 years.

4.4 Soil Erosion and Potential Sources of Sediments Deposited in Kalundu Reservoir

Soil erosion and potential sources of sediments deposited in Kalundu reservoir was determined by evaluating sources of sediments through LULC change analysis and spatial examination of soil erosion using MUSLE model. Sediment characteristics in terms of particle size distribution was also assessed. The outcome from these analyses are discussed in the sections below.

4.4.1 Land Use and Land Cover Change Analysis

Land use and land cover change analysis was done by successfully identifying eight different land cover types through a pixel based supervised image classification using Erdas Imaging 2016. These classes of land cover included water body, forest land, built-up and bare land, shrubs, cropland, cropland/bare land, grassland and built-up land/sands (Table 4.1).

4.4.1.1 LULC Changes in the Period between 2000 and 2020

LULC changes in the period between 2000 and 2020 showed a significant change in

Kalundu sub-basin (Figure 4.22 a and b). The land cover types that were slightly affected positively or negatively (Table 4.2) within the period between 2000 and 2020 were grasslands, shrubs and forest lands (Table 4.2).

Table 4.1: List of LULC types in Kalundu sub-basin (Source: Kasuki, 2020)

LULC Classes	Description
Water body	This is the land covered by water bodies such as a lake, perennial river channel, river canal, water reservoir, and ponds
Forest land	Dense trees particularly the evergreen ones, sparse woodlands and broad-leaved trees along river banks
Built-up/bare land	These are areas will old buildings with low reflectance roofing material e.g rusted iron sheets that mostly would appear brown in color in normal light as similar to bare soils.
Shrubs	Areas covered by natural short and thorny trees and bushes
Cropland	This class is defined based on the land use and not what is observed on the land. Therefore, these are farmlands with crops at different stages.
Crops/bare land	These are tilled farmlands with eroded soil surfaces and exposed soils covered with sparse crops.
Grassland	These are areas covered with grass as the main land cover. Mostly observed in ranches, grazing areas and plain lands where cropping is limited.
Built-up/sands	This describes the rural and urban residential and industrial areas including the pavements and sands occurring along the dry riverbeds

In the year 2010 shrubs covered over 1500ha throughout the period while the rest of the land cover type faced significant changes (Figure 4.22). The built-up, areas covered with sands and forest were significantly higher in 2020 covering 297ha (5%) and 1964ha (35%) than in 2000 covering 80.9ha (1%), and 363ha (7%), respectively. The results also show that water bodies were significantly few throughout the period. The area covered by croplands was also large in 2000 occupying about 1750ha (%) compared to the year 2010 (292ha, 5%) and 2020 (900ha, 16%). The changes in LULC were presented in terms of decreases or increases between the year 2000 and 2020 (Table 4.2). The decreases were shown as negative values while the increased land coverage was presented as positive values. The outcome in Table 4.2 indicate that the water bodies rose by 11ha (0.2%) between 2000 and 2020. There was a slight increase of water bodies by 2ha in the period between 2000 and 2010 (Table 4.3). In the period between 2010 and 2020 the area covered by the water bodies increased by 9ha (Table 4.4).

Table 4.2: Land use and land cover patterns in Kalundu sub-basin in 2000 and 2020 (Source: Kasuki, 2022)

LULC Classes	**LULC 2000**		**LULC 2020**		**LULC Change 2000-2020**	
	Area (ha)	**% Coverage**	**Area (ha)**	**% Coverage**	**Area (ha)**	**% Coverage**
Water body	0.9	<1%	12	<1%	11	0.20%
Forest land	362.6	7%	1964.3	35%	1602	28.90%
Built-up/bare land	665.1	12%	108.1	2%	-557	-10.10%
Shrubs	800.4	14%	1488.1	27%	688	12.40%
Cropland	1728	31%	899.8	16%	-828	-14.90%
Crops/bare land	680.7	12%	479.9	9%	-201	-3.60%
Grassland	1223	22%	293.8	5%	-929	-16.80%
Built-up/sands	80.9	1%	297.4	5%	217	3.90%
Grand Total	**5541.5**	**100%**	**5541.5**	**100%**		

In the period between the year 2000-2020, the built-up land/bare land decreased by 10.1%. In the period between 2000-2010, the built-up area/bare land decreased by 12%. Shrubs increased by 12.4% within the last two decades but the croplands and grasslands decreased by 14.9% and 16.8% respectively. The sand areas slightly increased by 3.9% within 2000 and 2020. Generally, the shrubs area, water bodies, forest lands and built-up areas including the sands area coverage experienced significant increase in the period between 2000 and 2020 while grasslands decreased by 17%, within the same period (Table 4.2). In the period between the year 2000 and 2020, the croplands have decreased by 14.9% and 25.9% (Table 4.2 and Table 4.3) respectively. The area under grassland cover increased by 5.5% in the period between 2000 –2010 but decreased by 16.8% in the period between 2000 and 2020. The shrubs have increased by between 12.4% and 19.2% while the forest cover increased by 1602ha (28.9%) between the year 2000 and 2020 and by 1300ha (23.5%) in the period between 2000 and 2010 (Table 4.3). The increase in forest cover as a result of reforestation and shrubs is important in view of their role in controlling hydrology of the basin. Table 4.3 shows the LULC changes that occurred in the period between 2000 and 2010. During that period, the area under water bodies had the lowest increase by 2ha compared to the other land use and land cover categories. In the period between 2000 and 2010, the forests, shrubs and grasslands increased by 23.5%, 19.2% and 5.5%, respectively. The built-up/bare lands as well as the built-up/sands reduced by 12% and 0.4%, respectively. Similarly, in the same period, the area under cultivation including the croplands reduced by between 25.9% and 10%.

Table 4.3: Land use and land cover change in Kalundu sub-basin in 2000 and 2010 (Source: Kasuki 2022)

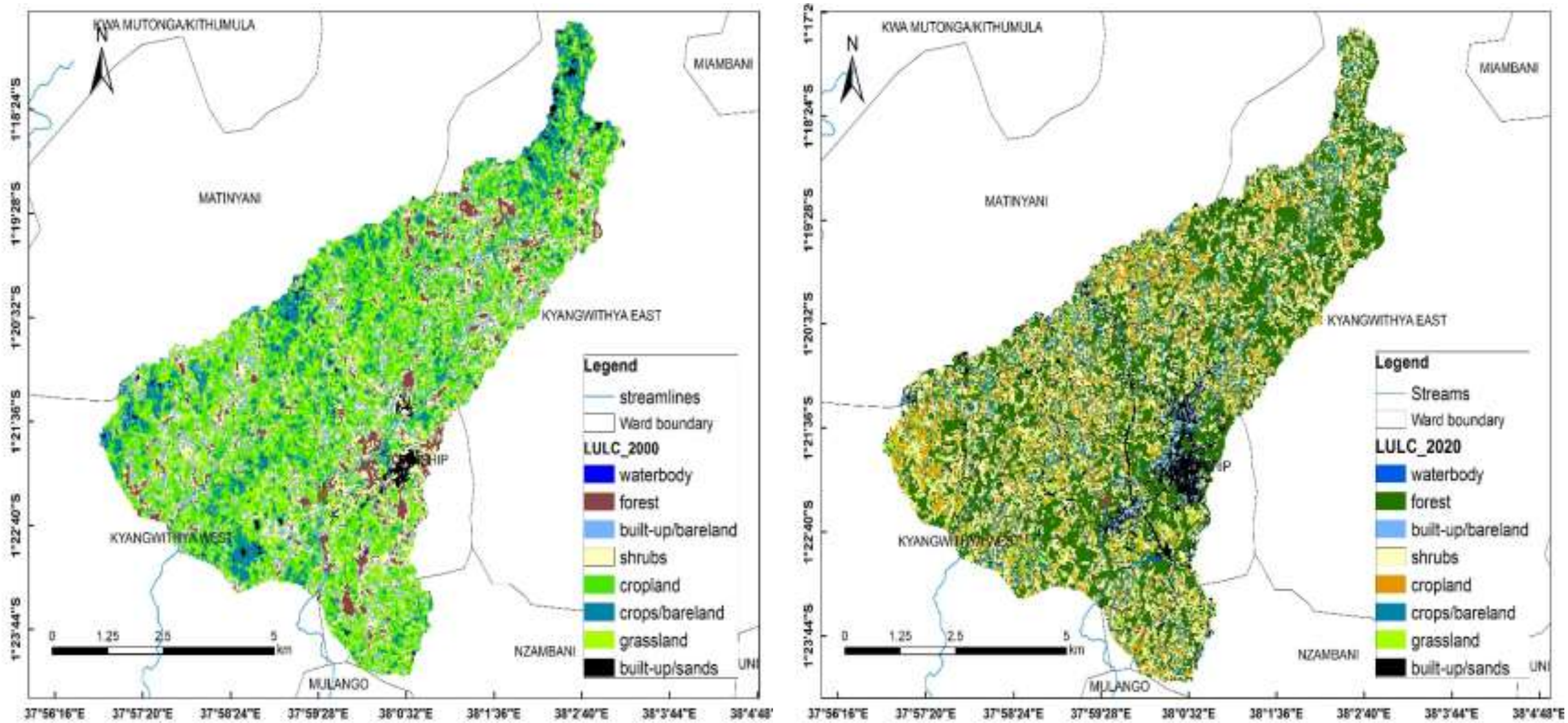
LULC Classes	**LULC 2000**		**LULC 2010**		**LULC Change 2000-2010**	
	Area (ha)	**% Coverage**	**Area (ha)**	**% Coverage**	**Area (ha)**	**% Coverage**
Water body	0.9	<1%	2.7	<1%	2	<1%
Forest land	362.6	7%	1663	30%	1300	23.50%
Built-up/bare land	665.1	12%	1.8	0%	-663	-12.00%
Shrubs	800.4	14%	1864.4	34%	1064	19.20%
Cropland	1728	31%	292.2	5%	-1436	-25.90%
Crops/bare land	680.7	12%	128.3	2%	-552	-10.00%
Grassland	1223	22%	1529.2	28%	306	5.50%
Built-up/sands	80.9	1%	59.9	1%	-21	-0.40%
Grand Total	**5541.5**	**100%**	**5541.5**	**100%**		

4.4.1.2 LULC Changes in the Period between 2010 and 2020

LULC changes in the period between 2010 and 2020 showed a significant change in Kalundu sub-basin (Figure 4.24). The land covered by the water bodies was significantly small in the period between 2010 compared to 2020 (Table 4.4). During that period, the area under water bodies still had the lowest increase by 9ha (0.2%) compared to the rest of the land use and land cover categories. In the period between 2010 and 2020, the forest cover had increased by 5.4%. The area under shrubs and grasslands however decreased by 6.8% and 22.3%, respectively over the same period. In the period between 2010 and 2020, the built-up/barelands as well as the built-up/sands increased by 1.9% and 4.3%, respectively. Similarly, the area under cultivation that included the croplands and crops/barelands increased by between 11% and 6.3%.

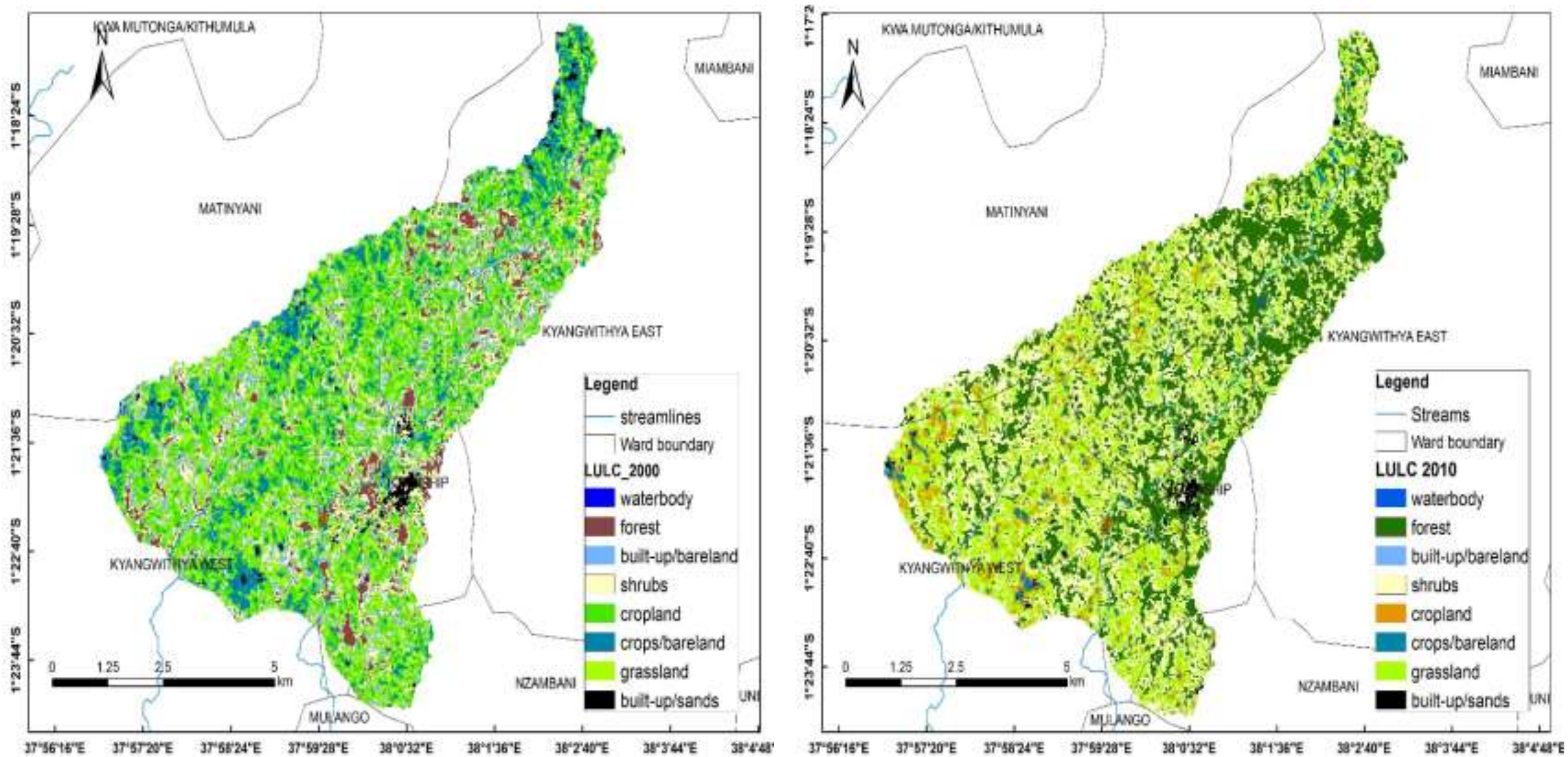
Table 4.4: Land use and land cover changes in Kalundu sub-basin in 2010 and 2020 (Source: Kasuki 2022)

LULC Classes	**LULC 2010**		**LULC 2020**		**LULC Change 2010-2020**	
	Area (ha)	**% Coverage**	**Area (ha)**	**% Coverage**	**Area (ha)**	**% Coverage**
Water body	2.7	<1%	12	<1%	9	0.20%
Forest land	1663	30%	1964.3	35%	301	5.40%
Built-up/bare land	1.8	0%	108.1	2%	106	1.90%
Shrubs	1864.4	34%	1488.1	27%	-376	-6.80%
Cropland	292.2	5%	899.8	16%	608	11.00%
Crops/bare land	128.3	2%	479.9	9%	352	6.30%
Grassland	1529.2	28%	293.8	5%	-1235	-22.30%
Built-up/sands	59.9	1%	297.4	5%	238	4.30%
Grand Total	**5541.5**	**100%**	**5541.5**	**100%**		



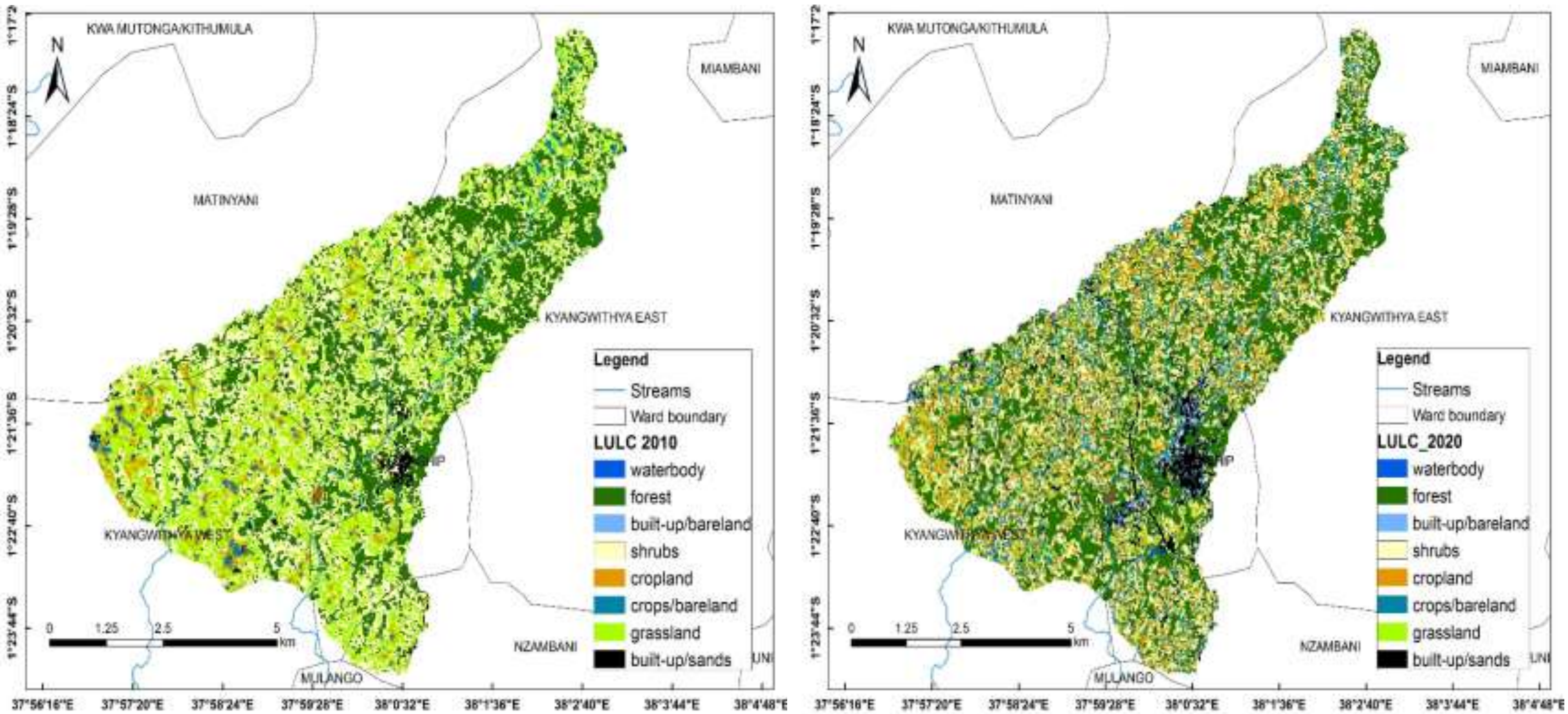
(a) (b)

Figure 4.20: Land use and land cover change in the Kalundu sub-basin in 2000 (a) and in 2020 (b) (Source: Kasuki 2022)



(a) (b)

Figure 4.21: Land use and land cover change in the Kalundu sub-basin in 2000 (a) and in 2010 (b) (Source: Kasuki, 2022)



(a) (b)

Figure 4.22: Land use and land cover change in the Kalundu sub-basin in 2010 (a) and in 2020 (b) (Source: Kasuki, 2022)

4.4.1.3 Accuracy assessment in the LULC change analysis

The results presented in the above sections were derived from image classification using maximum likelihood algorithm which was achieved at an overall accuracy of 77.8% as shown in Table 4.5. A total 54 ground truthing sites were used to assess correctness of the classified land use and land cover types in the study area.

Table 4.5: LULC analysis accuracy assessment for the period 2000-2020 (Source: Kasuki, 2022)

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Water body	6	7	6	100%	86%
Forest	15	15	13	87%	87%
Shrubs	3	2	2	67%	100%
Grassland	7	5	3	43%	60%
Built-up/bare land	8	6	5	63%	83%
Cropland	4	3	3	75%	100%
Crops/bare land	4	5	4	100%	80%
Built-up	7	10	6	86%	60%
Totals	54	53	42		
Overall Classification Accuracy		**77.8%**			

Table 4.6: LULC changes in Kalundu sub-basin in the period between 2000 and 2010 (Source: Kasuki 2022)

		2010															
		Water body		**Forest land**		**Built-up/bare land**		**Shrubs**		**Cropland**		**Crops/bare land**		**Grassland**		**Built-up/sands**	
	LULC Classes	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**
2000	Waterbody	**0.1**	**3%**	0.8	0%		0%	0.0	0%		0%		0%		0%		0%
	Forest land	1.3	49%	**250.6**	**15%**		0%	78.6	4%	3.7	1%	0.3	0%	27.3	2%	0.7	1%
	Built-up/bare land	0.0	1%	247.7	15%	**0.3**	**18%**	280.6	15%	14.0	5%	3.8	3%	113.5	7%	5.2	9%
	Shrubs	1.0	36%	478.5	29%		0%	**238.8**	**13%**	4.4	1%	1.1	1%	70.7	5%	5.9	10%
	Cropland	0.1	4%	280.0	17%	0.1	6%	597.4	32%	**119.4**	**41%**	27.1	21%	696.1	46%	7.7	13%
	Crops/bare land		0%	41.4	2%	0.7	37%	132.4	7%	116.6	40%	**76.6**	**60%**	299.8	20%	13.2	22%
	Grassland	0.1	5%	353.2	21%		0%	523.0	28%	28.8	10%	5.2	4%	**310.0**	**20%**	2.7	4%
	Built-up/sands	0.0	1%	10.8	1%	0.7	40%	13.6	1%	5.3	2%	14.2	11%	11.7	1%	**24.5**	**41%**
	Grand Total	**2.7**	100 %	**1663.0**	100 %	**1.8**	100 %	**1864.4**	100%	**292.2**	**100%**	**128.3**	100 %	**1529.2**	100 %	**59.9**	100 %

Table 4.7: Land use and land cover changes in Kalundu sub-basin in the period 2010 and 2020 (Source: Kasuki, 2022)

		2020															
		Water body		**Forest land**		**Built-up/bare land**		**Shrubs**		**Cropland**		**Crops/bare land**		**Grassland**		**Built-up/sands**	
	LULC Classes	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**
	Water body	**0.1**	**1%**	2.1	0%		0%	0.2	0%		0%	0.1	0%	0.0	0%	0.2	0%
	Forest land	4.2	35%	**1085.4**	**55%**	24.5	23%	332.9	22%	79.8	9%	29.3	6%	18.4	6%	88.5	30%
	Built-up/bare land		0%		0%	**0.1**	**0%**	0.1	0%	0.2	0%	0.0	0%	0.7	0%	0.8	0%
	Shrubs	2.6	21%	619.8	32%	41.3	38%	**643.6**	**43%**	287.5	32%	112.2	23%	68.8	23%	88.6	30%
	Cropland	0.9	8%	18.6	1%	4.0	4%	51.6	3%	**100.7**	**11%**	55.5	12%	46.5	16%	14.7	5%
	Crops/bare land	2.2	19%	6.5	0%	0.7	1%	15.8	1%	33.0	4%	**36.9**	**8%**	25.5	9%	7.8	3%
2010	Grassland	1.7	14%	230.5	12%	28.9	27%	441.5	30%	393.8	44%	242.1	50%	**126.2**	**43%**	64.6	22%
	Built-up/sands	0.3	2%	0.9	0%	8.4	8%	1.9	0%	4.7	1%	3.8	1%	8.0	3%	**32.0**	**11%**
	Grand Total	**12.0**	100%	**1963.9**	100%	**107.9**	100%	**1487.5**	100%	**899.7**	100%	**479.9**	100%	**294.0**	100%	**297.2**	100%

4.4.2 Assessment of Soil Erosion in Kalundu Sub-basin

Assessment of soil erosion in Kalundu sub-basin showed that Kalundu River sub-basin experiences significant rates of soil erosion. The extent of soil erosion was determined using MUSLE model. The MUSLE parameters that were determined are; slope length and Steepness factor (LS), Soil erodibility factor (K), Rainfall erosivity factor (R), Crop Management Factor (C), and Conservation practices factor (P).

4.4.2.1 Establishment of Topographic Factor

Establishment of topographic factor was done by describing two sub-factors (slope-length (L) and slope gradient which were derived from Digital Elevation Model (DEM) for Kalundu basin.

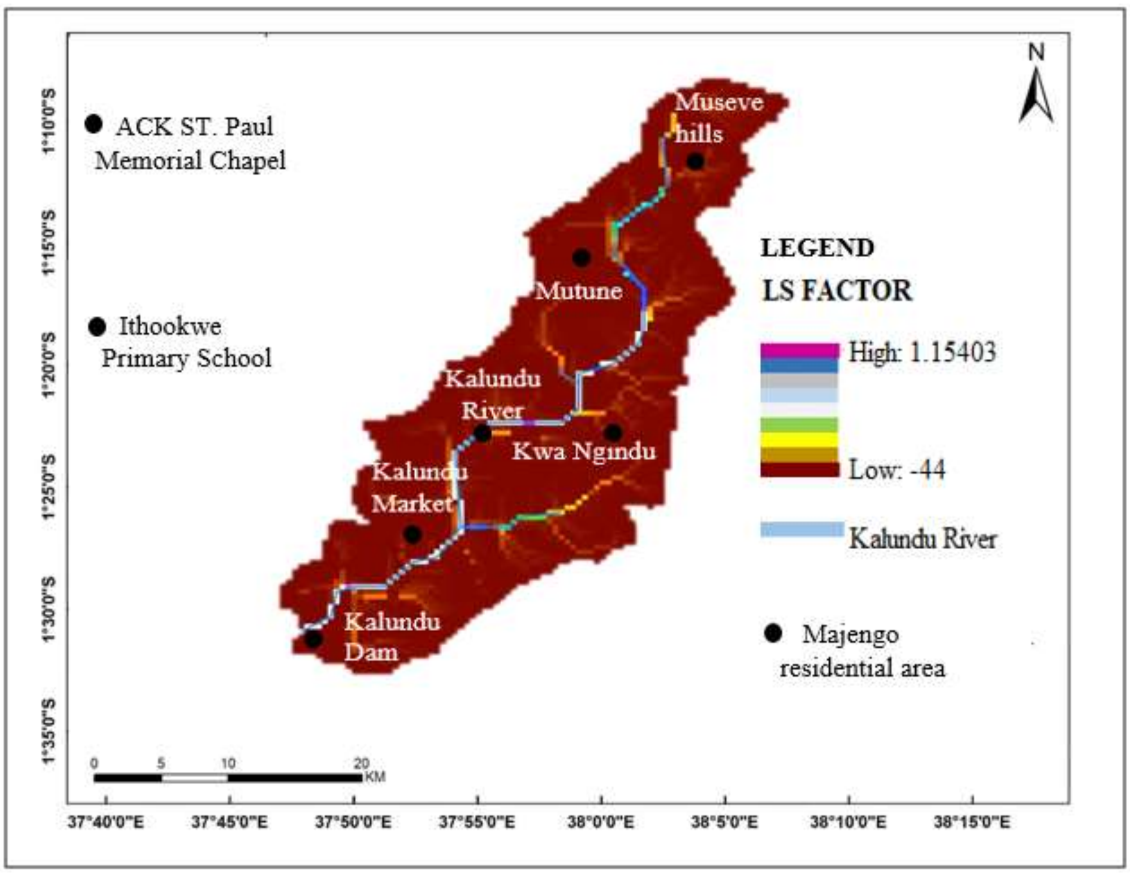


Figure 4.23: Spatial variability of topographic factor (LS) in Kalundu sub-basin (Source: Kasuki, 2022)

The results showed that LS factors ranged between -44 and 1.15 (Figure 4.23). The upper zone of the basin was comprised by short slope length and high slope gradient which were -0.09m and -1.8% respectively. The middle zone of the sub-basin was characterized by -7m slope length and -34.4% slope gradient. The lower zone of the sub-basin was comprised by -1.7m slope length and -14% slope gradient. These findings indicate that the upper zone of the Kalundu sub-basin is more susceptible to soil erosion.

4.4.2.2 Soil Erodibility Factor

Soil erodibility factor was determined using soil erodibility index map retreived from FAO's soil map of the study area. Kalundu sub-basin consists of poorly drained clayey soils. Soil erodability factor ranged from 0.018 to 0.04 (Figure 4.24). Erodability index of soils in the upper zone of the sub-basin was 0.04. In the middle zone of the sub-basin the erodability index ranged from 0.04 to 0.018. In the lower zone of the sub-basin the erodability index was 0.018. These results show that the upper zone of the basin is comprised by high soil erodability index, implying that the upper zone is susceptible to soil erosion.

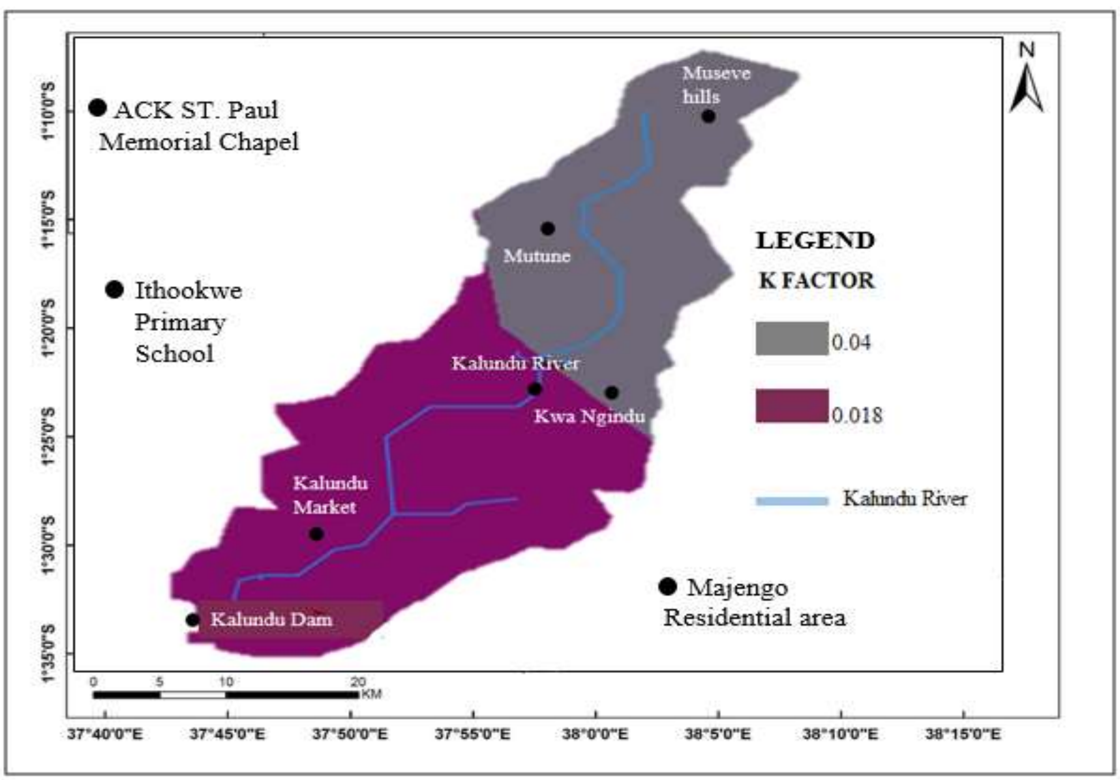


Figure 4.24: Soil erodibility factor (K) in Kalundu sub-basin (Source: Kasuki, 2022)

4.4.2.3 Rainfall Erosivity Factor

Rainfall erosivity factor (R) was established by using a standard method where the energy values of each rainfall event in a given period is summarized according to (Wischmeier and Smith, 1978). It was measured in mega joules/hectare (MJ/ha). The average annual rainfall amount in the sub-basin ranges between 600-1200 mm. The soil erodibility factor map generally corresponds to rainfall distribution in the study area (Figure 4.25).

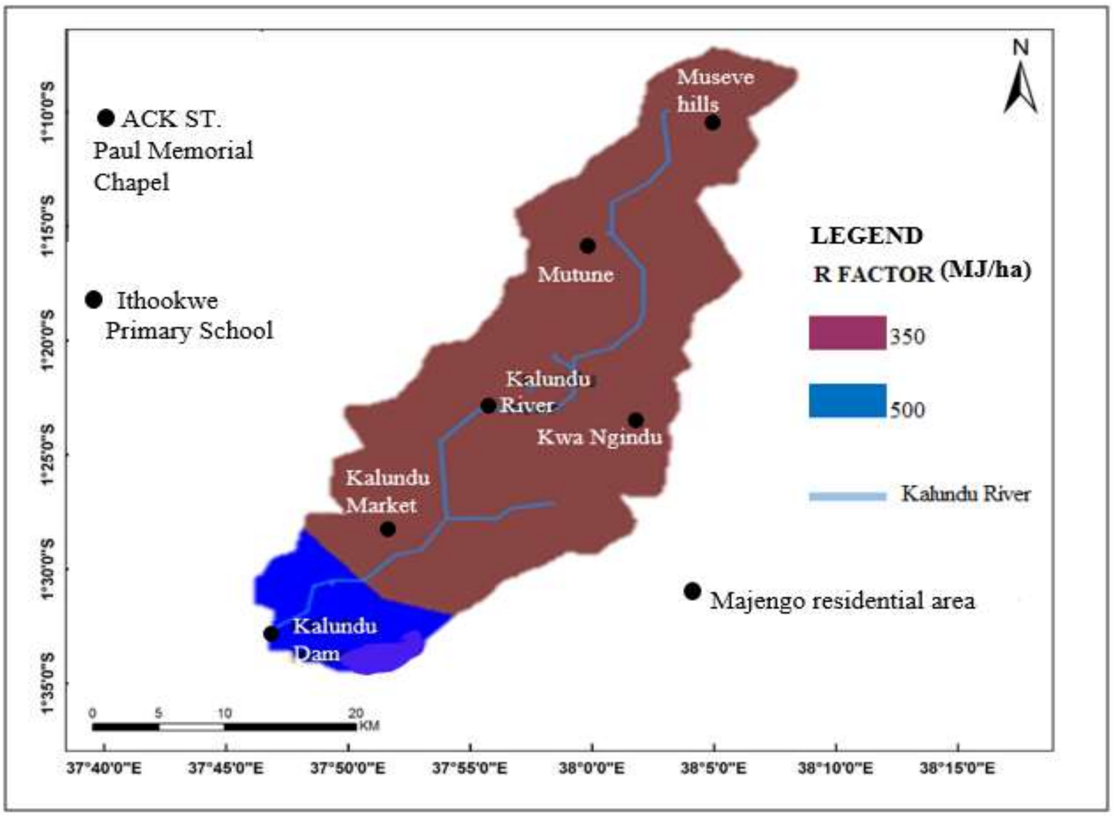


Figure 4.25: Rainfall erosivity factor (R) in Kalundu sub-basin (Source: Kasuki, 2022)

The mean erosivity factor in the upper zone of the sub-basin was 500 MJ/ha. In the middle zone of the sub-basin the rainfall erosivity factor was 500MJ/ha. In the lower zone of the sub-basin rainfall erosivity factor was 350MJ/ha. In general, the upper zones of the sub-basin were characterized by high rainfall erosivity factor (R). This indicates that the upper zones of Kalundu sub-basin are more susceptible to soil erosion than the middle and lower zones.

4.4.2.4 Crop Management Factor

Crop Management Factor (C) was determined according to Zhao et al. (2013). After supervised classification was done on Landsat imagery, four main LULC classes were derived namely; forest, agriculture, build-up and bare land. Crop management factor that ranges between zero and one were allocated to each of these land cover types use as follows: forest 0.003, agricultural land 0.63, build-up areas 0.09, and bareland 0.48 as shown in Figure 4.26. Low values of C-factor meant that no soil loss is experienced and the higher values implied a likelihood of soil loss.

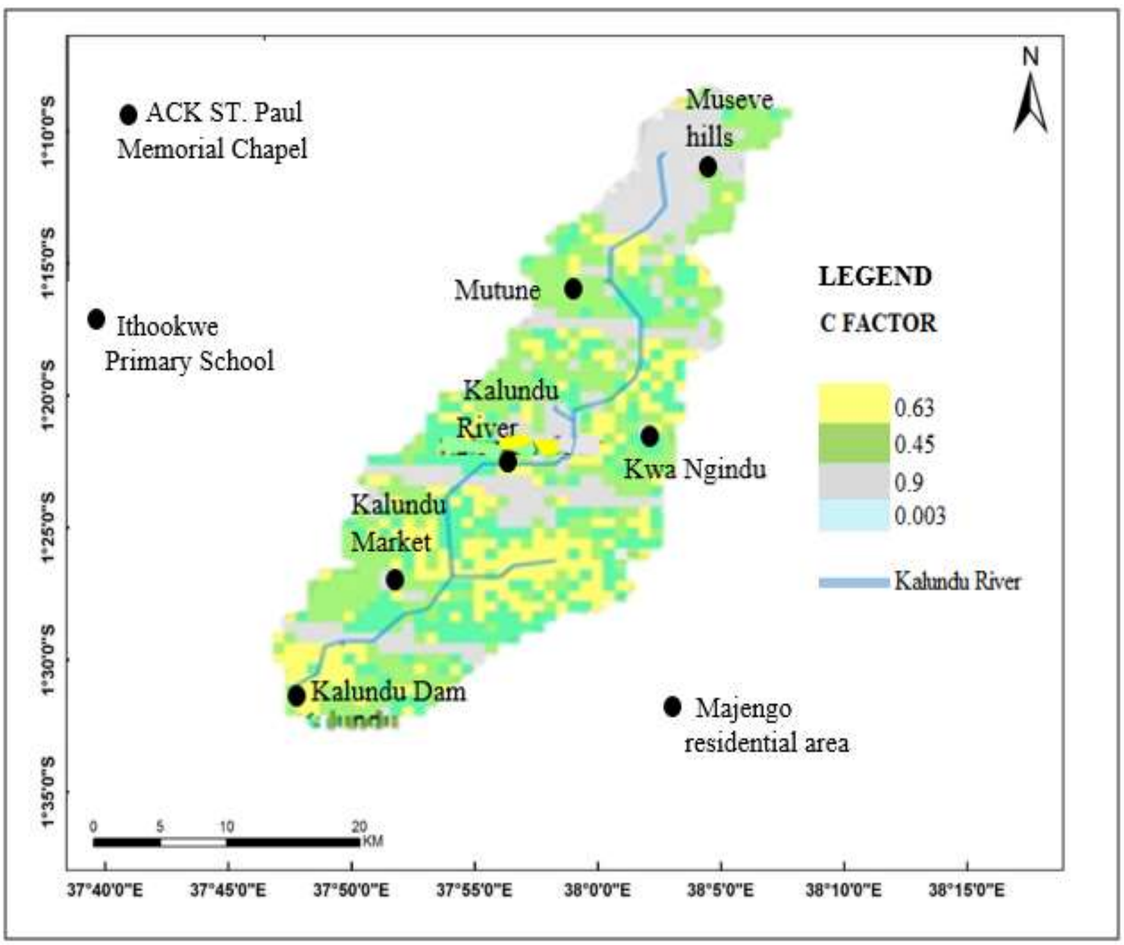


Figure 4.26: Crop management factor (C) in Kalundu sub-basin (Source: Kasuki, 2022)

4.4.2.5 Conservation Support Practices Factor

Conservation support practices factor (P) was determined according to Morgan (1994) and Ali and Hagos (2016). The P-factor presents the impacts of the conservation practices that decrease the quantity and rate of runoff, and consequently, decrease soil erosion. The P factor values were asigned over the land-use/land-cover map, depending on the management practices (Ali and Hagos 2016; Morgan, 1994). These P-factors are forest (0.1), agriculture (0.2), built-up (0.4) and bareland (0.7) (see Figure 4.27). Areas covered with forest are less likely to experience soil loss compared to barelands. Kalundu sub-basin seems to experience varied extent of soil erosion based on the P-factor variability.

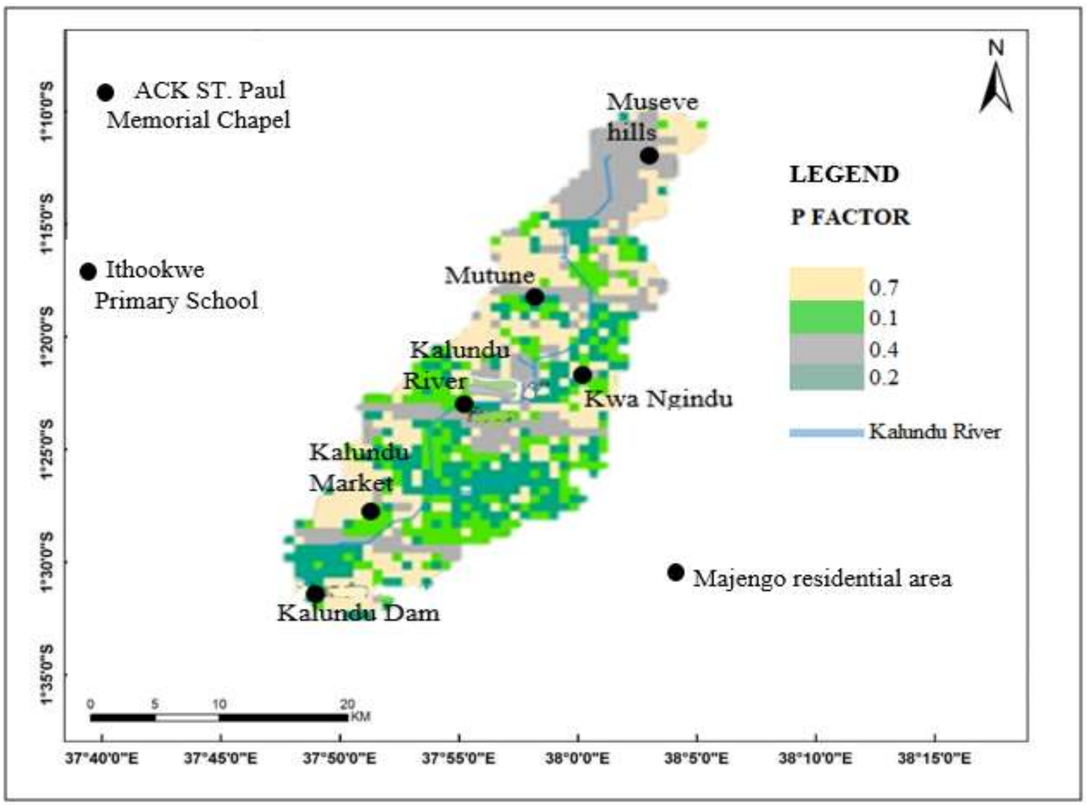


Figure 4.27: Conservation practices factor (P) in Kalundu sub-basin (Source: Kasuki, 2022)

4.4.2.6 Spatial Distribution of Soil Erosion in the Sub-basin

Spatial distribution of soil erosion in the Kalundu sub-basin showed a significant spatial distribution of soil erosion rates. (Figure 4.28). The spatial distribution of soil erosion rates in the sub-basin were established as a multiplicative function of five parameters namely; rainfall erosivity, soil erodibility, slope length and steepness, crop management and conservation factors. These input datasets were processed in ArcGIS environment using MUSLE to derive an integrated map showing the potential erosion in the study area shown in Figure 4.30.

In the upper zone of the sub-basin the rates of soil erosion ranged from 5 to 1230 tons/ha/yr (0.0005 to 0.123tons/km^2/yr). In the middle zone of the sub-basin the rates of soil erosion ranged from 1540 tons/ha/yr to 45,786 tons/ha/yr (0.154tons/km^2/yr to 4.5786 tons/km^2/yr). In the lower zone of the sub-basin the rates of soil erosion were relatively higher ranging between 15,783tons/ha/yr (1.5783 tons/km^2/yr) and 51,840tons/ha/yr (5.1840 tons/km^2/yr). Thus, the middle and lower zones of the sub-basin experiences high erosion rates.

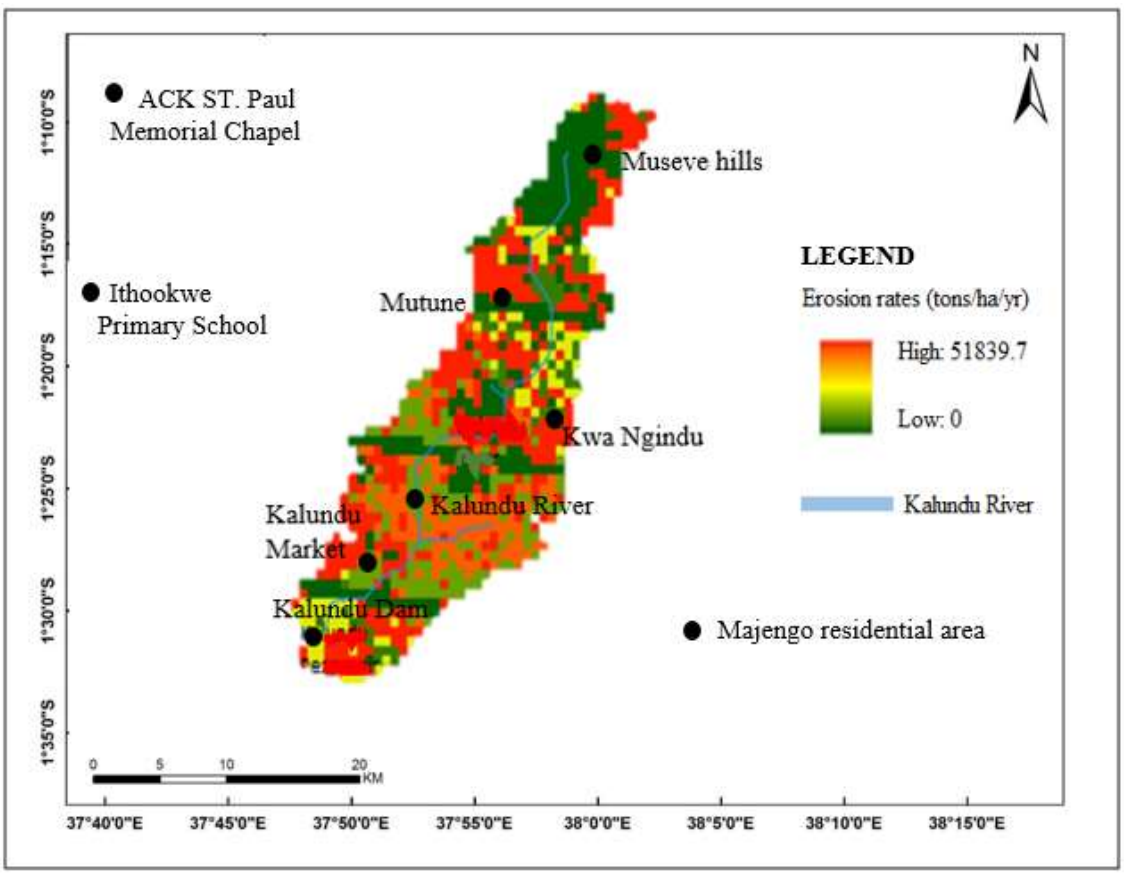


Figure 4.28: Potential soil erosion map of Kalundu sub-basin (Source: Kasuki, 2022)

4.4.3 Distribution of Particle Sizes of Sediments Deposited in Kalundu Reservoir

Distribution of particle sizes of sediments deposited in Kalundu reservoir was analysed using particle size analysis. The results showed that the sediments deposited in Kalundu reservoir were composed of sands (48%) at the upper zone compared to the middle zone of the reservoir where sand composition was 30% as well as the lower zone (35%) (Table 4.8). Sediments deposited at the upper zone comprised of sand (48%), silt (28%) and clays (24%). More silt and clays deposition dominated at the middle zone of the reservoir (35% and 36% respectively) than the sands. This concurs with the findings from a study undertaken to investigate the sedimentation patterns in Conowingo Dam occurring along the Susquehanna River in the New York (Palinkas and Russ, 2019).

More sands (35%) than silt (33%) and clay (32%) were deposited at the lower zone of the reservoir (see also Figure 4.29). This is attributed to the steep nature of geographical location of Kalundu reservoir which is relatively steep gradient mainland and the slope at the point where Kalundu reservoir connects with Kalundu River makes it easy for large portion of courser sediments to flow towards the lower section of the reservoir. The fact the length of Kalundu reservoir is about 365m also makes it to be categorized as a short length reservoir which make it possible for course sediment tend to flow towards the lower section of the dam.

Table 4.8: Particle size distribution for the sediments deposited in Kalundu reservoir in October 2021 (Source: Kasuki, 2022)

Sampling point at the dam	Ref.	Gravel (>2mm)	Sand (0.006-2mm)	Silt (0.002-0.06)	Clay (<0.002mm)	Specific Gravity
Upper Zone	ES	0	48	28	24	2.71
Middle Zone	MS	0	30	35	36	2.69
Lower Zone	SS	0	35	33	32	2.7

Generally, the sediments collected from the upper zone of the reservoir (ES) were poorly graded sandy clay loam while the sediments from the middle zone and at the lower zone

(MS and SS) were mainly clay loam (Figure 4.29).

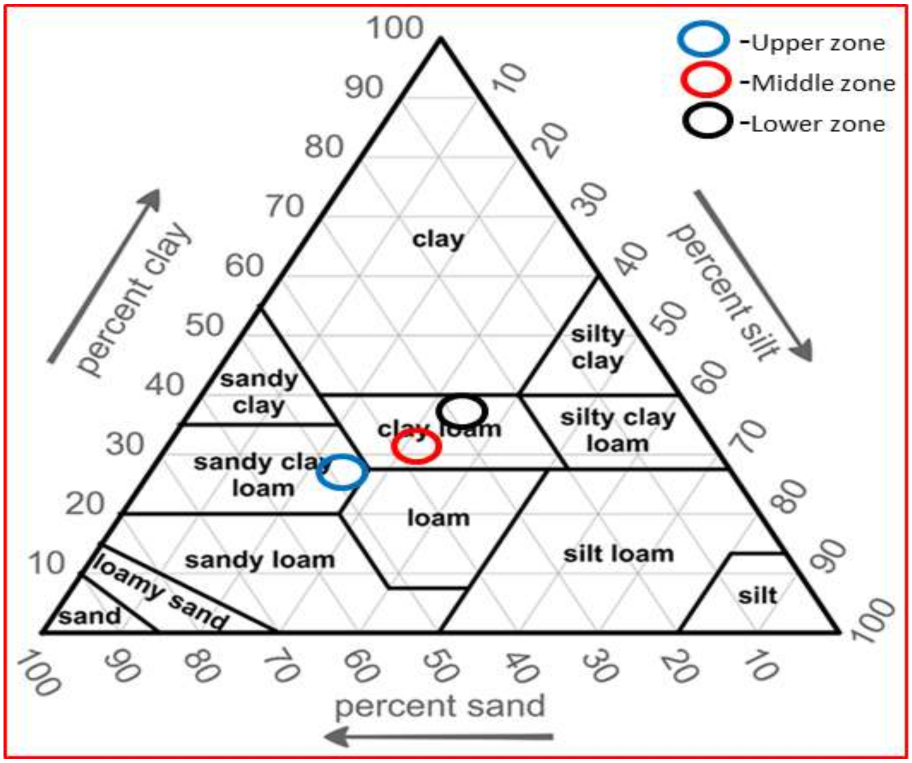


Figure 4.29: Classification of sediments deposited in Kalundu reservoir in October 2021 (Source: Kasuki 2022)

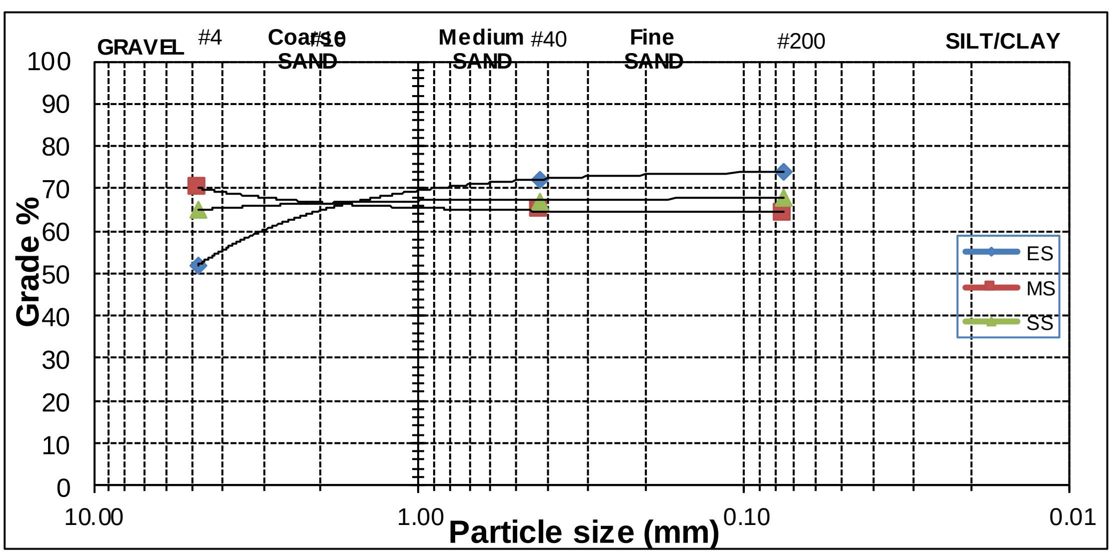


Figure 4.30: Gradation of sediments deposited in Kalundu reservoir in October 2021 (Source: Kasuki, 2022)

In terms of gradation of sediments, Figure 4.30 shows different grades of sediments that were established from the gradation test. The tested sediment samples were in three categories comprised of poorly graded sediments whereby 60-74% measured almost the same grade. There were more fine sands in the sediment samples obtained from the upper zone compared to the lower and middle zones of the reservoir. The percentage of clay in the sediments from the upper part of the reservoir was less (50%) compared to silt composition at the middle (70%) and sand at the lower parts of the reservoir (65%) (Figure 4.29).

4.5 Impact of Reservoir Sedimentation on Community Water Use

Impact of reservoir sedimentation on community water use was found to be significant. Several human activities in the study area were found to be impacted by the decreased storage of water in Kalundu Dam. The information gathered from selected respondents in this study showed that sedimentation in Kalundu reservoir affected the following activities. Sedimentation of the Kalundu reservoir has influenced how the community uses water from the reservoir. This study revealed that 30% used the water in the construction work, 22% in washing clothes, 17% in watering livestock, 8% in fishing and recreation activities, 6% use the water in small scale irrigation and 12% never used the water at all. None of the users used the water for drinking purposes due to high sediments and contamination.

A cross-tabulation analysis showed that sedimentation of water significantly influenced how the water got used given that Pearson Chi-square value was 23.35, with 5 degrees of freedom and p-value of 0.000. With these results, the study rejects the null hypothesis that Kalundu dam sedimentation has not impacted water use and or abstraction of water by the local community in the period 2013-2021. Cumulatively, users abstracted about 6300 litres of water daily from Kalundu reservoir. Almost a half of the respondents' population (46%), whose majority (58%) stated that they had abstracted more than 500litres of water from the dam on daily basis for more than 20 years. Most of them used pumping machines to abstract water from dam which strained the available water. Majority used the water in watering their livestock, construction work, and irrigation of crops.

Water in the Kalundu reservoir was occasionally polluted due to sedimentation. The respondents affirmed that increased turbidity of water in the dam was due to poor land use practices. They also complained that it took them more time and money to treat the water for domestic uses. Sometimes they found the water not suitable for washing and watering their livestock due to high turbidity. Sedimentation of Kalundu reservoir also negatively affected the livelihood and socio-economic activities of the local community in the Kalundu sub-basin. Those that depended on the dam for fishing and recreation purposes could not benefit much from the dam especially when turbidity of the water was high. Reduced fishing activity in the dam resulted to reduced income for the local community. The recreational value of Kalundu reservoir was reduced due to pollution and siltation. Some people indicated that their farms produce decreased since there was inadequate water to irrigate their crops while others incurred additional expenses to repair their water pumps. Eutrophication of water in Kalundu reservoir was also observed due to contamination of water by nutrients-bound in sediments discharged into the dam. This resulted to growth of aquatic plants (Figure 4.31) that contributed to the decline of fish in the dam and reduced recreational value of the dam. There was negligible amount of solid waste deposited into the reservoir. This showed insignificant effect of solid waste in the filling up of the reservoir but contamination of the water due to runoff from the streets and soil erosion was quite high.

According to the respondents, it was not clear whether there was an existing authority that controlled abstraction of water from Kalundu reservoir. This problem was attributed to mismanagement of the reservoir and abstraction of water from the reservoir. This research revealed that the decrease of water level in the dam was attributed to this high rate of abstraction of water from the reservoir since the local community depended on it as a source of water for various uses following the prolonged drought seasons in the area. Poor farming practices contributed to soil erosion in the Kalundu sub-basin hence the high rate of sediment accumulation in the reservoir. The study also revealed that most of the residents in the study area (79.6%) attributed sedimentation of the Kalundu reservoir with the erosion of the soils from the farm lands, construction sites and barelands where trees had been cleared. Using chi-square test, the researcher found that soil erosion from the Kalundu sub-basin significantly contributed to sedimentation of the reservoir X^2=12.27, df=2, p-value=0.002.

Figure 4.31: Aquatic vegetation growing in Kalundu reservoir in December 2021 (Source: Kasuki, 2022)

The study therefore rejects the null hypothesis that stated that soil erosion in the Kalundu sub-basin is not the cause of Kalundu Dam sedimentation in the period 2013 and 2021. This study also sought to gather opinion from the affected community on how sedimentation of Kalundu reservoir could be minimized in the future. Table 4.9 gives a summary of some of the practices suggested by 92 respondents of this research to reduce the rate of sediment accumulation in Kalundu Dam. These practices were categorized into agricultural, environmental and maintenance practices to mitigate the problem of sedimentation.

Table 4.9: Approaches for minimizing sedimentation in Kalundu reservoir (Source: Kasuki, 2022)

Mitigation measures	Category of action
Farmers to use the right farming practices e.g terracing, use of gabbions, avoid clearing and burning of farm lands	Agricultural
Planting trees and protecting the forest areas	
Enforce the law and practices on soil and water conservation	Environmental
Regular rehabilitation of the dam	Maintenance

Figure 4.32: Kalundu Reservoir during dry season in September 2021 (Source: Kasuki, 2022).

Figure 4.33: Kalundu Reservoir during wet season in December 2021 (Source: Kasuki, 2022).

Figure 4.34: Kalundu River discharging into Kalundu reservoir in November 2021 (Source: Kasuki, 2022)

Figure 4.35: Kalundu River discharging out of the reservoir in December 2021 (Source: Kasuki, 2022)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

This chapter gives a discussion of all the findings presented in chapter four. The discussions are presented in line with the objectives of the study. The results were discussed and compared with other studies undertaken elsewhere. The section expounded more on the study results on the relationship between river discharge and sediment yield. The section further discussed the results obtained on reservoir sedimentation and sediment budget as well as soil erosion and sources of sediments deposited in the reservoir. The impact of reservoir sedimentation on community water use was also discussed. These results gave detailed insights to understand sedimentation of Kalundu dam.

5.2 Relationship between River Discharge and Sediment Yield

The study findings showed significant seasonal variability due to variability of rainfall occurrence in the region. The historical data showed that Kalundu River had significant inter-annual variability in the stream flow with a relatively higher river discharge. Other studies affirm that seasonal variability of rainfall contributes to variation in the characteristic sediments that get deposited in a reservoir (Shotbolt et al., 2005). This can be attributed to spatial variation in sediment sources and land use practices. In the period between 1968-1978 the mean river discharge during the short rainy season ranged from 0.27-1.83m^3/day and 1.5-2.06m^3/day during the long rainy seasons. This suggests that transportation and deposition of sediments was likely to be high during the long rains due to high river flows than during the short rainy seasons. It was clear that the river discharge in Kalundu River was higher during the long rainy season than during the short rains.

These occurrences concur with results from previous studies in the region (Njogu and Kitheka, 2017). Other studies that concur with results noted that sediment yield and turbidity had a high positive correlation (0.63) and TDS (0.64) (Tundu et al, 2018). It was also noted that during any given runoff event, on the rising limp of a storm hydrograph had greater suspended sediment concentrations than those measured at equivalent flows on the falling limp (Ndambuki, 2018). The loess areas of China was observed to have a similar results with a very high sediment yield (Subramanian, 1993).

The river discharge significantly reduced after 1978 due to reduced rainfall. In the current study, during short rainy season (November- January) in 2020 the river flow in Kalundu River was quite high with a peak river discharge of 1.54m^3/day. During the long rainy season, the peak river discharge was 0.98m^3/day. Variance in the mean value was also observed given by 0.44-1.00m^3/day during short rains and 0.11-0.50m^3/day during the long rains season. The total amount of rainfall in Kitui during the short rainy season is usually higher and characterized with higher river discharge than during the long rain season (Kitui CIDP, 2018-2022).

This study revealed that TSSC and river discharge played a significant role in the accumulation of sediments in the Kalundu Reservoir. TSSC was relatively higher during the short rainy season with a mean value of 1,131.565 mg/L than during the long rains with a mean of 592.812 mg/L. The difference between TSSC deposited into the Kalundu reservoir and the discharged TSSC was a clear indication that a significant amount of sediments got trapped into the reservoir during both long and short rainy seasons. This shows that about 21.3% of TSSC got deposited into the reservoir during the short rains. Although the TSSC was relatively lower during the long rains with a mean value of 592.812 mg/L upstreams and 190.549 mg/L downstream, about 60% of TSSC got deposited into the reservoir during this season. This shows that deposition of sediments was more during the long rainy season than during the short rains season. The disproportionate outflow of the suspended sediments from the reservoir compared to the inflow during the long rains was because some portions of the sediments settled at the reservoir bed. This is the same impact that contributed to a decrease in the sediment loads downstream.

Turbidity of the water in Kalundu River was significantly influenced by the amount of TSS and river discharge. Variability in sediment load, turbidity and TSSC was associated with other factors such as erodability of the river and possible human activities in the basin resulting to soil loss and generation of sediments. This conclusion concurs with the majority of the respondents of this study (90%) who confirmed that high turbidity in Kalundu dam was more common at the peak of rainfall seasons. This was observed in April, May, November and December when most of them worked on their farms for cropping activities. Some of the activities thought to contribute to increased turbidity of the water included; poor farming practices, constructions and development activities, cutting down of tress, and runoff from the streets of Kitui town. The results showed significant relationship between river discharge and the reservoir discharge during the short rains and long rains seasons as well. However, during the two seasons, the dam discharge was slightly higher than at the river discharge. This was attributed to two main reasons. The first reason is that the direct rain water collected in the reservoir during the rainy days was part of the volume of water factored as the outflow volume at the spillway. This contributed to higher volume of water discharging from the dam than the actual river discharge measured at the RG station in Kalundu River. This impact was experienced until when the minimum water level at the spillway or zero dam discharge was reached after the rains.

The river discharge measured upstream was dependent on the river transport capacity in which the load is distributed over the cross-sectional area of the river bed. Therefore, channelized spillway was able to accommodate more load compared to the load in the river. Similar findings were observed where higher sediment yield rates were obtained during flood events where by runoff increased erosion and transport of sediment. Higher runoff was found to produce higher discharges (Ibisate, 2011). Another study concurred with these findings that surface runoff and sediment yield were found to have most likely risen in the long term as a result of escalate land use and land degradation resulting from population increase in the Ethiopian and Eritrean highlands feeding the upper Nile Basin (Hurni et al, 2005).

5.3 Reservoir Sedimentation and Sediment Budget

Reservoir sedimentation and sediment budget is being experienced by other water reservoirs located in ASALs in Kenya. Thus, Kalundu Dam is at risk of experiencing a recurrence of high accumulation of sediments and the problem of eutrophication due to accumulation of nutrient rich runoff from the land surface (Mwaura, 2003). These two problems have been cited in other studies attributed to land use changes in local basins (Kithiia, 2012). Silt and clay particles was found to be the primary carrier of adsorbed chemicals including nitrogen and phosphorus (Tundu et al, 2018). The first time Kalundu dam was silted up was within the first 20 years after the dam was constructed. Rehabilitation of the dam was done in 2013 but 8 years later (in 2021) it was evident that siltation had already taken place. The hydrological data collected in the period between October 2020- February 2021 during the short rainy season showed that a peak in the sediment load was observed in mid-November 2020 ranging from 56-97% of the transported sediments deposited in Kalundu Reservoir. Towards the end of that month, 25% of the sediments got trapped in the reservoir.

An increase in the river discharge contributed significantly in the overall increase in the TSSC in the river flow and increase in the sediment load. Due to increased river discharge and TSSC, sediment load in the Kalundu River was higher during the short rains (134,028.84 m^3) than during the long rains (28,448.87m^3). Similarly, the reservoir discharge was high during the short rains (108,074.10 m^3) than during the long rains (11,282.08m^3). High proportion of sediment load being discharged from the reservoir contributed to 47.73% of sediments being deposited during the short rainy season. Low proportion of sediment load being discharged from the Kalundu reservoir contributed to 55.91% of sediments being deposited during the long rainy season. This suggest that high accumulation of sediments in Kalundu Reservoir likely occurred during the long rainy seasons.

Through bathymetric survey, the researcher found out that a total of 522,534 tons of sediments had already accumulated in Kalundu reservoir at the rate of 65,317 tons/yr within a period of 8 years or 2,722 tons/km^2/yr. At this rate of sedimentation, the Useful Life Span (UL) of the dam was estimated to be about 3 years. The study established that the dam had already lost about 70% of its storage capacity and 11% decrease in the surface area by the year 2021. Similar studies have estimated that the loss in reservoir storage capacity ranges between 0.5% and 1% per annum (Mahmood, 1987; White, 2010). Sumi and Hirose (2009) noted that the gross storage capacity for the global reservoir is about 6000 km^3 and annual reservoir sedimentation rates are about 31 km^3 (0.52 %). Others have shown that high rate of reservoir sedimentation has the effect of reducing the life span of the (Ndambuki, 2003). Deposition of Sediment was noted to reduce the storage capacity and life span of reservoirs and river flows (Eroglu et al., 2010). However, due to time limitation and the scope of this study, the researcher did not account for the water lost from the reservoir through evaporation and underground seepage. This could help in explaining the spatial and temporal hydrological behavior of the Kalundu sub-basin. Future studies can look into these attributes to enhance understanding of the spatial and temporal hydrological behavior of the Kalundu sub-basin (Sohoulande, 2017). However, the results of this study show that the high rate of soil loss and sedimentation in Kalundu Dam needs to be given priority and soil conservation measures in the sub basin need to be put in place (Kumar et al., 2015). Kalundu Dam is located in a site that is characterized by soil erosion from the agricultural fields and urban development activities and unpredictable rainfall patterns. These conditions plus the land use practices were thought to have contributed to the rapid sedimentation of the dam.

Other studies have shown similar findings associated with the same land use practices (Harper et al., 2011; Maina, 2019). This study established that the problem of siltation reduced the functionality of the dam as a recreational site and reduced water for the local communities. Similar impacts were observed in Masinga dam about a decade ago (Bunyasi et al., 2013). Sumi and Hirose (2009) reported that the global reservoir gross storage capacity is about 6000 km^3 and annual reservoir sedimentation rates are about 31 km^3 (0.52 %). This suggests that at this sedimentation rate, the global reservoir storage capacity will be reduced to 50 % by year 2100.

5.4 Soil Erosion and Sources of Sediments Deposited in the Reservoir

The bathymetric data showed that the reservoir was deepest in the middle section with a maximum depth of 3.5m but shallow towards the upper and lower parts. Deposition of sediments near the dam entry point and at the spillway was dominated by sand particles (48%). Silt and clays (clay loam soils) were dominant in the middle section of the dam where the distribution of particle sizes was 35% silt and 36% clays. These findings suggest that trapping of coarser sediments was more likely to occur at the upper and lower parts of the reservoir than in the middle part. Sediments deposition in the dam is attributed to human activities like in the Kalundu sub-basin that contribute to soil erosion. A similar study that investigated sources of sediments deposited in small reservoirs in Burkina Faso found that human activities contributed a lot in the sedimentation of Wahble and Fafo reservoirs (Schmengler and Vlek, 2015).

The topography in the Kalundu sub-basin is a dominant factor affecting soil erosion. As the slope gradient increases, the kinetic energy and carrying capacity of the surface runoff increases thereby decreasing soil stability. The slope length increases the volume and velocity of runoff hence carrying more sediments (Mwangi et al., 2015). Kalundu River was characterized by higher sediment load in high gradient areas compared to low sediment load measured after the spillway in lower gradient areas. Almost identical outcomes were observed in a research carried out in Lake Naivasha (Maina, 2019). Deposition of relatively light and heavy sediments was likely to occur in the reservoir due to low gradient of the land where the dam is located and low inflow velocity. Apart from the influence of gradient, low deposition of sediments at the middle section of the dam is as a result of low impact of wind wave in the water due to the short fetch of the reservoir (Ndungu et al., 2015).

The results showed that more deposition occurred near the edges of the dam as a result of low inflow velocity. Deposition of sediments in the middle section of the dam would require a strong river regime to carry significant amount of sediments across the reservoir. Heavy and fine sediments were more likely to be deposited at the upper and middle zones of the reservoir while the fine and suspended sediments are carried to a lower gradient zone of the reservoir. In addition, areas dominated by erosive soils are likely to generate more sediments than from areas dominated with non-erosive soils. The northern parts of Kalundu sub-basin (uphill) are dominated with clay soils. The high values of soil erodibility factor in that area were attributed to these erodible clay soils.

Sedimentation in Kalundu reservoir is influenced by the erosion rates in Kalundu sub-basin which can be defined as “the amount of sediments lost per unit area and unit time” (ton/ha/yr) and sediment yield from the Kalundu River, expressed as ton/yr (Hunink and Droogers, 2011). Soil properties like texture and organic contents also influences the disjoin and transportability of sediments from the basin. Soil erosion process is less prone in the lowlands of the basin than in the hilly areas at the upper part of the sub-basin but dependent on the moisture content in the soils (Hunink and Droogers, 2011). This results conquer with the findings of Kogo et al., (2020), who noted that rate of soil erosion increased with slope because of high velocity and erosivity of the runoff. Moreover, rainfall intensity provides kinetic energy which accomplishes most of the erosional work through surface runoff. Runoff is also associated with shear stress which makes particles to be eroded. Areas dominated with soils containing high clay content in Kalundu sub-basin exhibited high erosivity factor because it has small size particles that is susceptible to erosion by rain water and the action of water and streams.

Soil loss estimation using MUSLE showed the maximum achievable rate of soil erosion in the sub-basin was 5.1840 tons/km^2/yr, which implies a severe rate of soil loss. Using the bathymetric data, the estimated sediment yield was 2,722 tons/km^2/yr. This variance of the results obtained from MUSLE and Bathymetry survey has been noted in other researches (Odongo et al., 2013; McAlister et al., 2013). Results may vary depending on the procedure followed in data collection and data input in the soil loss prediction model. Nevertheless, the results showed that most susceptible areas to soil erosion were distributed in the central and south western parts of Kalundu sub-basin because of the crop management and conservation support practices that are less done and a lot of farming that is exposing the land to erosion. Areas with extensive vegetation canopy and ground cover can reduce soil erosion especially during cropping season (Ali and Hagos, 2016). Plant canopy influences interception of rain, ground cover soak up raindrop impacts and root system gives unbreakable impacts to the soil particles.

The results from LULC analysis showed a number of drivers of land use changes and soil erosion in the study area. In the year 2000, Kalundu dam was completely silted up with only about 0.99ha of land covered by the water body. The largest portion of land in Kalundu sub-basin in 2000 was cropland covering 31% of the total area. Natural vegetation coverage which included forests and shrubs had low percentage. These findings suggest that the most probable source of sediments was from the croplands due to disturbance of soils in the farms than from the forests and shrub lands. Similar studies observed all land uses and practices in the drainage basin including deforestation, agriculture, mining, urbanization and fires affected runoff and sediment yield (Charlton, 2008).

Soil conservation practices particularly in the agricultural lands in the basin can greatly reduce soil loss and eventually reduce sedimentation of the reservoir (Kokpinar et al. 2015). Implementation of conservation practices has been found to be effective in other studies undertaken elsewhere (Hunink and Droogers, 2011). The expansion of land for croplands in Kalundu sub-basin might have contributed to decrease in forest cover and shrubs in the year 2000. In 2000 soil erosion from the abandoned croplands were attributed to soil loss which led to increased sedimentation in Kalundu Dam. Some studies have pointed that relatively high annual sediment yield is likely to be observed in small scale agricultural fields than from commercial agricultural farms and large scale plantations (Kroese et al., 2019).

Forest cover and shrub lands increased significantly in the period between 2000 and 2020. This correspondingly contributed to reduced soil erosion and sediment loss from the land. This reduced soil loss from the catchment resulting to increased river discharge that eventually contributed to increased water level in the dam in 2020. Within the same period, grasslands decreased due to the rise in built-up area. In the year 2010, water bodies including Kalundu dam covered 2.7ha. However, the dam was still occupied by a significant amount of sediments by that year as observed in the LULC result. The total land coverage of water bodies in 2010 was slightly higher than in the year 2000 as well as the coverage of forests and shrubs in the area. Minimal interference with the natural vegetation is likely to have contributed to increased water and soil conservation which resulted to reduced sedimentation in the dam. Increased grassland and forests plus the reduced croplands in 2010 is likely to have contributed to reduced soil erosion and runoff in the period between 2010 and 2020 which reflected in the LULC analysis results with 2% increase in the water bodies. This finding corresponds to reduced cropland and bare land in the same period by 26% and 22%, respectively.

By the year 2020, significant land was covered by forests, shrubs, and croplands. Compared to the previous years, the water bodies including Kalundu dam had increased significantly from a total area of 2.7ha in 2010 to 12ha in 2020. This increase in the water bodies was contributed to reduced cutting down of trees and conservation of natural vegetation which has been an initiative from the County Government of Kitui in an effort to reduce charcoal burning in the region. Although rehabilitation of the dam was done in 2013 to remove the sediments, cropping activities that occurred in the sub-basin after that year towards 2020 did not have significant impact in the water bodies. However, increased construction activities after 2010 and large scale infrastructural development around Kitui Town were associated with the recurrence of sedimentation in Kalundu dam.

Construction activities especially road construction which was observed in the area are likely to contribute to soil erosion in the affected land which results to increased runoff particularly within Kalundu basin. A study undertaken in Brazil shows the impact of such construction and agricultural activities in the catchment area can be disconnected from the stream network by introducing buffer zones close to the surface water reservoir. Such buffer zones can be in form of riparian lands/forest to minimize the problem of sedimentation of water reservoirs (Tiecher et al., 2017).

Soil erodibility index map showed that the upper zone of the sub-basin was more susceptible to soil erosion with an index of 0.04 than in the lower and central zone of the sub-basin. These results corresponded to the rainfall erosivity factor distribution in the study area. High rainfall erosivity factor was noted in the upper zone of the sub-basin where soil erodibility was also high. This suggests that more erosion happened at the upper zone of the study area leading to increased loss of sediments from the farms that eventually got deposited in the Kalundu Reservoir. The results also showed that soil loss was likely to happen from agricultural land and bare land given that the C-factor was highest in the agricultural land (0.63) and 0.48 on the bare land. Similar findings have been observed in a research carried out in the Ethiopian highlands (Esa et al., 2018). The findings of the study conquers with findings of Verstraeten et al., (2003) that the relationship between annual sediment and yield and catchment area depended on the complexity and viability of corresponding terrain linked such as topography, soils and climate Forest land and built-up areas showed low contribution in sediment loss given that their C-factor was 0.003 and 0.09, respectively.

The findings on LULC changes in the study area show that a slight change in land use might lead to soil erosion resulting from spatial and temporal variation in the C-factor in the basin. Similar findings were noted where, intensified land use in the rainfed highlands, cultivated land being expanded into grazing land, and continued deforestation in the areas where forests existed, especially in the western parts of the highlands (Hurni et al., 2005). Reduced forest cover was observed in the central Gojam (from 27% in 1957 to 0.3% in 1995 (Gete, 2000). Similar trend was observed in western Ethiopia from relatively extensive forest cover in the 1960s (Abate, 1994).

A significant coverage of croplands is common in the upper zone which is associated with soil erosion resulting from high rainfall erosivity factor and soil erodibility in the region. These conditions have been associated with soil erosion where sediments originate from (Kroese et al., 2020). In another study undertaken in a Zambian catchment, the results showed that communal cultivation lands formed the major sources of sediments (Collins et al., 2001). From this study, the high density network of streams in the upper zone served as the transportation channel for sediments generated from overgrazed hill slopes and community farms, calling for more enhancements of soil conservation measures. Another study noted that land use including forestry, agriculture and livestock grazing increased erosion of soil, sediment yield, water runoff and peak discharges due to reduced infiltration rates (Ibisate, 2011).

5.5 Impact of Reservoir Sedimentation on Community Water Use

Reservoir sedimentation on community water use was investigated in this study. It was noted that continuous sedimentation of Kalundu Dam affected the quality and quantity of water in the dam. In terms of water quality, this study revealed that the quality of water in Kalundu Reservoir was reduced as a result of increased level of turbidity and TSS concentration in the water. This impact was severe during the rainy seasons due to increased runoff and soil erosion from the land surfaces. Increased turbidity and TSS was attributed to erosion activities occurring from the agricultural fields in Kalundu sub-basin. Increasing agricultural activities in a catchment area have been identified in other studies as the major challenge attributed to accumulation of sediments in reservoirs and lakes in Africa (Uwemeye et al., 2020). In this case, reduced storage capacity of the dam due to siltation and reduced water quality resulted to inadequate water supply for watering livestock, construction works and cultivation of crops in the study area. Similar findings noted that currently, transportation of sediments in the water bodies has proved to be one of the major contributors to poor water quality (Lawson, 2011).

The drawback of siltation and reduced fishing activities in Kalundu reservoir have affected the livelihoods of the local community. The households that depend on the Kalundu Dam for their livelihoods, may have to find alternative sources of income. The polluted water in the dam forces the users to incur some added cost in water treatment whenever they need water for drinking purposes. The recreational value (Figure 4.36) and fishing activities (Figure 4.38) in Kalundu reservoir has reduced significantly due to reservoir water sedimentation leading to reservoir water turbidity. Like in other sub-Saharan countries, this problem of pollution and sedimentation of surface water reservoirs has been common in ASALs (Kroese et al., 2020). This conquers with findings that trapping of sediments by reservoirs leads to loss of aquatic habitats due to poor water quality (Kondolf, 1997; Merz, Pasternackc, and Wheaton, 2006; Power, Dietrich, and Finlay, 1996). The general findings from previous studies done in Kenya show that human encroachment and degradation of the catchment areas have been the main causes for siltation in surface water reservoirs and lakes located in ASALs. These include Naromoru catchment (Njeru et al., 1993), Lake Nakuru catchment (Mackenzie, 1993), Lake Victoria (Lung'ayia et al., 2001) and Masinga catchment (Bunyasi et al., 2013).

Apart from the environmental influences, abstraction of water from the dam has a great role in the reduction of the storage capacity of Kalundu Dam. Being the only readily accessible source of household water in Kalundu sub-basin, the reservoir suffered a high rate of water reduction due to high rates of water abstraction by the local community (Figure 4.37). Studies have shown water from boreholes and shallow wells located in Kitui Town and its neighbourhoods faces the problem of contamination with faecal coliforms (Abila et al., 2012).

Figure 4.36: Boating activities in Kalundu reservoir in November 2021 (Source: Kasuki, 2022)

This problem has been attributed to poor sewage management making the alternative source of household water not suitable for consumption. This is thought to have contributed to the increasing rate of abstraction of water from Kalundu reservoir. Similar study showed that effort of environmental rehabilitation, livestock management development and, reducing family growth rates would lead to long-term sustainablility of reservoir sedimentation (Hurni, 1993). Another study concurred with the results of this study where Chimhanda treatment plant water works in Zimbabwe showed that the quality of water is deteriorating due to increase in sediment accumulation in the dam (Tundu et al., 2018). Another similar study carried out in Yellow River showed that flushing of sediments in 2010 was estimated to cause fish mortality of 0–20% (Baoligao, 2016).

Figure 4.37: Water pumping for farm irrigation from Kalundu reservoir in March 2021 (Source: Kasuki, 2022)

Figure 4.38: Fishing activites in the Kalundu reservoir in August 2021 (Source: Kasuki, 2022)

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter highlights the summary of outcomes, Conclusion and recommendations from the study. The summary of findings, conclusion as well as recommendations of this study were derived from the key findings and in line with the objectives of the research. The summary of findings points out the key findings of the study for ease of understanding the general discussion of results of the study. Conclusions points out that the objectives of the study were met and recommendations gives possible way forward to amend the study findings contributing to negative effects.

6.2 Summary of Findings

The main findings of the study are as follows:

(i) The analysis on hydrological data showed that river discharge, sediment load and TSS were strongly related with the sedimentation in Kalundu reservoir during the short rains. A decrease in either river discharge, sediment load or TSSC inflow resulted to a decrease in the sediment load. A significant relationship between river discharge and total suspended sediments as well as turbidity was established. High turbidity in the reservoir was likely to be observed when TSSC was high. A decrease in the river discharge during the long rainy season was associated with the decline in the amount of rainfall in the region.

(ii) This study established that TSSC played a significant role in the sedimentation of the reservoir during both short and long rainy seasons but dependent on the river discharge. The estimated TSSC that got deposited into the reservoir was 21.3% and 61% during the short rains and long rains, respectively. The study estimated that within the period between 2013 and 2021 when rehabilitation of the dam was done, the reservoir had accumulated about 350,098m^3 of sediments at a mean annual sedimentation rate of 65,317 tons/yr with an average trap efficiency of 55%. The mean depth of water in the reservoir was 2.1m and a maximum of 3.5m. The deepest part of the reservoir (3.5m) was measured at the middle part of the dam. The reservoir suffered reduced surface area of water by 11% while the dam storage capacity had decreased by more than half (70%) of its original design capacity. The estimated storage volume of the reservoir based on the bathymetric data as at December 2021 was 149,902m^3. The Useful Life Span (UL) of the reservoir was estimated to be about 3 years.

(iii) The deposited sediments in the reservoir comprised of silt (35%) and clays (36%) while sands (48%) were common at the entrance and near the spillway of dam (35%). Soil gradation analysis showed that these sediments were well graded which signified normal deposition regime in the sub-basin.

(iv) The decrease of the storage volume of the dam was as a result of deposition of sediments originating from soil loss from the agricultural fields and abandoned croplands in Kalundu sub-basin. The results from LULC analysis of the study area between the period 2000-2020 showed that croplands and built-up areas increased significantly within a period of 20 years. Shrubs reduced by 20% due to clearing of land for settlement. Cultivation land reduced by 20% in the same period. Bare land covered 18% of the total land where 40% resulted from abandoned cropping land.

Bareland and abandoned croplands were attributed to soil erosion in the study area leading to sedimentation of Kalundu Dam. Within a period of 20 years, 22% of the cultivation land was changed to built-up areas. Estimation of soil erosion using MUSLE also showed that high erosion was likely to occur at the upper part of the sub-basin characterized by agricultural fields and barelands. Poor farming practices, urban land development activities, heavy infrastructural development and clearing of natural vegetation in the sub-basin strongly contributed to the increased sedimentation of the dam in the period between (2010-2020).

(v) The household survey showed that almost 50% of the community abstracted more than 500 litres of water from the reservoir per day. Being the only readily accessible source of household water in Kalundu sub-basin, the reservoir suffered high rates of water abstraction due to overreliance by the local community. Sedimentation of the reservoir reduced the associated benefits to the local community including reduced food production, reduced water for the livestock, unsustainable livelihood among other general socio-economic benefits. This calls for specific strategic plans to enhance management of the reservoir with specific efforts to minimize soil erosion within the catchment area and reduce misuse of water from the reservoir.

6.3 Conclusions of the Study

The following are the specific conclusions based on the specific findings of the study.

(i) The analysis of river discharge, sediment load and TSS of the both the reservoir and Kalundu River it was clear that they were strongly related. It can therefore be concluded that high amounts of rainfall led to high amounts of river discharge, sediment load and TSS. This resulted to dam water being turbid and deposition of sediments in the dam. This shows that the dam is experiencing sedimentation.

ii) Bathymetric survey in Kalundu reservoir helped to understand the trends and extent of sedimentation in Kalundu sub-basin. Remote sensing and spatial analysis aided in the historical analysis on land use and land cover that helped to establish the key drivers of soil erosion in the study area. The rate of deposition of sediments to Kalundu Dam has increased gradually as a result of erosion and poor land use. There is significant increase in sedimentation during short and long rainy seasons. Different sediments were deposited at different parts of the dam. Sand is deposited at the upper part of the dam while clay and silt is deposited at the middle of the dam. From the findings of bathymetry survey, it can be concluded that Kalundu dam is experiencing sedimentation due to high amounts of soil particles being deposited in the dam.

iii) Sedimentation in Kalundu Dam resulted to other problems including increased turbidity, reduced fishing in the reservoir, water scarcity, reduced crops cultivation, reduced aesthetic value of the dam and reduced income for the households that depended on the dam for their livelihood. From the LULC analysis, the study established that the main causes and source of sediments that get discharged into the Kalundu Dam originated from the agricultural field in the catchment due to poor farming practices, abandoned croplands, urban and infrastructural development in Kitui town and deforestation in the period between 2010-2020. This showed that the dam is experiencing sedimentation.

iv) Estimation of soil erosion using MUSLE model showed that the sub-basin is experiencing high soil loss. All these lost soil is transported to the dam through the Kalundu River, which in turn is deposited in the Kalundu dam. This shows that the dam is experiencing sedimentation due to high amounts of rainfall, human activities that aggravate the soil erosion including poor farming practices, abandoned croplands, urban and infrastructural development in Kitui town and deforestation in the period between 2010-2020.

6.4 Recommendations of the study

The recommendations of the study are directed to specific stakeholders in order to facilitate their effective implementation. The recommendations from this research are as presented below.

6.4.1 Recommendation to the National and County Government

i) This study also recommends that the National Environment Management Authority (NEMA) should implement appropriate environmental laws to minimize soil erosion and water pollution in the sub-basin. The aspect of ssustainability should be incorporated in the design of surface water reservoirs in ASALs. Such reservoirs are very important in the ASALs as important sources of water for domestic uses and other activities such as small scale irrigation, fishing, and recreation.

ii) The national government through the Ministry of Agriculture, Water, Sanitation and Irrigation, the National Water Conservation and Pipeline Corporation (NWCPC) and Environment should roll out outreach programs to educate the local farmers on how to apply improved cropping practices to minimize soil erosion from the area. This will help to minimize the rate of sedimentation in Kalundu dam. However, regular monitoring of the dam should be done to ensure that the necessary rehabilitation action is taken at the right time.

iii) Water Resources Authority can use the outcome of this research as a guide in Kenya in the formulation of strategic plans for water resources development and conservation of surface water reservoirs in ASALs.

iv) This study recommends that WRUA's should be supportive of initiatives from the government, NGO's, CBO's and other stakeholders that contribute to the conservation and management of soil and water in their region. This might help to minimize misuse of water resources, the risk of water shortage and contamination of the available water bodies.

v) This study established that the rate at which sediments accumulated in Kalundu reservoir was extremely high at 65,317 tons/yr within a period of 8 years. This rate of sedimentation calls for urgent action to minimize soil loss in Kalundu sub-basin. This study recommends that the county government of Kitui should come up with strategies of improving agricultural practices in the Kalundu sub-basin. This study also calls on the county government of Kitui through the Kenya Forest Service to protect the forest lands in the basin and plant more trees in the study area.

6.4.2 Recommendations to Community Based Organization (CBO's) and Non-Governmental Organizations (NGO's)

This study recommends that the County Government of Kitui should design controlled urban development plans in Kitui town to improve management of natural resources and minimize practices that trigger soil erosion leading to sedimentation of the Kalundu Dam. Infrastructural development should also adhere to the environment laws and regulations that are already set to conserve water and soils and general management of the environment.

This study recommends that the Community-based Organizations (CBO's) and Non-Governmental Organizations (NGO's) should come up with educational programs for farmers to improve farming practices and reduce soil erosion in their farms. These practices may include building of gabions and terraces to conserve soils on the farmlands situated on steep hills in the study area. The outdated practice of clearing and burning of debris on farm soils should be stopped to minimize loss of important components of the soils and reduce chances of soil erosion. Controlling soil erosion will assist to sustain the benefits of the reservoir to local communities.

6.4.3 Suggestion for Further Studies

This study recommends for further studies to investigate the chemical and bacteriological quality of water in Kalundu Dam in different seasons of the year. This will help to determine the suitability of water fetched from Kalundu Dam for household uses. The current study established that during periods of extreme drought majority of the residents of Kitui town located near the dam are likely to use water from the dam in their domestic needs. Since the main source of sediments are from the farmlands and streets of Kitui town, there is a likelihood of contaminating water with pesticides and sewage respectively. Therefore, it would be very appropriate to establish the factors that impact the quality of water that drains into the dam.

Future studies should examine the trend in sedimentation of surface water reservoirs located in other arid and semi-arid lands in Kenya to add knowledge on the appropriate catchment protection measures in different regions.

6.5 Conclusion

To conclude this study, the objectives of the study were met. It demonstrated the nexus between land use and land cover change, hydrology and reservoir sedimentation in ASALs and has implication on the future planning and construction of small-sized reservoirs in Kenya and Africa at large. The research showed that the relationship between river discharge and sediment yield in Kalundu River sub- basin was found to be significant. Reservoir sedimentation rates and sediment budget in Kalundu dam were found to have a significant relationship. Kalundu dam was found to be experiencing high rate of sedimentation of 65,317 tons/yr.

The main sources of sediments deposited in the dam for were found to be agricultural areas, bare land and areas under construction. The dam was also found to be at the risk of experiencing eutrophication because of nutrient bound sediment inflow in the dam from agricultural areas. Sedimentation of the dam was found to be impacting water use or abstraction by the local community negatively. The community stated that the dam water was too turbid during the peak rainy months. For Kalundu dam reservoir, the long term sustainability is in jeopardy due to continued degradation of the catchment areas. Without controlling population growth and land conversion in the Kalundu sub-basin, it is unlikely that the rate of reservoir sedimentation with the Kalundu dam would decrease, especially in this era of climate change.

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APPENDICES

Annex I: Questionnaire

General Instructions

This data collection tool is made to gather data on reservoir sedimentation in arid and semi-arid river basin: a case study of Kalundu dam in Kitui County, Kenya. You are kindly requested to honest as you can while providing responses. Information gathered will be strictly confined by the researcher. The questionnaire consists of two sections. Thank you in advance.

Section A: Background Information

Please tick accordingly

1. Gender 1) Male ( ) 2) Female ( )
2. Marital status 1) Married ( ) 2) Single ( ) 3) Divorced ( ) 4) Windowed ( )
3. Age 1) Below 18 years ( ) 2) 18-35 years ( ) 3) Above 35years ( )
4. Education level 1) Secondary School ( ) 2) College ( ) 3) University ( )
5. How many years have you lived in Kalundu dam sub-basin?

1)1-5 years ( ) 2) 6-10yrs ( ) 3) 11-15yrs ( ) 4) 16-20yrs ( ) 5) Over 20 years ( )

Section B: Impacts of Kalundu Dam Sedimentationon Water Use/Abstraction

Please tick accordingly

1. Do you use water from Kalundu dam? Yes ( ) 2) No ( )
2. If Yes, what do you use the water for?

....

How many litres of water do you use from Kalundu dam per day? ……………………….

3. What means of water withdrawal do you use to get water from Kalundu dam?…………
4. What challenges do you face by the means you use to draw water from Kalundu dam?………………………………………………………………………………………

………………………………………………………………………………………………
5. In which months of the year is the water level very high? ....
6. In which months of the year is the water level very low?..

7. In which months of the year is the water too turbid?…………………………………

8. What do you think are the causes of turbidity of water in Kalundu dam? ....

………………………………………………………………………………………………

………………………………………………………………………………………………

9. How does Kalundu dam sedimentation affect your social life?…………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

10. How does Kalundu dam sedimentation affect you economically?..................................

………………………………………………………………………………………………

………………………………………………………………………………………………

What challenges do you face that are associated with the Kalundu dam water being turbid/ with ……..

11. What challenges do you foresee if Kalundu dam continues to fill with sediments?..

....

12. Make suggestions that can reduce or mitigate negative effects of the turbid water/sedimentation of Kalundu dam

………………………………………………………………………………………………

………………………………………………………………………………………………

Annex II: Kalundu River Discharge (Historical data) from May 1968 to 1978

KALUNDU RIVER		**KALUNDU RIVER**		**KALUNDU RIVER**	
Time	G/HT. 1	Time	G/HT. 2	Time	G/HT. 1
01/12/1975 08:00	0.38	01/12/1975 14:00	0.36	01/10/1966 08:00	0.22
02/12/1975 08:00	0.39	02/12/1975 14:00	0.37	02/10/1966 08:00	0.21
03/12/1975 08:00	0.47	03/12/1975 14:00	0.41	03/10/1966 08:00	0.2
04/12/1975 08:10	0.38	04/12/1975 14:00	0.37	04/10/1966 08:00	0.2
05/12/1975 08:00	0.36	05/12/1975 14:00	0.34	05/10/1966 08:00	0.23
06/12/1975 08:00	0.3	06/12/1975 14:00	0.28	06/10/1966 08:00	0.2
07/12/1975 08:10	0.26	07/12/1975 14:00	0.24	07/10/1966 08:00	0.2
08/12/1975 08:00	0.2	08/12/1975 14:00	0.17	08/10/1966 08:00	0.18
09/12/1975 08:00	0.12	09/12/1975 14:00	0.1	09/10/1966 08:00	0.18
10/12/1975 08:00	0.08	10/12/1975 14:00	0.08	10/10/1966 08:00	0.19
11/12/1975 08:00	0.07	11/12/1975 14:00	0.06	11/10/1966 08:00	
12/12/1975 08:00		12/12/1975 14:00		12/10/1966 08:00	0.18
13/12/1975 08:00	0.03	13/12/1975 14:00		13/10/1966 08:00	
14/12/1975 08:00		14/12/1975 14:00		14/10/1966 08:00	0.17
15/12/1975 08:00	0.02	15/12/1975 14:00	0.02	15/10/1966 08:00	
16/12/1975 08:00	0.02	16/12/1975 14:00	0.01	16/10/1966 08:00	
17/12/1975 08:10	0.01	17/12/1975 14:00	0.01	17/10/1966 08:00	0.14
18/12/1975 08:00	0	18/12/1975 14:00	0	18/10/1966 08:00	
19/12/1975 08:00	0	19/12/1975 14:00	0	19/10/1966 08:00	0.13
20/12/1975 08:00	0	20/12/1975 14:00	0	20/10/1966 08:00	
21/12/1975 08:00	0	21/12/1975 14:00	0	21/10/1966 08:00	0.1
22/12/1975 08:00	0	22/12/1975 14:00	0	22/10/1966 08:00	
23/12/1975 08:00	0	23/12/1975 14:00	0	23/10/1966 08:00	
24/12/1975 08:00	0	24/12/1975 14:00	0	24/10/1966 08:00	0.04
25/12/1975 08:00	0	25/12/1975 14:00	0	25/10/1966 08:00	
26/12/1975 08:00	0	26/12/1975 14:00	0	26/10/1966 08:00	0.02
27/12/1975 08:00	0	27/12/1975 14:00	0	27/10/1966 08:00	
28/12/1975 08:00	0	28/12/1975 14:00	0	28/10/1966 08:00	0
29/12/1975 08:00	0	29/12/1975 14:00	0	29/10/1966 08:00	
30/12/1975 08:00	0	30/12/1975 14:00	0	30/10/1966 08:00	0
31/12/1975 08:00	0	31/12/1975 14:00	0	31/10/1966 08:00	
01/01/1976 08:00	0	01/01/1976 14:00	0	01/11/1966 08:00	1.8
02/01/1976 08:00	0	02/01/1976 14:00	0	02/11/1966 08:00	
03/01/1976 08:00	0	03/01/1976 14:00	0	03/11/1966 08:00	
04/01/1976 08:00	0	04/01/1976 14:00	0	04/11/1966 08:00	1.44

05/01/1976 08:00	0	05/01/1976 14:00	0	05/11/1966 08:00	2.64
06/01/1976 08:00	0	06/01/1976 14:00	0	06/11/1966 08:00	
07/01/1976 08:00	0	07/01/1976 14:00	0	07/11/1966 08:00	2.72
08/01/1976 08:00	0	08/01/1976 14:00	0	08/11/1966 08:00	1.9
09/01/1976 08:00	0	09/01/1976 14:00	0	09/11/1966 08:00	2.5
10/01/1976 08:00	0	10/01/1976 14:00	0	10/11/1966 08:00	2.2
11/01/1976 08:00	0	11/01/1976 14:00	0	11/11/1966 08:00	2.31
12/01/1976 08:00	0	12/01/1976 14:00	0	12/11/1966 08:00	2.14
13/01/1976 08:00	0	13/01/1976 14:00	0	13/11/1966 08:00	
14/01/1976 08:00	0	14/01/1976 14:00	0	14/11/1966 08:00	1.7
15/01/1976 08:00	0	15/01/1976 14:00	0	15/11/1966 08:00	1.65
16/01/1976 08:00	0	16/01/1976 14:00	0	16/11/1966 08:00	1.6
17/01/1976 08:00	0	17/01/1976 14:00	0	17/11/1966 08:00	1.56
18/01/1976 08:00	0	18/01/1976 14:00	0	18/11/1966 08:00	1.51
19/01/1976 08:00	0	19/01/1976 14:00	0	19/11/1966 08:00	1.49
20/01/1976 08:00	0	20/01/1976 14:00	0	20/11/1966 08:00	
21/01/1976 08:00	0	21/01/1976 14:00	0	21/11/1966 08:00	1.47
22/01/1976 08:00	0	22/01/1976 14:00	0	22/11/1966 08:00	1.45
23/01/1976 08:00	0	23/01/1976 14:00	0	23/11/1966 08:00	1.44
24/01/1976 08:00	0	24/01/1976 14:00	0	24/11/1966 08:00	1.7
25/01/1976 08:00	0	25/01/1976 14:00	0	25/11/1966 08:00	1.46
26/01/1976 08:00	0	26/01/1976 14:00	0	26/11/1966 08:00	1.43
27/01/1976 08:00	0	27/01/1976 14:00	0	27/11/1966 08:00	
28/01/1976 08:00	0	28/01/1976 14:00	0	28/11/1966 08:00	1.4
29/01/1976 08:00	0	29/01/1976 14:00	0	29/11/1966 08:00	1.38
30/01/1976 08:00	0	30/01/1976 14:00	0	30/11/1966 08:00	1.38
31/01/1976 08:00	0	31/01/1976 14:00	0	01/12/1966 08:00	
01/02/1976 08:00	0	01/02/1976 14:00	0	02/12/1966 08:00	
02/02/1976 08:00	0	02/02/1976 14:00	0	03/12/1966 08:00	
03/02/1976 08:00	0	03/02/1976 14:00	0	04/12/1966 08:00	
04/02/1976 08:00	0.4	04/02/1976 14:00	0.03	05/12/1966 08:00	
05/02/1976 08:00	0	05/02/1976 14:00	0	06/12/1966 08:00	
06/02/1976 08:00	0	06/02/1976 14:00	0	07/12/1966 08:00	
07/02/1976 08:00	0	07/02/1976 14:00	0	08/12/1966 08:00	
08/02/1976 08:00	0	08/02/1976 14:00	0	09/12/1966 08:00	
09/02/1976 08:00	0	09/02/1976 14:00	0	10/12/1966 08:00	
10/02/1976 08:00	0	10/02/1976 14:00	0	11/12/1966 08:00	
11/02/1976 08:00	0	11/02/1976 14:00	0	12/12/1966 08:00	
12/02/1976 08:00	0	12/02/1976 14:00	0	13/12/1966 08:00	

13/02/1976 08:00	0	13/02/1976 14:00	0	14/12/1966 08:00	
14/02/1976 08:00	0	14/02/1976 14:00	0	15/12/1966 08:00	
15/02/1976 08:00	0	15/02/1976 14:00	0	16/12/1966 08:00	
16/02/1976 08:00	0	16/02/1976 14:00	0	17/12/1966 08:00	
17/02/1976 08:00	0	17/02/1976 14:00	0	18/12/1966 08:00	
18/02/1976 08:00	0	18/02/1976 14:00	0	19/12/1966 08:00	
19/02/1976 08:00	0	19/02/1976 14:00	0	20/12/1966 08:00	
20/02/1976 08:00	0	20/02/1976 14:00	0	21/12/1966 08:00	
21/02/1976 08:00	0	21/02/1976 14:00	0	22/12/1966 08:00	
22/02/1976 08:00	0	22/02/1976 14:00	0	23/12/1966 08:00	
23/02/1976 08:00	0	23/02/1976 14:00	0	24/12/1966 08:00	
24/02/1976 08:00	0	24/02/1976 14:00	0	25/12/1966 08:00	
25/02/1976 08:00	0	25/02/1976 14:00	0	26/12/1966 08:00	
26/02/1976 08:00	0	26/02/1976 14:00	0	27/12/1966 08:00	
27/02/1976 08:00	0	27/02/1976 14:00	0	28/12/1966 08:00	
28/02/1976 08:00	0	28/02/1976 14:00	0	29/12/1966 08:00	
29/02/1976 08:00	0	29/02/1976 14:00	0	30/12/1966 08:00	
01/03/1976 08:00		01/03/1976 14:00		31/12/1966 08:00	
02/03/1976 08:00		02/03/1976 14:00		01/01/1967 08:00	
03/03/1976 08:00		03/03/1976 14:00		02/01/1967 08:00	
04/03/1976 08:00		04/03/1976 14:00		03/01/1967 08:00	
05/03/1976 08:00		05/03/1976 14:00		04/01/1967 08:00	
06/03/1976 08:00		06/03/1976 14:00		05/01/1967 08:00	
07/03/1976 08:00		07/03/1976 14:00		06/01/1967 08:00	
08/03/1976 08:00		08/03/1976 14:00		07/01/1967 08:00	
09/03/1976 08:00		09/03/1976 14:00		08/01/1967 08:00	
10/03/1976 08:00		10/03/1976 14:00		09/01/1967 08:00	
11/03/1976 08:00		11/03/1976 14:00		10/01/1967 08:00	
12/03/1976 08:00		12/03/1976 14:00		11/01/1967 08:00	
13/03/1976 08:00		13/03/1976 14:00		12/01/1967 08:00	
14/03/1976 08:00		14/03/1976 14:00		13/01/1967 08:00	
15/03/1976 08:00		15/03/1976 14:00		14/01/1967 08:00	
16/03/1976 08:00		16/03/1976 14:00		15/01/1967 08:00	
17/03/1976 08:00		17/03/1976 14:00		16/01/1967 08:00	
18/03/1976 08:00		18/03/1976 14:00		17/01/1967 08:00	
19/03/1976 08:00		19/03/1976 14:00		18/01/1967 08:00	
20/03/1976 08:00		20/03/1976 14:00		19/01/1967 08:00	
21/03/1976 08:00		21/03/1976 14:00		20/01/1967 08:00	
22/03/1976 08:00		22/03/1976 14:00		21/01/1967 08:00	

23/03/1976 08:00		23/03/1976 14:00		22/01/1967 08:00	
24/03/1976 08:00		24/03/1976 14:00		23/01/1967 08:00	
25/03/1976 08:00		25/03/1976 14:00		24/01/1967 08:00	
26/03/1976 08:00		26/03/1976 14:00		25/01/1967 08:00	
27/03/1976 08:00		27/03/1976 14:00		26/01/1967 08:00	
28/03/1976 08:00		28/03/1976 14:00		27/01/1967 08:00	
29/03/1976 08:00		29/03/1976 14:00		28/01/1967 08:00	
30/03/1976 08:00		30/03/1976 14:00		29/01/1967 08:00	
31/03/1976 08:00		31/03/1976 14:00		30/01/1967 08:00	
01/04/1976 08:00	0	01/04/1976 14:00	0	31/01/1967 08:00	
02/04/1976 08:00	0	02/04/1976 14:00	0	01/02/1967 08:00	
03/04/1976 08:00	0	03/04/1976 14:00	0	02/02/1967 08:00	
04/04/1976 08:00	0	04/04/1976 14:00	0	03/02/1967 08:00	
05/04/1976 08:00	0	05/04/1976 14:00	0	04/02/1967 08:00	
06/04/1976 08:00	0	06/04/1976 14:00	0	05/02/1967 08:00	
07/04/1976 08:00	0	07/04/1976 14:00	0	06/02/1967 08:00	
08/04/1976 08:00	0	08/04/1976 14:00	0	07/02/1967 08:00	
09/04/1976 08:00	0	09/04/1976 14:00	0	08/02/1967 08:00	
10/04/1976 08:00	0	10/04/1976 14:00	0	09/02/1967 08:00	
11/04/1976 08:00	0	11/04/1976 14:00	0	10/02/1967 08:00	
12/04/1976 08:00	0.34	12/04/1976 14:00	0.25	11/02/1967 08:00	
13/04/1976 08:00	0.003	13/04/1976 14:00	0	12/02/1967 08:00	
14/04/1976 08:00	0	14/04/1976 14:00	0	13/02/1967 08:00	
15/04/1976 08:00	0	15/04/1976 14:00	0	14/02/1967 08:00	
16/04/1976 08:00	1.5	16/04/1976 14:00	1	15/02/1967 08:00	
17/04/1976 08:00	0.37	17/04/1976 14:00		16/02/1967 08:00	
18/04/1976 08:00		18/04/1976 14:00		17/02/1967 08:00	
19/04/1976 08:00		19/04/1976 14:00		18/02/1967 08:00	
20/04/1976 08:00	0.11	20/04/1976 14:00	0.08	19/02/1967 08:00	
21/04/1976 08:00	0.05	21/04/1976 14:00	0.03	20/02/1967 08:00	
22/04/1976 08:00	0.01	22/04/1976 14:00	0	21/02/1967 08:00	
23/04/1976 08:00	0	23/04/1976 14:00	0	22/02/1967 08:00	
24/04/1976 08:00	0	24/04/1976 14:00	0	23/02/1967 08:00	
25/04/1976 08:00		25/04/1976 14:00		24/02/1967 08:00	
26/04/1976 08:00	0.08	26/04/1976 14:00	0.07	25/02/1967 08:00	
27/04/1976 08:00	0.11	27/04/1976 14:00	0.07	26/02/1967 08:00	
28/04/1976 08:00	0.49	28/04/1976 14:00	0.44	27/02/1967 08:00	
29/04/1976 08:00	0.45	29/04/1976 14:00	0.3	28/02/1967 08:00	
30/04/1976 08:00	0.16	30/04/1976 14:00	0.14	01/03/1967 08:00	

01/05/1976 08:00		01/05/1976 14:00		02/03/1967 08:00	
02/05/1976 08:00		02/05/1976 14:00		03/03/1967 08:00	
03/05/1976 08:00	0.08	03/05/1976 14:00	0.08	04/03/1967 08:00	
04/05/1976 08:00	0.06	04/05/1976 14:00	0.06	05/03/1967 08:00	
05/05/1976 08:00	0.04	05/05/1976 14:00	0.03	06/03/1967 08:00	
06/05/1976 08:00	0.03	06/05/1976 14:00	0.02	07/03/1967 08:00	
07/05/1976 08:00	0.02	07/05/1976 14:00	0.02	08/03/1967 08:00	
08/05/1976 08:00	0.02	08/05/1976 14:00	0.01	09/03/1967 08:00	
09/05/1976 08:00		09/05/1976 14:00		10/03/1967 08:00	
10/05/1976 08:00	0	10/05/1976 14:00	0	11/03/1967 08:00	
11/05/1976 08:00	0	11/05/1976 14:00	0	12/03/1967 08:00	
12/05/1976 08:00	0	12/05/1976 14:00	0	13/03/1967 08:00	
13/05/1976 08:00	0	13/05/1976 14:00	0	14/03/1967 08:00	
14/05/1976 08:00	0	14/05/1976 14:00	0	15/03/1967 08:00	
15/05/1976 08:00	0	15/05/1976 14:00	0	16/03/1967 08:00	
16/05/1976 08:00	0	16/05/1976 14:00	0	17/03/1967 08:00	
17/05/1976 08:00	0	17/05/1976 14:00	0	18/03/1967 08:00	
18/05/1976 08:00	0	18/05/1976 14:00	0	19/03/1967 08:00	
19/05/1976 08:00	0	19/05/1976 14:00	0	20/03/1967 08:00	
20/05/1976 08:00	0	20/05/1976 14:00	0	21/03/1967 08:00	
21/05/1976 08:00	0	21/05/1976 14:00	0	22/03/1967 08:00	
22/05/1976 08:00	0	22/05/1976 14:00	0	23/03/1967 08:00	
23/05/1976 08:00	0	23/05/1976 14:00	0	24/03/1967 08:00	
24/05/1976 08:00	0	24/05/1976 14:00	0	25/03/1967 08:00	
25/05/1976 08:00	0	25/05/1976 14:00	0	26/03/1967 08:00	
26/05/1976 08:00	0	26/05/1976 14:00	0	27/03/1967 08:00	
27/05/1976 08:00	0	27/05/1976 14:00	0	28/03/1967 08:00	
28/05/1976 08:00	0	28/05/1976 14:00	0	29/03/1967 08:00	
29/05/1976 08:00	0	29/05/1976 14:00	0	30/03/1967 08:00	
30/05/1976 08:00	0	30/05/1976 14:00	0	31/03/1967 08:00	
31/05/1976 08:00	0	31/05/1976 14:00	0	01/04/1967 08:00	
01/06/1976 08:00	0	01/06/1976 14:00	0	02/04/1967 08:00	
02/06/1976 08:00	0	02/06/1976 14:00	0	03/04/1967 08:00	
03/06/1976 08:00	0	03/06/1976 14:00	0	04/04/1967 08:00	
04/06/1976 08:00	0	04/06/1976 14:00	0	05/04/1967 08:00	
05/06/1976 08:00	0	05/06/1976 14:00	0	06/04/1967 08:00	
06/06/1976 08:00	0	06/06/1976 14:00	0	07/04/1967 08:00	
07/06/1976 08:00	0	07/06/1976 14:00	0	08/04/1967 08:00	
08/06/1976 08:00	0	08/06/1976 14:00	0	09/04/1967 08:00	

09/06/1976 08:00	0	09/06/1976 14:00	0	10/04/1967 08:00	
10/06/1976 08:00	0	10/06/1976 14:00	0	11/04/1967 08:00	
11/06/1976 08:00	0	11/06/1976 14:00	0	12/04/1967 08:00	
12/06/1976 08:00	0	12/06/1976 14:00	0	13/04/1967 08:00	
13/06/1976 08:00	0	13/06/1976 14:00	0	14/04/1967 08:00	
14/06/1976 08:00	0	14/06/1976 14:00	0	15/04/1967 08:00	
15/06/1976 08:00	0	15/06/1976 14:00	0	16/04/1967 08:00	
16/06/1976 08:00	0	16/06/1976 14:00	0	17/04/1967 08:00	
17/06/1976 08:00	0	17/06/1976 14:00	0	18/04/1967 08:00	
18/06/1976 08:00	0	18/06/1976 14:00	0	19/04/1967 08:00	
19/06/1976 08:00	0	19/06/1976 14:00	0	20/04/1967 08:00	
20/06/1976 08:00	0	20/06/1976 14:00	0	21/04/1967 08:00	
21/06/1976 08:00	0	21/06/1976 14:00	0	22/04/1967 08:00	
22/06/1976 08:00	0	22/06/1976 14:00	0	23/04/1967 08:00	
23/06/1976 08:00	0	23/06/1976 14:00	0	24/04/1967 08:00	
24/06/1976 08:00	0	24/06/1976 14:00	0	25/04/1967 08:00	
25/06/1976 08:00	0	25/06/1976 14:00	0	26/04/1967 08:00	
26/06/1976 08:00	0	26/06/1976 14:00	0	27/04/1967 08:00	
27/06/1976 08:00	0	27/06/1976 14:00	0	28/04/1967 08:00	
28/06/1976 08:00	0	28/06/1976 14:00	0	29/04/1967 08:00	
29/06/1976 08:00	0	29/06/1976 14:00	0	30/04/1967 08:00	
30/06/1976 08:00	0	30/06/1976 14:00	0	01/05/1967 08:00	
01/07/1976 08:00	0	01/07/1976 14:00	0	02/05/1967 08:00	
02/07/1976 08:00	0	02/07/1976 14:00	0	03/05/1967 08:00	
03/07/1976 08:00	0	03/07/1976 14:00	0	04/05/1967 08:00	
04/07/1976 08:00	0	04/07/1976 14:00	0	05/05/1967 08:00	
05/07/1976 08:00	0	05/07/1976 14:00	0	06/05/1967 08:00	
06/07/1976 08:00	0	06/07/1976 14:00	0	07/05/1967 08:00	
07/07/1976 08:00	0	07/07/1976 14:00	0	08/05/1967 08:00	
08/07/1976 08:00	0	08/07/1976 14:00	0	09/05/1967 08:00	
09/07/1976 08:00	0	09/07/1976 14:00	0	10/05/1967 08:00	
10/07/1976 08:00	0	10/07/1976 14:00	0	11/05/1967 08:00	
11/07/1976 08:00	0	11/07/1976 14:00	0	12/05/1967 08:00	
12/07/1976 08:00	0	12/07/1976 14:00	0	13/05/1967 08:00	
13/07/1976 08:00	0	13/07/1976 14:00	0	14/05/1967 08:00	
14/07/1976 08:00	0	14/07/1976 14:00	0	15/05/1967 08:00	
15/07/1976 08:00	0	15/07/1976 14:00	0	16/05/1967 08:00	
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27/06/1977 08:00		27/06/1977 14:00		27/04/1968 10:00	1.3
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29/06/1977 08:00		29/06/1977 14:00		29/04/1968 07:00	2.75
30/06/1977 08:00		30/06/1977 14:00		30/04/1968 10:00	
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16/07/1977 08:00	0	16/07/1977 14:00	0	16/05/1968 10:00	1.68
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19/07/1977 08:00	0	19/07/1977 14:00	0	19/05/1968 10:00	
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21/07/1977 08:00	0	21/07/1977 14:00	0	21/05/1968 10:00	1.62
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24/07/1977 08:00	0	24/07/1977 14:00	0	24/05/1968 10:00	1.6
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26/07/1977 08:00	0	26/07/1977 14:00	0	26/05/1968 10:00	2.08
27/07/1977 08:00	0	27/07/1977 14:00	0	27/05/1968 10:00	
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31/07/1977 08:00	0	31/07/1977 14:00	0	31/05/1968 00:00	1.6
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02/08/1977 08:00	0	02/08/1977 14:00	0	02/06/1968 10:00	
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24/09/1977 08:00	0	24/09/1977 14:00	0	25/07/1968 14:00	1.35
25/09/1977 08:00	0	25/09/1977 14:00	0	26/07/1968 14:00	
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22/10/1977 08:00	0	22/10/1977 14:00		22/08/1968 09:30	1.22
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02/11/1977 08:00	0	02/11/1977 14:00		02/09/1968 09:20	1.14
03/11/1977 08:00	1	03/11/1977 14:00	0.8	03/09/1968 10:10	1.13
04/11/1977 08:00	1.5	04/11/1977 14:00	0.7	04/09/1968 09:30	1.09
05/11/1977 08:00	0.4	05/11/1977 14:00	0.2	05/09/1968 10:00	
06/11/1977 08:00	0.05	06/11/1977 14:10	0.03	06/09/1968 10:00	
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08/11/1977 08:00	0.7	08/11/1977 14:20	0.6	08/09/1968 10:00	
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10/11/1977 08:00	0.45	10/11/1977 14:30	0.4	10/09/1968 10:00	
11/11/1977 08:00	0.42	11/11/1977 14:00	0.37	11/09/1968 11:30	0.97
12/11/1977 08:00	0.32	12/11/1977 14:15	0.3	12/09/1968 09:30	0.95
13/11/1977 08:00	0.8	13/11/1977 14:00	0.45	13/09/1968 11:00	0.91
14/11/1977 08:00	0.41	14/11/1977 14:00		14/09/1968 10:00	0.88
15/11/1977 08:00	0.38	15/11/1977 14:00	0.36	15/09/1968 10:00	
16/11/1977 08:00	0.35	16/11/1977 14:00	0.35	16/09/1968 08:20	0.88
17/11/1977 08:00	0.35	17/11/1977 14:00	0.34	17/09/1968 07:20	0.85
18/11/1977 08:00	0.39	18/11/1977 14:00	0.38	18/09/1968 09:20	0.91
19/11/1977 08:00	0.85	19/11/1977 14:00	0.8	19/09/1968 09:20	
20/11/1977 08:00	0.9	20/11/1977 14:00	0.65	20/09/1968 09:20	0.49
21/11/1977 08:00	1.1	21/11/1977 14:00	0.85	21/09/1968 09:20	0.48
22/11/1977 08:30	0.66	22/11/1977 14:05	0.63	22/09/1968 10:00	
23/11/1977 08:00	0.49	23/11/1977 14:00	0.46	23/09/1968 06:30	0.54
24/11/1977 08:00	0.46	24/11/1977 14:00	0.45	24/09/1968 10:00	
25/11/1977 08:00	0.55	25/11/1977 14:10	0.53	25/09/1968 09:30	0.48
26/11/1977 08:00	0.55	26/11/1977 14:00	0.53	26/09/1968 09:30	0.46
27/11/1977 08:00	0.56	27/11/1977 14:10	0.56	27/09/1968 09:30	
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29/11/1977 08:00	0.6	29/11/1977 14:00	0.58	29/09/1968 10:00	
30/11/1977 08:00	0.48	30/11/1977 14:15	0.46	30/09/1968 06:20	0.32
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02/12/1977 08:00	0.46	02/12/1977 14:10	0.45	02/10/1968 10:00	
03/12/1977 08:00	0.43	03/12/1977 14:00	0.43	03/10/1968 10:00	
04/12/1977 08:00		04/12/1977 14:00		04/10/1968 09:40	0.47
05/12/1977 08:00	0.41	05/12/1977 14:10	0.4	05/10/1968 09:45	0.44
06/12/1977 09:40	0.6	06/12/1977 14:00	0.7	06/10/1968 09:40	

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08/12/1977 08:00	0.41	08/12/1977 14:00	0.41	08/10/1968 09:30	
09/12/1977 11:00	0.39	09/12/1977 16:00	0.38	09/10/1968 09:30	0.35
10/12/1977 10:30	0.46	10/12/1977 15:30	0.46	10/10/1968 11:00	0.36
11/12/1977 08:00		11/12/1977 14:00		11/10/1968 09:10	0.42
12/12/1977 10:45	0.43	12/12/1977 17:00	0.42	12/10/1968 09:40	
13/12/1977 10:15	0.4	13/12/1977 14:00	0.4	13/10/1968 09:40	
14/12/1977 10:15	0.46	14/12/1977 15:30	0.43	14/10/1968 09:40	0.38
15/12/1977 10:30	0.6	15/12/1977 14:00	0.59	15/10/1968 09:45	0.37
16/12/1977 11:00	0.63	16/12/1977 14:00	0.63	16/10/1968 09:30	0.4
17/12/1977 10:00	0.57	17/12/1977 14:00	0.56	17/10/1968 09:20	0.48
18/12/1977 08:00		18/12/1977 14:00		18/10/1968 09:20	0.72
19/12/1977 10:30	0.48	19/12/1977 16:00	0.5	19/10/1968 09:20	
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21/12/1977 10:00	0.6	21/12/1977 14:00	0.56	21/10/1968 09:20	0.46
22/12/1977 10:00	0.53	22/12/1977 14:00	0.5	22/10/1968 09:30	
23/12/1977 10:00	0.45	23/12/1977 14:00	0.44	23/10/1968 09:30	0.44
24/12/1977 10:00	0.42	24/12/1977 16:00	0.41	24/10/1968 09:30	0.33
25/12/1977 08:00		25/12/1977 14:00		25/10/1968 09:20	0.39
26/12/1977 08:00		26/12/1977 14:00		26/10/1968 11:00	0.44
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28/12/1977 08:00	0.47	28/12/1977 16:00	0.46	28/10/1968 06:40	0.33
29/12/1977 10:00	0.46	29/12/1977 16:30	0.46	29/10/1968 09:20	0.39
30/12/1977 10:00	0.47	30/12/1977 18:00	0.48	30/10/1968 09:20	0.33
31/12/1977 10:15	0.46	31/12/1977 15:30	0.45	31/10/1968 09:30	0.31
01/01/1978 08:00		01/01/1978 14:00		01/11/1968 09:00	0.44
02/01/1978 08:00		02/01/1978 14:00		02/11/1968 11:30	0.35
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04/01/1978 08:00		04/01/1978 14:00		04/11/1968 11:30	0.27
05/01/1978 08:00		05/01/1978 14:00		05/11/1968 09:10	0.27
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10/01/1978 08:00	0.43	10/01/1978 14:10	0.43	10/11/1968 09:00	
11/01/1978 08:00	0.43	11/01/1978 14:00	0.43	11/11/1968 06:25	1.47
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14/01/1978 08:00	0.42	14/01/1978 14:00		14/11/1968 09:30	1.88

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17/01/1978 08:00	0.4	17/01/1978 14:00	0.4	17/11/1968 09:00	
18/01/1978 08:00	0.39	18/01/1978 16:30	0.46	18/11/1968 09:35	1.53
19/01/1978 08:00	0.42	19/01/1978 14:00	0.38	19/11/1968 09:30	1.34
20/01/1978 08:00	0.36	20/01/1978 14:10	0.36	20/11/1968 10:00	2.68
21/01/1978 08:00	0.38	21/01/1978 14:00		21/11/1968 10:00	2.44
22/01/1978 08:00		22/01/1978 14:00		22/11/1968 09:20	2.5
23/01/1978 08:00	0.34	23/01/1978 14:45	0.34	23/11/1968 09:00	
24/01/1978 08:00	0.34	24/01/1978 14:00	0.33	24/11/1968 09:10	2.73
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27/01/1978 08:00	0.3	27/01/1978 14:00	0.29	27/11/1968 10:00	2.03
28/01/1978 08:00	0.28	28/01/1978 14:00		28/11/1968 09:00	
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01/02/1978 08:00		01/02/1978 14:00		02/12/1968 09:30	2.22
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03/02/1978 08:00		03/02/1978 14:00		04/12/1968 09:30	
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07/02/1978 08:00		07/02/1978 14:00		08/12/1968 09:30	
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09/02/1978 08:00		09/02/1978 14:00		10/12/1968 09:10	
10/02/1978 08:00		10/02/1978 14:00		11/12/1968 09:10	1.72
11/02/1978 08:00		11/02/1978 14:00		12/12/1968 09:10	
12/02/1978 08:00		12/02/1978 14:00		13/12/1968 09:10	1.72
13/02/1978 08:00		13/02/1978 14:00		14/12/1968 09:10	1.66
14/02/1978 08:00		14/02/1978 14:00		15/12/1968 09:10	
15/02/1978 08:00		15/02/1978 14:00		16/12/1968 09:55	1.62
16/02/1978 08:00		16/02/1978 14:00		17/12/1968 09:25	1.73
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19/02/1978 08:00		19/02/1978 14:00		20/12/1968 09:30	1.57
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21/02/1978 08:00		21/02/1978 14:00		22/12/1968 09:10	
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26/02/1978 08:00		26/02/1978 14:00		27/12/1968 09:30	1.47
27/02/1978 08:00		27/02/1978 14:00		28/12/1968 09:20	1.46
28/02/1978 08:00		28/02/1978 14:00		29/12/1968 09:10	
01/03/1978 08:00	0.34	01/03/1978 14:00	0.42	30/12/1968 09:10	1.45
02/03/1978 08:00	0.48	02/03/1978 14:00	0.44	31/12/1968 09:10	
03/03/1978 08:00	0.5	03/03/1978 14:10	0.45	01/01/1969 09:40	
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05/03/1978 08:00		05/03/1978 14:00		03/01/1969 09:40	
06/03/1978 08:00	0.33	06/03/1978 14:10	0.33	04/01/1969 09:30	1.4
07/03/1978 08:00	0.32	07/03/1978 14:00	0.32	05/01/1969 09:40	
08/03/1978 08:00	0.31	08/03/1978 14:00	0.31	06/01/1969 09:40	1.38
09/03/1978 08:00	0.3	09/03/1978 14:00	0.29	07/01/1969 07:35	1.38
10/03/1978 08:10	0.28	10/03/1978 14:20	0.26	08/01/1969 09:40	
11/03/1978 08:40	0.26	11/03/1978 14:00		09/01/1969 10:10	1.37
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13/03/1978 08:00	0.24	13/03/1978 14:10	0.22	11/01/1969 09:10	1.36
14/03/1978 08:10	0.2	14/03/1978 14:00	0.2	12/01/1969 09:40	
15/03/1978 08:00	0.18	15/03/1978 14:10	0.18	13/01/1969 09:25	1.34
16/03/1978 08:10	0.17	16/03/1978 14:20	0.22	14/01/1969 13:45	1.35
17/03/1978 08:10	0.22	17/03/1978 14:15	0.21	15/01/1969 09:15	1.36
18/03/1978 08:00	0.2	18/03/1978 14:00		16/01/1969 09:20	1.34
19/03/1978 08:00		19/03/1978 14:00		17/01/1969 09:35	1.35
20/03/1978 08:00	0.2	20/03/1978 14:20	0.2	18/01/1969 09:20	1.33
21/03/1978 08:00	0.19	21/03/1978 14:00	0.19	19/01/1969 09:40	
22/03/1978 08:00	0.28	22/03/1978 14:10	0.26	20/01/1969 09:45	1.33
23/03/1978 08:10	0.26	23/03/1978 14:00	0.28	21/01/1969 09:15	1.34
24/03/1978 08:00		24/03/1978 14:00		22/01/1969 09:20	1.33
25/03/1978 08:10	0.52	25/03/1978 14:00		23/01/1969 09:40	
26/03/1978 08:00		26/03/1978 14:00		24/01/1969 09:10	1.32
27/03/1978 08:00		27/03/1978 14:00		25/01/1969 09:30	1.32
28/03/1978 08:20	0.48	28/03/1978 14:00	0.46	26/01/1969 09:40	
29/03/1978 08:10	0.5	29/03/1978 14:00	0.5	27/01/1969 09:35	1.34
30/03/1978 08:00	0.7	30/03/1978 14:10	0.63	28/01/1969 09:40	1.32
31/03/1978 08:00	0.6	31/03/1978 14:00	0.41	29/01/1969 09:45	1.32
01/04/1978 08:00	0.39	01/04/1978 14:00		30/01/1969 09:40	
02/04/1978 08:00		02/04/1978 14:00		31/01/1969 09:35	1.3

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05/04/1978 08:00	0.53	05/04/1978 14:10	0.48	03/02/1969 10:15	1.38
06/04/1978 08:00	0.6	06/04/1978 14:45	0.57	04/02/1969 09:10	1.32
07/04/1978 08:00	0.78	07/04/1978 14:10	0.65	05/02/1969 09:10	1.3
08/04/1978 08:00	0.5	08/04/1978 14:00		06/02/1969 09:40	
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12/04/1978 08:00	0.9	12/04/1978 14:00	0.7	10/02/1969 10:50	1.26
13/04/1978 08:00	1.35	13/04/1978 14:10	0.62	11/02/1969 10:00	1.26
14/04/1978 08:00	0.85	14/04/1978 14:00	0.66	12/02/1969 09:25	1.25
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16/04/1978 08:00		16/04/1978 14:00		14/02/1969 09:30	1.25
17/04/1978 08:00	0.7	17/04/1978 14:00	0.64	15/02/1969 09:40	
18/04/1978 08:00	0.56	18/04/1978 14:10	0.53	16/02/1969 09:40	
19/04/1978 08:00	0.5	19/04/1978 14:00	0.48	17/02/1969 09:40	1.24
20/04/1978 08:00	0.46	20/04/1978 14:00	0.46	18/02/1969 09:40	1.3
21/04/1978 08:00	0.45	21/04/1978 14:00	0.45	19/02/1969 09:40	1.34
22/04/1978 08:10	0.75	22/04/1978 14:00		20/02/1969 09:40	1.28
23/04/1978 08:00		23/04/1978 14:00		21/02/1969 10:00	1.25
24/04/1978 08:00	0.7	24/04/1978 14:10	0.67	22/02/1969 09:10	1.23
25/04/1978 08:00	0.8	25/04/1978 14:00	0.74	23/02/1969 09:40	
26/04/1978 08:00	0.75	26/04/1978 14:10	0.7	24/02/1969 09:15	1.26
27/04/1978 08:00	0.58	27/04/1978 14:00	0.58	25/02/1969 10:25	1.64
28/04/1978 08:00	0.54	28/04/1978 14:10	0.5	26/02/1969 10:25	2.03
29/04/1978 08:00	0.46	29/04/1978 14:00		27/02/1969 09:40	
30/04/1978 08:00		30/04/1978 14:00		28/02/1969 09:40	
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02/05/1978 08:00	0.6	02/05/1978 14:00	0.6	02/03/1969 09:40	
03/05/1978 08:00	0.6	03/05/1978 14:00	0.6	03/03/1969 09:30	1.43
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05/05/1978 08:00	0.6	05/05/1978 14:00	0.6	05/03/1969 09:45	1.98
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11/05/1978 08:00	0.54	11/05/1978 14:00	0.54	11/03/1969 09:45	1.5

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13/05/1978 08:00	0.54	13/05/1978 14:00		13/03/1969 10:00	2.15
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15/05/1978 08:00	0.51	15/05/1978 14:10	0.51	15/03/1969 09:50	1.54
16/05/1978 08:00	0.5	16/05/1978 14:15	0.5	16/03/1969 09:40	
17/05/1978 08:00	0.5	17/05/1978 14:00	0.49	17/03/1969 09:45	1.9
18/05/1978 08:00	0.48	18/05/1978 14:00	0.47	18/03/1969 09:40	1.63
19/05/1978 08:00	0.45	19/05/1978 14:15	0.45	19/03/1969 10:00	1.57
20/05/1978 08:00	0.43	20/05/1978 14:00		20/03/1969 09:40	
21/05/1978 08:00		21/05/1978 14:00		21/03/1969 09:15	1.48
22/05/1978 08:10	0.43	22/05/1978 14:00	0.43	22/03/1969 09:35	1.45
23/05/1978 08:00	0.43	23/05/1978 14:10	0.43	23/03/1969 09:40	
24/05/1978 08:00	0.42	24/05/1978 14:00	0.42	24/03/1969 09:10	1.43
25/05/1978 08:00	0.42	25/05/1978 14:10	0.42	25/03/1969 10:05	1.41
26/05/1978 08:00	0.41	26/05/1978 14:00	0.41	26/03/1969 09:40	1.44
27/05/1978 08:00	0.41	27/05/1978 14:00		27/03/1969 09:30	1.44
28/05/1978 08:00		28/05/1978 14:00		28/03/1969 09:40	
29/05/1978 08:00	0.41	29/05/1978 14:10	0.41	29/03/1969 09:40	
30/05/1978 08:10	0.4	30/05/1978 14:00	0.4	30/03/1969 09:40	
31/05/1978 08:00	0.4	31/05/1978 14:10	0.4	31/03/1969 09:55	1.74
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02/06/1978 08:00	0.4	02/06/1978 14:10	0.4	02/04/1969 09:35	1.46
03/06/1978 08:10	0.4	03/06/1978 14:00		03/04/1969 09:40	
04/06/1978 08:00		04/06/1978 14:00		04/04/1969 09:40	
05/06/1978 08:00	0.39	05/06/1978 14:00	0.39	05/04/1969 09:40	
06/06/1978 08:00	0.39	06/06/1978 14:10	0.39	06/04/1969 09:40	
07/06/1978 08:00	0.38	07/06/1978 14:00	0.38	07/04/1969 10:40	1.4
08/06/1978 08:00	0.38	08/06/1978 14:15	0.38	08/04/1969 09:40	1.4
09/06/1978 08:00	0.38	09/06/1978 14:00	0.38	09/04/1969 09:55	1.39
10/06/1978 08:00	0.37	10/06/1978 14:00		10/04/1969 09:40	1.7
11/06/1978 08:00		11/06/1978 14:00		11/04/1969 09:45	1.41
12/06/1978 08:00	0.35	12/06/1978 14:00	0.35	12/04/1969 09:40	1.38
13/06/1978 08:00	0.34	13/06/1978 14:00	0.34	13/04/1969 09:40	
14/06/1978 08:00	0.33	14/06/1978 14:10	0.33	14/04/1969 09:30	1.48
15/06/1978 08:00	0.32	15/06/1978 14:00	0.32	15/04/1969 09:40	
16/06/1978 08:00	0.32	16/06/1978 14:00	0.32	16/04/1969 09:15	1.38
17/06/1978 08:10	0.3	17/06/1978 14:00	0.3	17/04/1969 09:20	1.37
18/06/1978 08:00		18/06/1978 14:00		18/04/1969 17:15	1.37
19/06/1978 08:00	0.29	19/06/1978 14:10	0.29	19/04/1969 09:40	

20/06/1978 08:10	0.29	20/06/1978 14:00	0.29	20/04/1969 09:40	
21/06/1978 08:00	0.28	21/06/1978 14:00	0.28	21/04/1969 09:25	1.33
22/06/1978 08:00	0.28	22/06/1978 14:00	0.28	22/04/1969 09:30	2.12
23/06/1978 08:00	0.27	23/06/1978 14:00	0.27	23/04/1969 09:10	1.7
24/06/1978 08:00	0.27	24/06/1978 14:00		24/04/1969 09:20	1.59
25/06/1978 08:00		25/06/1978 14:00		25/04/1969 09:40	1.55
26/06/1978 08:00	0.26	26/06/1978 14:00	0.26	26/04/1969 09:40	
27/06/1978 08:00	0.26	27/06/1978 14:00	0.26	27/04/1969 09:40	
28/06/1978 08:00	0.26	28/06/1978 14:10	0.26	28/04/1969 09:15	1.45
29/06/1978 08:00	0.25	29/06/1978 14:00	0.25	29/04/1969 09:45	1.44
30/06/1978 08:00	0.25	30/06/1978 14:10	0.25	30/04/1969 09:30	1.38

Rainfall Data for the period 1968 - 1978

1968	81.68
1969	37.23
1970	43.18
1971	49.93
1972	46.07
1973	40.62
1975	37.43
1976	35.83
1977	72.42
1978	83.59

Annex III: Kalundu River Turbidity and TSSC Data (2020-2021)

SHORT RAINY SEASON (OCTOBER, NOVEMBER, DECEMBER 2020, JANUARY, FEBRUARY 2021)					
UPSTREAM (KALUNDU RIVER) OF THE DAM				**DOWNSTREAM (SPILLWAY) OF THE DAM**	
S/No.	**Sampling Date**	**Turbidity (KS EAS-12:2018) STANDARDS MAX 5.0)**	**Total Suspended Solids (KS EAS-12:2018) STANDARDS MAX30.0)**	**Turbidity (KS EAS-12:2018) STANDARDS MAX 5.0)**	**Total Suspended Solids (KS EAS-12:2018) STANDARDS MAX 30.0)**
RL503a/2022	28/10/2020	103.9662	151.3582	0	0
RL503b/2022	29/10/2020	47.5401	118.48	0	0
RL503c/2022	30/10/2020	148.3962	134.771	0	0
RL503d/2022	31/10/2020	ND	44.7262	0	0
RL503e/2022	01/11/2020	211.0425	270.1344	0	0
RL504a/2022	02/11/2020	44.43	93.5992	0	0
RL504b/2022	03/11/2020	77.3082	131.809	0	0
RL504c/2022	04/11/2020	237.1081	299.4582	0	0
RL504d/2022	05/11/2020	148.3962	215.7817	0	0
RL504e/2022	06/11/2020	119.0724	177.72	0	0
RL504f/2022	07/11/2020	177.72	226.593	0	0
RL504g/2022	08/11/2020	59.24	74.05	0	0
RL505a/2022	09/11/2020	121.442	162.91	0	0
RL505b/2022	10/11/2020	138.1773	202.3046	0	0
RL505c/2022	11/11/2020	75.6791	115.518	0	0
RL505d/2022	12/11/2020	29.62	74.05	0	0
RL505e/2022	13/11/2020	66.645	89.1562	29.64	16.4502
RL505f/2022	14/11/2020	1481.2962	1812.0035	1545.1332	1438.5774
RL505g/2022	15/11/2020	2725.7805	3213.77	222.3	106.8522
RL506a/2022	16/11/2020	2281.7767	2177.07	1511.64	1526.46
RL506b/2022	17/11/2020	3184.5943	3827.9407	3398.3742	2994.381
RL506c/2022	18/11/2020	6746.8436	7258.5291	6227.6604	6101.9868
RL506d/2022	19/11/2020	3682.6546	4285.5697	3245.58	3125.3898
RL506e/2022	20/11/2020	636.2376	745.2392	342.342	274.911
RL506f/2022	21/11/2020	29.4719	14.81	ND	ND
RL506g/2022	22/11/2020	326.1162	444.3	334.932	267.0564

RL507a/2022	23/11/2020	592.4	750.2746	564.4938	599.3208
RL507b/2022	24/11/2020	1118.8955	1482.3329	1318.98	1157.2938
RL507c/2022	25/11/2020	740.9443	687.7764	ND	28.7508
RL507d/2022	26/11/2020	698.1434	940.1388	745.8906	653.8584
RL507e/2022	27/11/2020	426.2318	518.35	327.6702	258.609
RL507f/2022	28/11/2020	6781.2028	7079.18	5098.08	4528.992
RL507g/2022	29/11/2020	3507.4523	4225.293	2928.8766	2788.8276
RL508a/2022	30/11/2020	2696.7529	2962	2233.9668	1826.2686
RL508b/2022	01/12/2020	5910.9672	6399.5491	4548.1098	4290.5382
RL508c/2022	02/12/2020	6458.1967	6689.5289	5425.602	5248.0584
RL508d/2022	03/12/2020	7561.5417	8593.2063	5349.8718	5132.6106
RL508e/2022	04/12/2020	1040.4025	1422.0562	760.8588	608.361
RL508f/2022	05/12/2020	3501.8245	3763.5172	3507.7458	3378.5154
RL508g/2022	06/12/2020	2603.3018	2981.5492	2728.5102	2315.625
RL509a/2022	07/12/2020	834.0992	1158.8825	775.9752	723.0678
RL509b/2022	08/12/2020	1099.6425	1464.4128	859.7082	609.2502
RL509c/2022	09/12/2020	1426.6473	1711.2955	1482	1292.8968
RL509d/2022	10/12/2020	223.4829	414.68	226.746	200.9592
RL509e/2022	11/12/2020	490.5072	641.273	414.96	298.0302
RL509f/2022	12/12/2020	156.2455	266.58	148.2	143.754
RL509g/2022	13/12/2020	1327.7165	1703.8905	1452.5082	1104.9792
RL510a/2022	14/12/2020	1493.5885	1529.1325	1156.8492	1026.1368
RL510b/2022	15/12/2020	1283.2865	1453.0091	923.286	843.1098
RL510c/2022	16/12/2020	1944.8492	1829.9236	1618.6404	1397.2296
RL510d/2022	17/12/2020	593.5848	739.6114	483.132	378.9474
RL510e/2022	18/12/2020	294.4228	296.2	163.4646	119.1528
RL510f/2022	19/12/2020	417.1977	489.3224	370.5	299.6604
RL510g/2022	20/12/2020	44.1338	29.62	ND	ND
RL511a/2022	21/12/2020	128.847	162.91	11.7078	ND
RL511b/2022	22/12/2020	211.0425	222.15	19.7106	ND
RL511c/2022	23/12/2020	304.7898	373.5082	230.451	181.3968
RL511d/2022	24/12/2020	444.3	433.933	263.4996	220.6698
RL511e/2022	25/12/2020	712.9534	784.6338	544.4868	439.413
RL511f/2022	26/12/2020	1259.7386	1039.0696	873.9354	699.9486
RL511g/2022	27/12/2020	743.3139	854.6851	740.8518	544.0422
RL512a/2022	28/12/2020	489.1743	609.5796	526.11	460.7538
RL512b/2022	29/12/2020	1438.6434	1574.5992	1174.0404	966.7086

RL512c/2022	30/12/2020	1304.761	1447.9737	1156.701	1067.04
RL512d/2022	31/12/2020	2324.8738	2802.4963	2148.9	1866.7272
RL512e/2022	01/01/2021	3669.1775	3845.1203	3619.044	3512.0436
RL512f/2022	02/01/2021	3504.9346	3708.5721	2672.787	2445.5964
RL512g/2022	03/01/2021	2073.6962	2338.3509	678.3114	594.4302
RL513a/2022	04/01/2021	2122.7173	2284.1463	1170.4836	1021.6908
RL513b/2022	05/01/2021	843.8738	1069.7263	810.654	713.2866
RL513c/2022	06/01/2021	1306.9825	1482.7772	1185.6	1100.385
RL513d/2022	07/01/2021	1324.7545	1540.24	1259.7	1423.1646
RL513e/2022	08/01/2021	269.8382	300.643	222.3	182.7306
RL513f/2022	09/01/2021	296.2	266.58	163.02	148.4964
RL513g/2022	10/01/2021	217.5589	238.5891	192.66	166.5768
RL514a/2022	11/01/2021	118.7762	148.1	118.8564	92.3286
RL514b/2022	12/01/2021	83.8246	111.075	74.1	48.0168
RL514c/2022	13/01/2021	87.0828	89.0081	63.726	42.5334
RL514d/2022	14/01/2021	67.5336	86.4904	47.8686	36.6054
RL514e/2022	15/01/2021	34.9516	60.2767	37.05	23.4156
RL514f/2022	16/01/2021	33.3225	59.24	30.0846	20.1552
RL514g/2022	17/01/2021	45.1705	66.645	15.1164	ND
RL515a/2022	18/01/2021	ND	44.7262	ND	ND
RL515b/2022	19/01/2021	29.4719	65.9045	42.978	20.1552
RL515c/2022	20/01/2021	27.6947	52.5755	47.424	36.309
RL515d/2022	21/01/2021	55.6856	42.8009	14.82	24.7494
RL515e/2022	22/01/2021	ND	15.5505	3.705	ND
RL515f/2022	23/01/2021	21.4745	37.025	2.964	ND
RL515g/2022	24/01/2021	19.9935	42.5047	14.82	ND
RL516a/2022	25/01/2021	24.2884	29.62	ND	ND
RL516b/2022	26/01/2021	73.4576	92.1182	ND	ND
RL516c/2022	27/01/2021	34.8035	61.0172	29.64	18.6732
RL516d/2022	28/01/2021	15.5505	33.3225	13.0416	ND
RL516e/2022	29/01/2021	0	27.6947	1.482	ND
RL516f/2022	30/01/2021	37.6174	44.43	0.8892	ND
RL516g/2022	31/01/2021	74.9386	89.1562	ND	ND
RL517a/2022	01/02/2021	29.0276	44.7262	ND	ND
RL517b/2022	02/02/2021	19.9935	44.43	ND	ND
RL517c/2022	03/02/2021	34.5073	59.5362	ND	ND
RL517d/2022	04/02/2021	29.62	47.392	ND	ND

RL517e/2022	05/02/2021	45.0224	59.9805	37.05	22.5264
RL517f/2022	06/02/2021	43.8376	74.05	29.64	18.3768
RL517g/2022	07/02/2021	115.8142	88.86	44.46	43.8672
RL518a/2022	08/02/2021	ND	ND	ND	ND

DAM WATER SAMPLES (ENTRANCE, MIDDLE, SPILLWAY)				
DRY SEASON (FEB, MARCH, APRIL 2021)		**RAINY SEASON (OCT, NOV, DEC 2020, JAN, FEB 2021) SHORT RAINS**		
S/No./DATE	**TURBIDITY**	**S/No./DATE**	**TURBIDITY**	**TSSC**
08/02/2021		28/10/2020 08:00		
RL519de/2022	625.5	RL503de/2022	355.2	346.87
RL519dm/2022	2400	RL503dm/2022	310.81	301.25
RL519ds/2022	770.4	RL503ds/2022	3507.96	2760
15/02/2021		04/11/ 2020 0800		
RL520de/2022	423.6	RL504de/2022	3360	3192
RL520dm/2022	1561.8	RL504dm/2022	2899.2	2737.8
RL520ds/2022	318.3	RL504ds/2022	3291.6	2700
22/02/2021		11/11/2020 0800		
RL521de/2022	360.3	RL505de/2022	1651.32	1614
RL521dm/2022	1166.7	RL505dm/2022	979.44	907.38
RL521ds/2022	299.7	RL505ds/2022	1730.1	1560.3
01/03/2021		18/11/2020 0800		
RL522de/2022	280.8	RL506de/2022	6052.19	6895.07
RL522dm/2022	1299.9	RL506dm/2022	5774.02	5904.05
RL522ds/2022	272.7	RL506ds/2022	5983.21	6564.44
08/03/2021		25/11/2020 0800		
RL523de/2022	181.5	RL507de/2022	7250.69	3789
RL523dm/2022	1740	RL507dm/2022	6625.33	2538.5
RL523ds/2022	240	RL507ds/2022	6809.54	6999.99
15/03/2021		02/12/2020 08:00		
RL524de/2022	256.8	RL508de/2022	4081.98	4207
RL524dm/2022	1200	RL508dm/2022	2360.42	3194.84
RL524ds/2022	316.2	RL508ds/2022	3479.46	4261.36
22/03/2021		09/12/2020 08:00		
RL525de/2022	106.5	RL509de/2022	4561.48	4143.12
RL525dm/2022	901.5	RL509dm/2022	3015.54	2885.63
RL525ds/2022	251.1	RL509ds/2022	3535.26	4081.74
29/03/2021		16/12/2020 08:00		

RL526de/2022	166.5
RL526dm/2022	1830
RL526ds/2022	348.3

DAM WATER SAMPLES FOR LONG RAINY SEASON (APRIL, MAY, JUNE 2021)

SNo./DATE	**TURBIDITY**
03/04/2021 08:00	
RL527de/2022	92.6
RL527dm/2022	89.8
RL527ds/2022	93
10/04/2021 08:00	
RL528de/2022	10120
RL528dm/2022	9435.36
RL528ds/2022	9819.92
17/04/2021 08:00	
RL529de/2022	6054.84
RL529dm/2022	3478.42
RL529ds/2022	7040
24/04/2021 08:00	
RL530de/2022	5864.76
RL530dm/2022	1417.24
RL530ds/2022	1589.06
01/05/2021 08:00	
RL531de/2022	1970.32
RL531dm/2022	1100
RL531ds/2022	1737.78
08/05/2021 08:00	
RL532de/2022	1735.58
RL532dm/2022	1374.34
RL532ds/2022	1525.48
15/05/2021 08:00	
RL533de/2022	1148.4
RL533dm/2022	848.98
RL533ds/2022	1017.94
22/05/2021 08:00	

RL510de/2022	2710.18	2043
RL510dm/2022	1456.72	3485.25
RL510ds/2022	2278.7	4241.56
23/12/2020 08:00		
RL511de/2022	1820.94	1918
RL511dm/2022	1730	1754
RL511ds/2022	1682.18	1840.48
30/12/2020 08:00		
RL512de/2022	2616.74	2743.88
RL512dm/2022	2320.16	2367.02
RL512ds/2022	2486.7	2605.23
06/01/2021 08:00		
RL513de/2022	955.38	979.5
RL513dm/2022	827.36	752.2
RL513ds/2022	769.48	890
13/01/2021 08:00		
RL514de/2022	813.22	922.16
RL514dm/2022	696	777.76
RL514ds/2022	760.12	884
20/01/2021 08:00		
RL515de/2022	650.46	990
RL515dm/2022	525.74	736
RL515ds/2022	579.74	908
27/01/2021 08:00		
RL516de/2022	461.92	532
RL516dm/2022	216.06	306
RL516ds/2022	314.1	418
03/02/2021 08:00		
RL517de/2022	109.2	144
RL517dm/2022	271.2	294
RL517ds/2022	22.08	12

RL534de/2022	1797.5
RL534dm/2022	1396
RL534ds/2022	1516.12
29/05/2021 08:00	
RL535de/2022	976.78
RL535dm/2022	788
RL535ds/2022	630.55
05/06/2021 08:00	
RL536de/2022	781.28
RL536dm/2022	548.84
RL536ds/2022	412.64
12/06/2021 08:00	
RL537de/2022	117.26
RL537dm/2022	22
RL537ds/2022	27.5
19/06/2021 08:00	
RL538de/2022	97.26
RL538dm/2022	22
RL538ds/2022	27.59

Annex IV: Kalundu Reservoir Water Depth Data in December 2021

ID	Y	X	ELEVATION	NAME	DAM WATER DEPTH
1	-1.3718	37.9931	1112.829	458	0
2	-1.3717	37.993	1113.091	476	0
3	-1.3726	37.9911	1114.263	340	0.01
4	-1.3726	37.9928	1110.623	319	0.03
5	-1.3715	37.992	1109.279	546	0.04
6	-1.3715	37.9921	1108.176	556	0.15
7	-1.3733	37.9911	1111.205	203	0.3
8	-1.3721	37.9916	1112.591	460	0.33
9	-1.373	37.9925	1110.612	218	0.35
10	-1.372	37.9917	1112.764	478	0.4
11	-1.3714	37.9923	1108.456	549	0.4
12	-1.3725	37.9912	1113.932	362	0.42
13	-1.3714	37.9924	1108.142	550	0.42
14	-1.3722	37.9915	1112.543	441	0.43
15	-1.3716	37.992	1109.425	535	0.45
16	-1.3737	37.9925	1107.464	89	0.47
17	-1.3727	37.9928	1109.063	299	0.49
18	-1.3717	37.992	1110.801	522	0.49
19	-1.3713	37.9925	1124.595	558	0.52
20	-1.3717	37.9921	1109.559	523	0.56
21	-1.3727	37.9928	1106.301	280	0.6
22	-1.3718	37.992	1110.312	509	0.6
23	-1.3736	37.9925	1106.564	104	0.65
24	-1.3739	37.9913	1108.226	91	0.7
25	-1.3715	37.9923	1109.078	538	0.73
26	-1.3717	37.9921	1110.358	511	0.74
27	-1.3718	37.9921	1110.451	510	0.75
28	-1.3737	37.9924	1107.577	88	0.76
29	-1.3728	37.9926	1110.244	255	0.77
30	-1.3731	37.9924	1109.834	184	0.78
31	-1.3721	37.9917	1112.851	461	0.78
32	-1.3715	37.9924	1109.431	539	0.78

33	-1.3713	37.9926	1123.272	559	0.78
34	-1.3718	37.9921	1110.911	497	0.79
35	-1.3735	37.9924	1105.937	119	0.8
36	-1.372	37.9918	1112.415	479	0.8
37	-1.3717	37.9922	1109.92	524	0.8
38	-1.3723	37.9913	1112.311	420	0.82
39	-1.3715	37.993	1110.875	507	0.82
40	-1.3732	37.9924	1110.017	152	0.85
41	-1.3718	37.9922	1110.567	498	0.85
42	-1.3722	37.9914	1112.676	440	0.86
43	-1.3715	37.9922	1108.506	548	0.87
44	-1.3734	37.9924	1107.048	134	0.88
45	-1.372	37.9929	1112.435	419	0.88
46	-1.3719	37.993	1112.807	438	0.88
47	-1.3729	37.9926	1109.916	236	0.89
48	-1.3712	37.9927	1122.785	561	0.89
49	-1.3716	37.9921	1108.841	536	0.9
50	-1.3733	37.9924	1108.698	150	0.92
51	-1.3736	37.9923	1106.331	102	0.94
52	-1.3718	37.9922	1112.366	483	0.97
53	-1.3719	37.992	1111.089	495	0.97
54	-1.3716	37.9922	1108.895	537	0.99
55	-1.3738	37.9923	1107.195	87	1
56	-1.3737	37.9921	1107.173	100	1.01
57	-1.373	37.9924	1110.788	200	1.01
58	-1.3714	37.9925	1108.088	551	1.01
59	-1.3714	37.9925	1107.931	552	1.04
60	-1.3735	37.9923	1106.444	117	1.05
61	-1.3735	37.9924	1106.292	118	1.05
62	-1.3712	37.9927	1123.078	560	1.07
63	-1.3728	37.9927	1106.172	279	1.08
64	-1.3736	37.9922	1107.784	101	1.1
65	-1.3736	37.9912	1107.301	136	1.1
66	-1.3722	37.9916	1112.65	442	1.1
67	-1.3715	37.9924	1110.042	527	1.13

68	-1.3736	37.9924	1106.631	103	1.15
69	-1.3713	37.9929	1109.567	545	1.15
70	-1.3715	37.9921	1108.138	547	1.15
71	-1.3713	37.9927	1107.457	554	1.15

Annex V: Kalundu River Discharge (field measurements 2020-2021)

OND(OCTOBER, NOVEMBER, DECEMBER 2020, JANUARY, FEBRUARY 2021) SHORT RAINS			
BEFORE THE DAM		**AFTER THE DAM**	
AV.R.Q GAUGE No. 1& 2		**AV. R.Q GAUGE No. 3**	
28/10/2020 08:00	0.02	28/10/2020 08:00	0
29/10/2020 08:00	0.02	29/10/2020 08:00	0
30/10/2020 08:00	0.02	30/10/2020 08:00	0
31/10/2020 08:00	0.01	31/10/2020 08:00	0
01/11/ 2020 0800	0.44	01/11/ 2020 0800	0
02/11/ 2020 0800	0.34	02/11/ 2020 0800	0
03/11/ 2020 0800	0.21	03/11/ 2020 0800	0
04/11/ 2020 0800	0.48	04/11/ 2020 0800	0
05/11/2020 0800	0.56	05/11/2020 0800	0
06/11/2020 0800	0.38	06/11/2020 0800	0
07/11/2020 0800	0.34	07/11/2020 0800	0
08/11/2020 0800	0.38	08/11/2020 0800	0
09/11/2020 0800	0.42	09/11/2020 0800	0
10/11/2020 0800	0.31	10/11/2020 0800	0
11/11/2020 0800	0.26	11/11/2020 0800	0
12/11/2020 0800	0.27	12/11/2020 0800	0
13/11/2020 0800	0.51	13/11/2020 0800	0.23
14/11/2020 0800	1.08	14/11/2020 0800	0.45
15/11/2020 0800	1.12	15/11/2020 0800	0.44
16/11/2020 0800	1.23	16/11/2020 0800	0.78
17/11/2020 0800	1.3	17/11/2020 0800	1.35
18/11/2020 0800	1.54	18/11/2020 0800	1.83
19/11/2020 0800	1.1	19/11/2020 0800	1.78
20/11/2020 0800	1.3	20/11/2020 0800	1.7
21/11/2020 0800	1.23	21/11/2020 0800	1.29
22/11/2020 0800	1.25	22/11/2020 0800	1.3
23/11/2020 0800	1.13	23/11/2020 0800	1.2
24/11/2020 0800	1.21	24/11/2020 0800	1.29
25/11/2020 0800	1	25/11/2020 0800	1.15
26/11/2020 0800	1.21	26/11/2020 0800	1.3

27/11/2020 08:00	1.45	27/11/2020 08:00	1.5
28/11/2020 08:00	1.36	28/11/2020 08:00	1.42
29/11/2020 08:00	1.23	29/11/2020 08:00	1.32
30/11/2020 08:00	1.25	30/11/2020 08:00	1.31
01/12/2020 08:00	1.34	01/12/2020 08:00	1.45
02/12/2020 08:00	1.4	02/12/2020 08:00	1.5
03/12/2020 08:00	1.51	03/12/2020 08:00	1.63
04/12/2020 08:10	1.34	04/12/2020 08:10	1.45
05/12/2020 08:00	1.42	05/12/2020 08:00	1.6
06/12/2020 08:00	1.33	06/12/2020 08:00	1.4
07/12/2020 08:10	1.26	07/12/2020 08:10	1.32
08/12/2020 08:00	1.36	08/12/2020 08:00	1.43
09/12/2020 08:00	1.32	09/12/2020 08:00	1.42
10/12/2020 08:00	1.23	10/12/2020 08:00	1.3
11/12/2020 08:00	1.12	11/12/2020 08:00	1.2
12/12/2020 08:00	1.11	12/12/2020 08:00	1.2
13/12/2020 08:00	1	13/12/2020 08:00	1.2
14/12/2020 08:00	1	14/12/2020 08:00	1.22
15/12/2020 08:00	1.1	15/12/2020 08:00	1.13
16/12/2020 08:00	1.2	16/12/2020 08:00	1.3
17/12/2020 08:10	0.98	17/12/2020 08:10	1.12
18/12/2020 08:00	0.87	18/12/2020 08:00	0.9
19/12/2020 08:00	0.82	19/12/2020 08:00	0.91
20/12/2020 08:00	0.81	20/12/2020 08:00	0.9
21/12/2020 08:00	0.72	21/12/2020 08:00	0.81
22/12/2020 08:00	0.73	22/12/2020 08:00	0.82
23/12/2020 08:00	0.7	23/12/2020 08:00	0.8
24/12/2020 08:00	0.66	24/12/2020 08:00	0.77
25/12/2020 08:00	0.62	25/12/2020 08:00	0.74
26/12/2020 08:00	0.93	26/12/2020 08:00	1.1
27/12/2020 08:00	0.65	27/12/2020 08:00	0.76
28/12/2020 08:00	0.55	28/12/2020 08:00	0.75
29/12/2020 08:00	0.6	29/12/2020 08:00	0.7
30/12/2020 08:00	0.55	30/12/2020 08:00	0.71
31/12/2020 08:00	0.7	31/12/2020 08:00	0.83

01/01/2021 08:00	0.93	01/01/2021 08:00	1.25
02/01/2021 08:00	0.78	02/01/2021 08:00	0.94
03/01/2021 08:00	0.65	03/01/2021 08:00	0.74
04/01/2021 08:00	0.98	04/01/2021 08:00	1.3
05/01/2021 08:00	0.68	05/01/2021 08:00	0.96
06/01/2021 08:00	0.75	06/01/2021 08:00	0.87
07/01/2021 08:00	0.75	07/01/2021 08:00	0.871
08/01/2021 08:00	0.6	08/01/2021 08:00	0.73
09/01/2021 08:00	0.53	09/01/2021 08:00	0.62
10/01/2021 08:00	0.55	10/01/2021 08:00	0.66
11/01/2021 08:00	0.5	11/01/2021 08:00	0.6
12/01/2021 08:00	0.43	12/01/2021 08:00	0.55
13/01/2021 08:00	0.43	13/01/2021 08:00	0.55
14/01/2021 08:00	0.43	14/01/2021 08:00	0.55
15/01/2021 08:00	0.42	15/01/2021 08:00	0.55
16/01/2021 08:00	0.42	16/01/2021 08:00	0.52
17/01/2021 08:00	0.38	17/01/2021 08:00	0.45
18/01/2021 08:00	0.32	18/01/2021 08:00	0.43
19/01/2021 08:00	0.4	19/01/2021 08:00	0.53
20/01/2021 08:00	0.36	20/01/2021 08:00	0.41
21/01/2021 08:00	0.33	21/01/2021 08:00	0.42
22/01/2021 08:00	0.31	22/01/2021 08:00	0.41
23/01/2021 08:00	0.36	23/01/2021 08:00	0.4
24/01/2021 08:00	0.28	24/01/2021 08:00	0.3
25/01/2021 08:00	0.22	25/01/2021 08:00	0.25
26/01/2021 08:00	0.18	26/01/2021 08:00	0.2
27/01/2021 08:00	0.15	27/01/2021 08:00	0.18
28/01/2021 08:00	0.11	28/01/2021 08:00	0.15
29/01/2021 08:00	0.1	29/01/2021 08:00	0.13
30/01/2021 08:00	0.1	30/01/2021 08:00	0.12
31/01/2021 08:00	0.08	31/01/2021 08:00	0.083
01/02/2021 08:00	0.07	01/02/2021 08:00	0.073
02/02/2021 08:00	0.05	02/02/2021 08:00	0.054
03/02/2021 08:00	0.03	03/02/2021 08:00	0.035
04/02/2021 08:00	0.02	04/02/2021 08:00	0.023

05/02/2021 08:00	0.01	05/02/2021 08:00	0.01
06/02/2021 08:00	0.01	06/02/2021 08:00	0.01
07/02/2021 08:00	0.01	07/02/2021 08:00	0.01
08/02/2021 08:00	0	08/02/2021 08:00	0

MAM (APRIL, MAY, JUNE 2021) LONG RAIN SEASON			
BEFORE THE DAM		**AFTER THE DAM**	
AV. R.Q GAUGE No. 1& 2		**AV.R.Q GAUGE No. 3**	
03/04/2021 08:00	0.001	03/04/2021 08:00	0
04/04/2021 08:00	0.018	04/04/2021 08:00	0
05/04/2021 08:00	0.12	05/04/2021 08:00	0
06/04/2021 08:00	0.28	06/04/2021 08:00	0
07/04/2021 08:00	0.35	07/04/2021 08:00	0
08/04/2021 08:00	0.36	08/04/2021 08:00	0
09/04/2021 08:00	0.45	09/04/2021 08:00	0
10/04/2021 08:00	0.38	10/04/2021 08:00	0
11/04/2021 08:00	0.48	11/04/2021 08:00	0
12/04/2021 08:00	0.56	12/04/2021 08:00	0
13/04/2021 08:00	0.52	13/04/2021 08:00	0
14/04/2021 08:00	0.52	14/04/2021 08:00	0
15/04/2021 08:00	0.5	15/04/2021 08:00	0
16/04/2021 08:00	0.48	16/04/2021 08:00	0
17/04/2021 08:00	0.59	17/04/2021 08:00	0
18/04/2021 08:00	0.71	18/04/2021 08:00	0
19/04/2021 08:00	0.78	19/04/2021 08:00	0.2
20/04/2021 08:00	0.9	20/04/2021 08:00	0.45
21/04/2021 08:00	0.85	21/04/2021 08:00	0.9
22/04/2021 08:00	0.81	22/04/2021 08:00	0.95
23/04/2021 08:00	0.79	23/04/2021 08:00	0.94
24/04/2021 08:00	0.98	24/04/2021 08:00	1.35
25/04/2021 08:00	0.6	25/04/2021 08:00	0.75

26/04/2021 08:00	0.6	26/04/2021 08:00	0.73
27/04/2021 08:00	0.62	27/04/2021 08:00	0.7
28/04/2021 08:00	0.6	28/04/2021 08:00	0.71
29/04/2021 08:00	0.6	29/04/2021 08:00	0.73
30/04/2021 08:00	0.58	30/04/2021 08:00	0.69
01/05/2021 08:00	0.56	01/05/2021 08:00	0.65
02/05/2021 08:00	0.55	02/05/2021 08:00	0.67
03/05/2021 08:00	0.54	03/05/2021 08:00	0.66
04/05/2021 08:00	0.54	04/05/2021 08:00	0.68
05/05/2021 08:00	0.54	05/05/2021 08:00	0.67
06/05/2021 08:00	0.54	06/05/2021 08:00	0.67
07/05/2021 08:00	0.41	07/05/2021 08:00	0.61
08/05/2021 08:00	0.45	08/05/2021 08:00	0.58
09/05/2021 08:00	0.39	09/05/2021 08:00	0.43
10/05/2021 08:00	0.37	10/05/2021 08:00	0.41
11/05/2021 08:00	0.39	11/05/2021 08:00	0.45
12/05/2021 08:00	0.33	12/05/2021 08:00	0.39
13/05/2021 08:00	0.38	13/05/2021 08:00	0.4
14/05/2021 08:00	0.39	14/05/2021 08:00	0.43
15/05/2021 08:00	0.35	15/05/2021 08:00	0.41
16/05/2021 08:00	0.34	16/05/2021 08:00	0.38
17/05/2021 08:00	0.33	17/05/2021 08:00	0.39
18/05/2021 08:00	0.32	18/05/2021 08:00	0.38
19/05/2021 08:00	0.32	19/05/2021 08:00	0.37
20/05/2021 08:00	0.3	20/05/2021 08:00	0.35
21/05/2021 08:00	0.32	21/05/2021 08:00	0.39
22/05/2021 08:00	0.29	22/05/2021 08:00	0.32
23/05/2021 08:00	0.29	23/05/2021 08:00	0.31
24/05/2021 08:00	0.28	24/05/2021 08:00	0.3

25/05/2021 08:00	0.28	25/05/2021 08:00	0.31
26/05/2021 08:00	0.27	26/05/2021 08:00	0.3
27/05/2021 08:00	0.23	27/05/2021 08:00	0.29
28/05/2021 08:00	0.15	28/05/2021 08:00	0.22
29/05/2021 08:00	0.1	29/05/2021 08:00	0.15
30/05/2021 08:00	0.08	30/05/2021 08:00	0.1
31/05/2021 08:00	0.11	31/05/2021 08:00	0.16
01/06/2021 08:00	0.49	01/06/2021 08:00	0.55
02/06/2021 08:00	0.45	02/06/2021 08:00	0.52
03/06/2021 08:00	0.26	03/06/2021 08:00	0.3
04/06/2021 08:00	0.13	04/06/2021 08:00	0.2
05/06/2021 08:00	0.12	05/06/2021 08:00	0.21
06/06/2021 08:00	0.08	06/06/2021 08:00	0.09
07/06/2021 08:00	0.06	07/06/2021 08:00	0.07
08/06/2021 08:00	0.04	08/06/2021 08:00	0.05
09/06/2021 08:00	0.03	09/06/2021 08:00	0.035
10/06/2021 08:00	0.02	10/06/2021 08:00	0.025
11/06/2021 08:00	0.02	11/06/2021 08:00	0.023
12/06/2021 08:00	0.018	12/06/2021 08:00	0.02
13/06/2021 08:00	0.015	13/06/2021 08:00	0.02
14/06/2021 08:00	0.01	14/06/2021 08:00	0.015
15/06/2021 08:00	0.01	15/06/2021 08:00	0.01
16/06/2021 08:00	0.01	16/06/2021 08:00	0.01
17/06/2021 08:00	0	17/06/2021 08:00	0

Annex VI: Kalundu Reservoir Sediment Gradation Report October 2021

Sampling No.	Client Ref.	Gravel (>2mm)	PARTICLE SIZE DISTRIBUTE			
			Sand (0.006-2mm)	Silt (0.002-0.06)	Clay (<0.002mm)	Specific Gravity
58/22/F	ES	0	48	28	24	2.71
59/22/F	MS	0	30	35	36	2.69
60/22/F	SS	0	35	33	32	2.7

Annex VII: Kalundu Reservoir Sediment Budget for the Short Rainy Season (Oct - Feb) 2021

Short Rainy Season					
Sampling Date	**Total sediment inflow (V_i)**	**Total sediment outflow (V_o)**	**Sediment budget**		**Trap Efficiency, T_e**
			(m^3/day)	**(Tons/day)**	**(V_i-V_o)/V_i *100**
28-10-20	3.03	0.00	3.03	4.52	100.00
29-10-20	2.37	0.00	2.37	3.54	100.00
30-10-20	2.70	0.00	2.70	4.02	100.00
31-10-20	0.45	0.00	0.45	0.67	100.00
01-11-20	118.86	0.00	118.86	177.40	100.00
02-11-20	31.82	0.00	31.82	47.50	100.00
03-11-20	27.68	0.00	27.68	41.31	100.00
04-11-20	143.74	0.00	143.74	214.54	100.00
05-11-20	120.84	0.00	120.84	180.35	100.00
06-11-20	67.53	0.00	67.53	100.80	100.00
07-11-20	77.04	0.00	77.04	114.99	100.00
08-11-20	28.14	0.00	28.14	42.00	100.00
09-11-20	68.42	0.00	68.42	102.12	100.00
10-11-20	62.71	0.00	62.71	93.60	100.00
11-11-20	30.03	0.00	30.03	44.83	100.00
12-11-20	19.99	0.00	19.99	29.84	100.00
13-11-20	45.47	6.82	38.65	57.69	85.01
14-11-20	1956.96	695.31	1261.65	1883.07	64.47
15-11-20	3599.42	97.81	3501.61	5226.28	97.28
16-11-20	2677.80	1179.08	1498.72	2236.89	55.97
17-11-20	4976.32	4587.81	388.52	579.88	7.81
18-11-20	11178.13	11396.62	-218.48	-326.10	-1.95
19-11-20	4714.13	5777.13	-1063.01	-1586.58	-22.55
20-11-20	968.81	581.98	386.83	577.36	39.93
21-11-20	18.22	0.00	18.22	27.19	100.00
22-11-20	555.38	435.41	119.96	179.05	21.60
23-11-20	847.81	677.39	170.42	254.35	20.10
24-11-20	1793.62	1701.48	92.14	137.52	5.14
25-11-20	687.78	0.00	687.78	1026.53	100.00
26-11-20	1137.57	969.66	167.91	250.61	14.76
27-11-20	751.61	491.51	260.10	388.21	34.61
28-11-20	9627.68	7239.27	2388.41	3564.79	24.81

29-11-20	5197.11	3866.12	1330.99	1986.56	25.61
30-11-20	3702.50	2926.50	776.00	1158.21	20.96
01-12-20	8575.40	6594.76	1980.64	2956.17	23.10
02-12-20	9365.34	8138.40	1226.94	1831.25	13.10
03-12-20	12975.74	8720.29	4255.45	6351.42	32.80
04-12-20	1905.56	1103.25	802.31	1197.48	42.10
05-12-20	5344.19	5612.39	-268.20	-400.30	-5.02
06-12-20	3965.46	3819.91	145.55	217.23	3.67
07-12-20	1460.19	1024.29	435.90	650.60	29.85
08-12-20	1991.60	1229.38	762.22	1137.64	38.27
09-12-20	2258.91	2104.44	154.47	230.55	6.84
10-12-20	510.06	294.77	215.29	321.32	42.21
11-12-20	718.23	497.95	220.27	328.77	30.67
12-12-20	295.90	177.84	118.06	176.21	39.90
13-12-20	1703.89	1743.01	-39.12	-58.39	-2.30
14-12-20	1529.13	1411.36	117.78	175.79	7.70
15-12-20	1598.31	1043.31	555.00	828.35	34.72
16-12-20	2195.91	2104.23	91.68	136.83	4.17
17-12-20	724.82	541.11	183.71	274.20	25.35
18-12-20	257.69	147.12	110.58	165.04	42.91
19-12-20	401.24	337.16	64.09	95.66	15.97
20-12-20	23.99	0.00	23.99	35.81	100.00
21-12-20	117.30	9.48	107.81	160.91	91.91
22-12-20	162.17	16.16	146.01	217.92	90.03
23-12-20	261.46	184.36	77.09	115.07	29.49
24-12-20	286.40	202.89	83.50	124.63	29.16
25-12-20	486.47	402.92	83.55	124.71	17.18
26-12-20	966.33	961.33	5.01	7.47	0.52
27-12-20	555.55	563.05	-7.50	-11.20	-1.35
28-12-20	335.27	394.58	-59.31	-88.53	-17.69
29-12-20	944.76	821.83	122.93	183.48	13.01
30-12-20	796.39	821.26	-24.87	-37.12	-3.12
31-12-20	1961.75	1783.59	178.16	265.91	9.08
01-01-21	3575.96	4523.81	-947.84	-1414.69	-26.51
02-01-21	2892.69	2512.42	380.27	567.56	13.15
03-01-21	1519.93	501.95	1017.98	1519.37	66.98
04-01-21	2238.46	1521.63	716.83	1069.90	32.02
05-01-21	727.41	778.23	-50.81	-75.84	-6.99

06-01-21	1112.08	1031.47	80.61	120.31	7.25
07-01-21	1155.18	1097.20	57.98	86.54	5.02
08-01-21	180.39	162.28	18.11	27.03	10.04
09-01-21	141.29	101.07	40.22	60.02	28.46
10-01-21	131.22	127.16	4.07	6.07	3.10
11-01-21	74.05	71.31	2.74	4.08	3.70
12-01-21	47.76	40.76	7.01	10.46	14.67
13-01-21	38.27	35.05	3.22	4.81	8.42
14-01-21	37.19	26.33	10.86	16.21	29.21
15-01-21	25.32	20.38	4.94	7.37	19.51
16-01-21	24.88	15.64	9.24	13.79	37.12
17-01-21	25.33	6.80	18.52	27.65	73.14
18-01-21	14.31	0.00	14.31	21.36	100.00
19-01-21	26.36	22.78	3.58	5.35	13.59
20-01-21	18.93	19.44	-0.52	-0.77	-2.73
21-01-21	14.12	6.22	7.90	11.79	55.93
22-01-21	4.82	1.52	3.30	4.93	68.49
23-01-21	13.33	1.19	12.14	18.12	91.11
24-01-21	11.90	4.45	7.46	11.13	62.64
25-01-21	6.52	0.00	6.52	9.73	100.00
26-01-21	16.58	0.00	16.58	24.75	100.00
27-01-21	9.15	5.34	3.82	5.70	41.71
28-01-21	3.67	1.96	1.71	2.55	46.63
29-01-21	2.77	0.19	2.58	3.85	93.04
30-01-21	4.44	0.11	4.34	6.47	97.60
31-01-21	7.13	0.00	7.13	10.65	100.00
01-02-21	3.13	0.00	3.13	4.67	100.00
02-02-21	2.22	0.00	2.22	3.32	100.00
03-02-21	1.79	0.00	1.79	2.67	100.00
04-02-21	0.95	0.00	0.95	1.41	100.00
05-02-21	0.60	0.37	0.23	0.34	38.23
06-02-21	0.74	0.30	0.44	0.66	59.97
07-02-21	0.89	0.44	0.44	0.66	49.97
Total	**134,028.84**	**108,074.10**	**25,954.74**		
Mean	**1,301.25**	**1,049.26**	**251.99**		**47.73**

Annex VIII: Kalundu Reservoir Sediment Budget for the Long Rainy Season (April - June) 2021

Sampling Date	Total sediment inflow (V_i)	Total sediment outflow (V_o)	Sediment budget		Trap Efficiency, T_e
			(m^3/day)	(Tons/day)	$(V_i-V_o)/V_i *100$
03/04/2021	0.00	0.00	0.00	0.00	100.00
04/04/2021	0.53	0.00	0.53	0.80	100.00
05/04/2021	27.17	0.00	27.17	40.56	100.00
06/04/2021	83.79	0.00	83.79	125.06	100.00
07/04/2021	120.49	0.00	120.49	179.83	100.00
08/04/2021	53.28	0.00	53.28	79.52	100.00
09/04/2021	148.52	0.00	148.52	221.67	100.00
10/04/2021	76.82	0.00	76.82	114.66	100.00
11/04/2021	44.26	0.00	44.26	66.06	100.00
12/04/2021	121.83	0.00	121.83	181.84	100.00
13/04/2021	53.72	0.00	53.72	80.18	100.00
14/04/2021	600.98	0.00	600.98	896.99	100.00
15/04/2021	1391.13	0.00	1391.13	2076.31	100.00
16/04/2021	1112.49	0.00	1112.49	1660.43	100.00
17/04/2021	2680.81	0.00	2680.81	4001.21	100.00
18/04/2021	5258.10	0.00	5258.10	7847.91	100.00
19/04/2021	3340.49	292.07	3048.42	4549.88	91.26
20/04/2021	636.30	201.15	435.15	649.47	68.39
21/04/2021	188.70	83.14	105.56	157.55	55.94
22/04/2021	303.54	204.26	99.28	148.18	32.71
23/04/2021	413.43	312.33	101.10	150.89	24.45
24/04/2021	4428.94	5032.37	-603.43	-900.64	-13.62
25/04/2021	843.69	460.07	383.61	572.56	45.47
26/04/2021	706.67	545.16	161.52	241.07	22.86
27/04/2021	396.04	373.39	22.64	33.79	5.72
28/04/2021	498.08	435.85	62.22	92.87	12.49
29/04/2021	863.94	594.97	268.96	401.44	31.13
30/04/2021	901.41	804.80	96.61	144.19	10.72
01/05/2021	724.29	449.19	275.10	410.59	37.98
02/05/2021	750.10	537.98	212.12	316.59	28.28
03/05/2021	121.96	88.51	33.45	49.93	27.43
04/05/2021	106.29	56.74	49.55	73.96	46.62

05/05/2021	44.68	0.00	44.68	66.68	100.00
06/05/2021	74.49	0.00	74.49	111.17	100.00
07/05/2021	141.75	42.81	98.94	147.67	69.80
08/05/2021	62.27	0.00	62.27	92.94	100.00
09/05/2021	82.71	46.64	36.07	53.84	43.61
10/05/2021	49.28	38.18	11.10	16.57	22.53
11/05/2021	65.05	62.49	2.56	3.82	3.94
12/05/2021	43.71	24.58	19.13	28.55	43.77
13/05/2021	40.89	17.88	23.01	34.34	56.27
14/05/2021	51.72	33.38	18.34	27.37	35.46
15/05/2021	38.12	9.16	28.96	43.23	75.96
16/05/2021	35.37	28.31	7.06	10.54	19.97
17/05/2021	30.23	24.75	5.48	8.17	18.12
18/05/2021	49.59	35.73	13.86	20.68	27.95
19/05/2021	41.63	26.35	15.28	22.80	36.70
20/05/2021	54.61	45.68	8.93	13.33	16.35
21/05/2021	76.30	57.01	19.29	28.79	25.28
22/05/2021	42.92	28.61	14.31	21.36	33.35
23/05/2021	32.23	10.81	21.42	31.98	66.47
24/05/2021	21.84	14.35	7.49	11.18	34.30
25/05/2021	18.90	9.24	9.66	14.42	51.11
26/05/2021	13.11	10.28	2.83	4.22	21.56
27/05/2021	10.14	5.36	4.79	7.14	47.18
28/05/2021	2.22	0.07	2.15	3.22	97.05
29/05/2021	1.41	0.00	1.41	2.10	100.00
30/05/2021	0.67	0.00	0.67	1.01	100.00
31/05/2021	4.88	4.79	0.09	0.14	1.89
01/06/2021	150.19	127.84	22.35	33.35	14.88
02/06/2021	116.42	79.49	36.92	55.11	31.72
03/06/2021	39.52	22.35	17.17	25.63	43.44
04/06/2021	5.52	0.00	5.52	8.24	100.00
05/06/2021	3.64	0.59	3.05	4.55	83.67
06/06/2021	1.36	1.34	0.02	0.03	1.51
07/06/2021	1.39	0.91	0.48	0.71	34.50
08/06/2021	0.59	0.34	0.25	0.37	42.80
09/06/2021	0.83	0.45	0.38	0.57	45.98
10/06/2021	0.45	0.19	0.26	0.39	58.60

11/06/2021	0.28	0.09	0.19	0.29	67.44
12/06/2021	0.14	0.04	0.10	0.15	72.03
13/06/2021	0.06	0.00	0.06	0.09	100.00
14/06/2021	0.00	0.00	0.00	0.00	0.00
15/06/2021	0.00	0.00	0.00	0.00	0.00
16/06/2021	0.00	0.00	0.00	0.00	0.00
Total	**28,448.87**	**11,282.08**	**17,166.79**	**25,622.08**	
Mean	**379.32**	**150.43**	**228.89**		**55.64**