The Effect of River Flow and Land use land Cover Dynamics on Reservoir Sedimentation in a Small ASAL Tropical Basin in Kenya

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Abstract:- Kalundu reservoir is one of the water reservoirs in arid and semi-arid lands in Kenya that has been experiencing periodic siltation since 1950s. Lack of data and information on the hydrological processes and land use practices has limited implementation of localized strategies to minimize sedimentation in the reservoir.The objective of this study was to determine the hydrological influences and land use practices that contributed to sedimentation of Kalundu reservoir in the period between (2000 – 2021). Hydrological datasetswere acquired from three sampling stations established at different points along KalunduRiver. Landsat imagery were used in the Land use andLand Cover analysis. Hydrological analysis showed that during the short rainy season, the mean river discharge ranged from 0.44-1.00m^3/day and 0.11-0.50m^3/day during the long rains. Sediment load discharged into the reservoir was more during the short rains (134,028.84m^3)than during the long rains (28,448.87 m^3) witha Trap Efficiency of 47.73%and 55.91%, respectively. The river discharge showed a significant relationship with TSSC (*r=0.69, P-value=0.03*), turbidity in the river (*r=0.68, R^2=0.45, p-value=0.03*) and sediment load (*r=0.68, R^2=0.46, p-value=0.03*). This results impliedhigh sediment load is likely to be observed during high flows.From bathymetric analysis, Kalundureservoir decreased its storage capacity by 70% from 500,000m^3 in 2013 to 149,902m^3 in 2021. This implied that 350,098m^3 of sediments were deposited within that period at an estimated rate of 65,317 tons/yr or 2,722 tons/km^2/yr. The total surface area of the reservoir decreased by 11% from 48,500m^2 in 2013 to 43,200m^2 in 2021.In 2021, the mean water depth in the reservoir was 2.1m and the deepest part was 3.5m. The Useful Life Span of the dam was estimated to be about 3 years.LULC analysis showed that croplands and built-up areas increased significantly within a period 20 years (2000-2020). Bareland and abandoned croplands were attributed to soil erosion in the study area leading to sedimentation of Kalundu Dam particularly during short rainy seasons. Poor farming practices, urban land development activities, heavy infrastructural development and clearing of natural vegetation in the sub-basin were strongly attributed to the increased sedimentation of the dam in the period between (2010-2020).

Keywords:- *Reservoir sedimentation, ASALs, sediment load, seasonal rivers, soil erosion.*

I. INTRODUCTION

Reservoir sedimentationresulting from soil erosion is a major problem affecting water resources development in arid and semi-arid lands in sub-Saharan Africa including Kenya. Rainfall experience in these ASALs is unreliable and seasonal. Seasonal Rivers in these areas flow in short period particularly during rainfall seasons [1]. Increased erosion activities and transport of sediments by the Rivers is observedduring such periods[2].Water erosion carries the sediments downhill through River transport where the suspended sediments form a major component of the sediments load which eventually get deposited in the receiving reservoirs[3]. This impact gets more intense during erosive rainfall periods.

1Worldwide, many water reservoirs have been constructed to provide many services including; electricity, irrigation, flood control and water supply for the ever-increasing population and to improve its standard of living[4]. Reservoir sedimentation can lead to serious challenges on water reservoirs meant for water management, flood control and production of energy. Continuous siltation of such water reservoirs negatively affects their effectiveness and reduces supply of water to the community[5].

Studies show that reservoir sedimentation can greatly reduce storage capacity of surface water reservoirs [6].Globally, it has been estimated that the loss in reservoir storage capacity is about 0.8% which is estimated to be about 45km^3 annually [7]. In Kenya, several studies undertaken on soil erosion and reservoir sedimentation. A study of soil erosion and reservoir sedimentation was undertaken in NguuTatu catchment in the north-east of Mombasa [8]. This study linked high rates of soil erosion to the rapid rates of sedimentation within the NguuTatu reservoirs [8].A study on sedimentation of Masinga dam showed that reservoir sedimentation was attributed to increased agricultural activities particularly on steep slopes in the watersheds and characteristics of the River flow [9]. From this study, it was established that by the year 2011, the dam had lost about 215m^3 (14%) of its initial design storage capacity.

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A number of factors are known to contribute to reservoir sedimentation. However, land use/land cover is one of the most important factors. Land use change including deforestation to open land for agriculture, mining, industrial, or residential uses adversely alters the hydrologic characteristics of the land surface, and also modifies pathways and rates of water flow in catchments or River basins [10]. These hydrologic imbalances in a watershed can lead to short- and long-term impacts such as increased downstream flooding, decreased long-term groundwater recharge and increased siltation in surface water bodies[11, 12].

Knowledge on how land use/cover change influence watershed hydrology, soil erosion processes and reservoir sedimentation is important for enabling policy makers to formulate and implement effective and appropriate response strategies to minimize undesirable effects of future land conversions. Improper land use and ecosystem management practices have been known to contribute to increased land degradation as well as reduced reservoir storage capacities [13]. Various land use practices meant to increase crop productivity and food security may promote soil erosion process which in turn affects the quality of water resources and reservoir storage capacity.This study sought to investigate the extent of how hydrology of KalunduRiver has been modified by the landuse and land cover changes and how these changes have contributed toincreased sedimentation within the Kalundu dam reservoir.

II. DESCRIPTION OF THE STUDY AREA

Kalundu dam reservoir. The dam is located at the upper part of the Kalundu sub basin with a surface area of about 24km^2.The Dam was constructed in the 1950's across the seasonal KalunduRiver. The dam was the main source of domestic water for Kitui Town and its environs in the period between 1950 and 1970s. According to the National Water Harvesting and Storage Authority, the Kalundu dam is a medium dam which had an initial design capacity of 300,000m^{3}and later increased to 500,000m^3 serving a population of about 70,000 people[14]. However, the reservoir was filled with sediments in the1970s and therefore could not serve the intended purpose. The NWCPC rehabilitated Kalundu dam in 2013as one of the Tanathi Water Service Board (TWSB) Pans and Small Dams 2011-12 projects, and expandedits capacity at cost of KSh. 310 million[15].Kalundu Dam Rehabilitation Project entailed breach repair of a 13.5m high Dam and its auxiliaries. 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. 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. The time this study was undertaken, high rates of sedimentation in the reservoir were still evident. The objective of this study was to investigate the impacts of land use and land cover changes on the hydrology of the basin and sedimentation of the Kalundu dam.

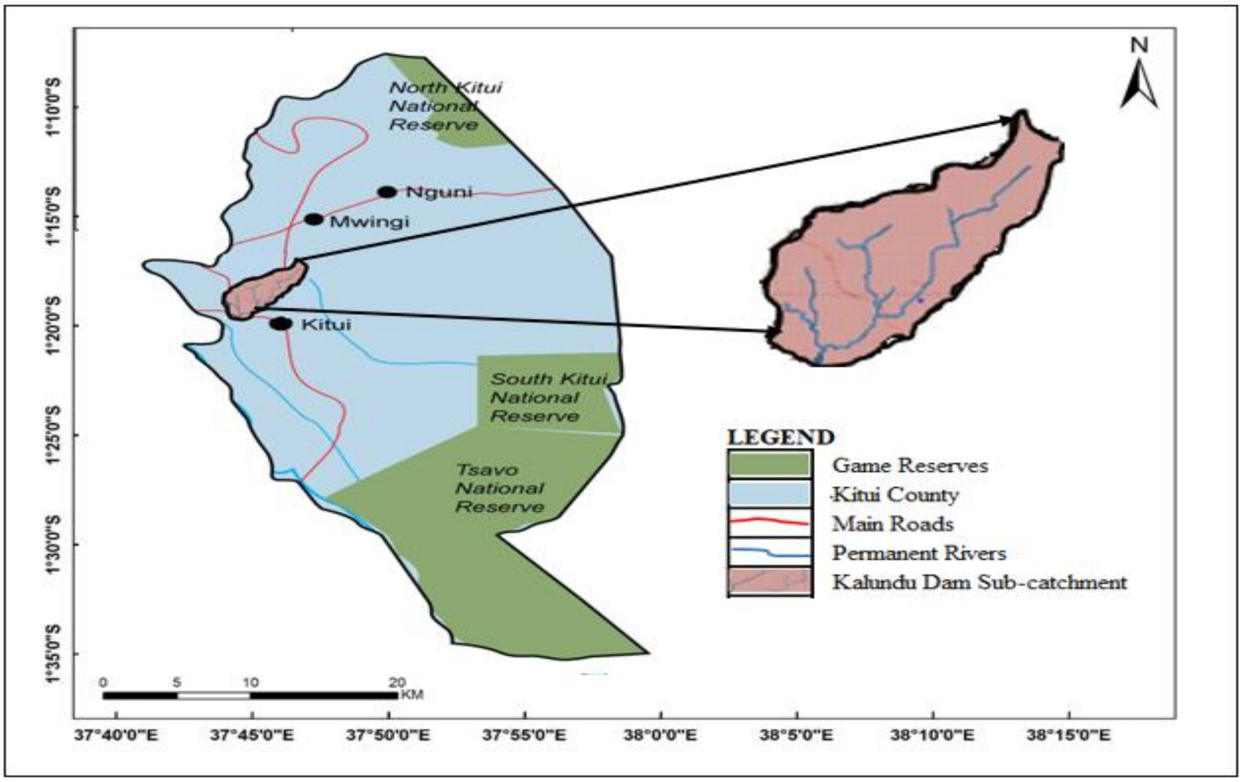

Fig. 1: Location of the study area in Kitui County, Kenya

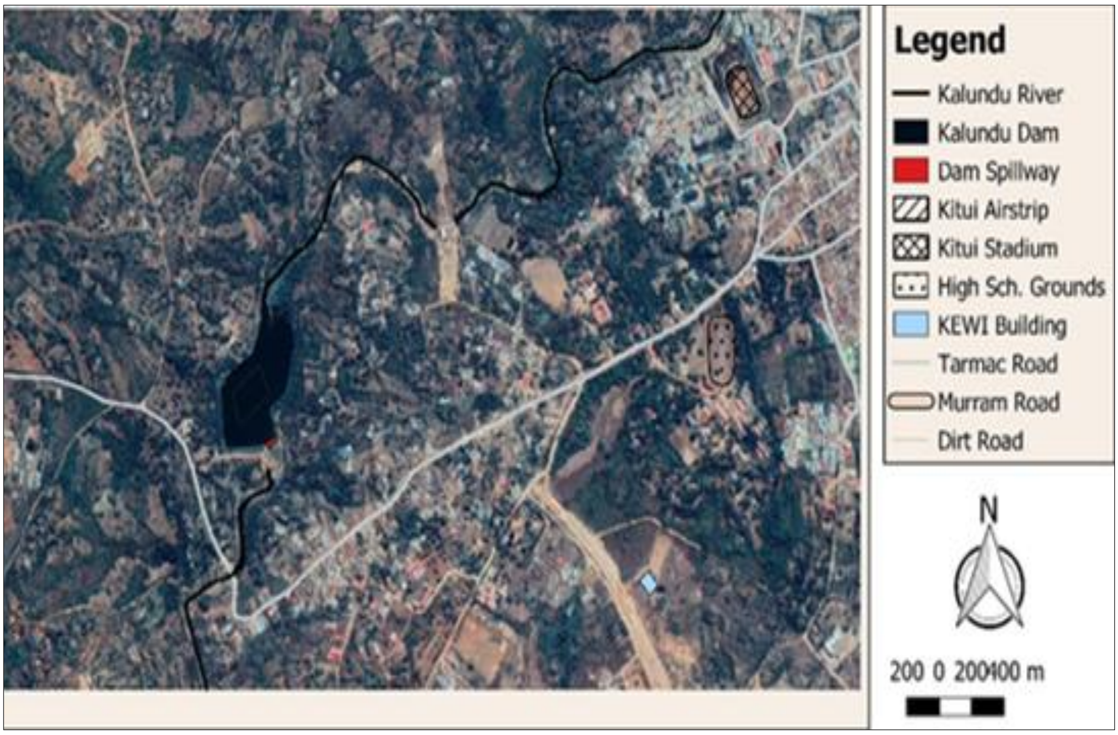

Fig. 2: A satellite imagery showing the Location of Kalundu dam within Kalundu River sub-basin in Kitui County, Kenya

III. MATERIALS AND METHODS

The datasets used in this study included 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 at designated points along Kalundu River.

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. Three dam water samples of 1 litre were taken on weekly basis during long and short rainy seasons at three sampling stations located at upper, middle and lower parts of the Kalundu dam reservoirs.

Water samples were collected using a depth integrated sampler for the determination of the Total Suspended Sediment Concentration (TSSC). The water samples weretaken to Kenya Water Institute Water Quality Laboratory in Nairobi for analysis on TSSC.Monitoring of river discharge and TSSC along Kalundu River was done during the short rains in (October-November-December 2020-January- February 2021) and during the long rains (April-May-June 2021). River discharge measurement involved determination of velocity and the cross-sectional area of the river at the 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 [16]. The velocity of flow (V) was determined by using surface floats made of wood and 15cm in diameter. The time (t) taken by float to travel a certain distance (L) was measured using a stopwatch. Particle size analysis was done at the Ministry of transport, infrastructure, housing and urban development laboratory in Nairobi. A turbid meter was used to test the turbidity.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 1.

$$Q = V * A$$ ………………………………… Equation 1

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 analyzed at Kenya Water Institute Water Quality Laboratory. The total suspended sediments concentration (TSSC) in mg/L was determined using gravimetric method according to [17]. The water samples were filtered using a 45 mm membrane filter and the residue dried in an oven at a temperature of 120°C. The TSSC was then computed using Equation 2[17].

$$TSS = \{(WBF + DR) - WBF\}\,(mg)\, x \frac{1000}{VFW}\,(mL) = mg/L$$
…………Equation 2

Where WBF = weight of membrane filter; DR = dry residual; VFW= Volume of filtered water.

This study employed calculation proposed by [18] to compute 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 [19].

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To compute the average sediment yield generated from the contributing watersheds, adjustment of the weight of the deposited sediment was done for the reservoir sediment trapping efficiency.

$$TE = 100\left[1 - \frac{1}{1+0.0021D\frac{C}{W}}\right] \text{.................... Equation 3}$$

Where D is a coefficient and has values ranging from 0.046 to 1 and a mean value of 0.1

IV. RESULTS

A. *Seasonal variability in the river discharge*

Kalundu River exhibit significant inter-annual variability in the stream flow which can be attributed to inter-annual variability of rainfall. The available historical data shows that river discharge during the long rains (March-June) in the period between 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 0.27-1.83m^3/day (Figure 3). In the period between 1976 and 1978, the river discharge decreased 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.

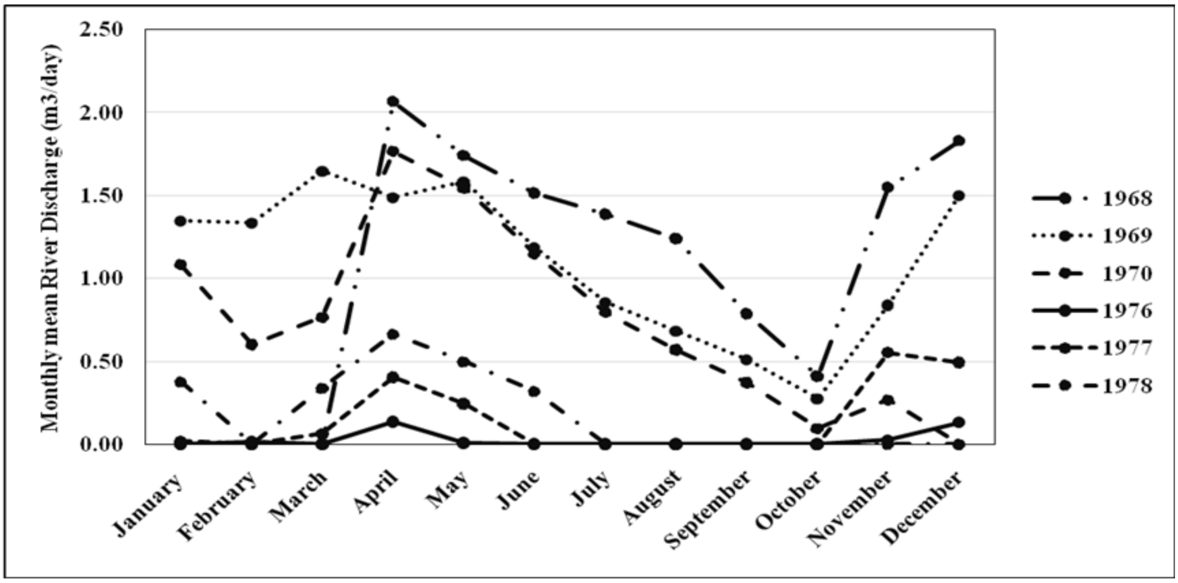

Fig. 3: Historical trend in variability of Kalundu River discharge in the period between 1968-1978

Our analysis shows that variability in the streamflow is essentially due to variability of rainfall occurrence in the basin. During the short rains (November-January) in 2020, the peak river discharge in Kalundu river ranged from 0.98-1.54m^3/day with a mean range of 0.44-1.00m^3/day (Figure 4).

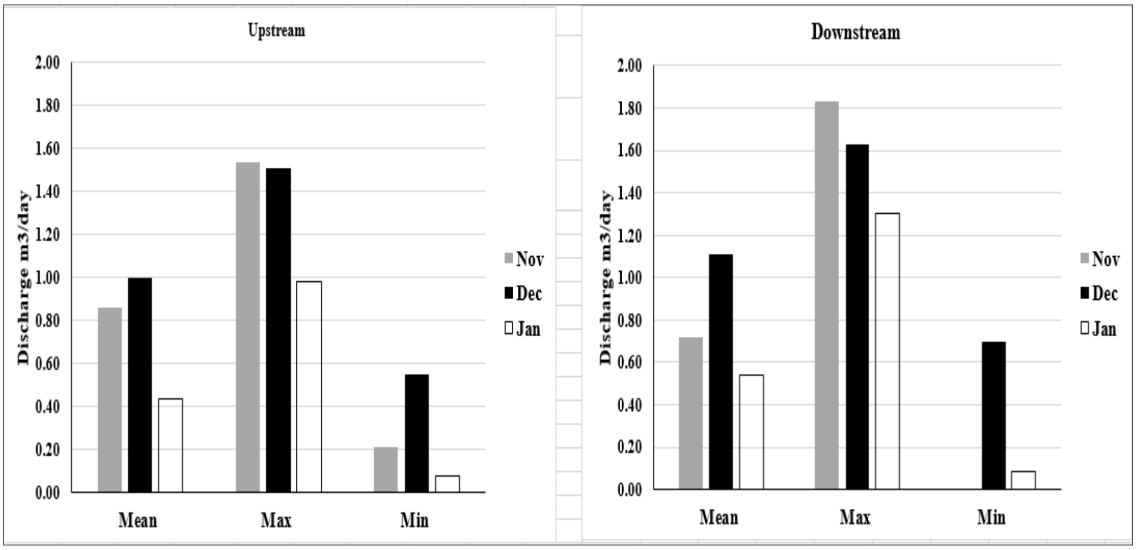

Fig. 4: Variability of KalunduRiver discharge in the upstream and downstream during the short rainy seasons (November 2020- January 2021)

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The dam discharge ranged from 1.30-1.83m3/day with a mean value ranging from 0.54-1.11m3/day (Figure 4). The minimum river discharge within the same season ranged from 0.08-0.55m3/day. During the same season the peak of river discharge was observed towards the end of November and in the beginning of December.

During the long rains (April-June 2021), the river discharge was highest in mid-Apriland in the beginning of May but reduced consistently towards June 2021. This is the reason why the maximum values of 0.98m^3/day in KalunduRiver(upstream) and 1.35m^3/day at the spillway were recorded in April (Figure 5).

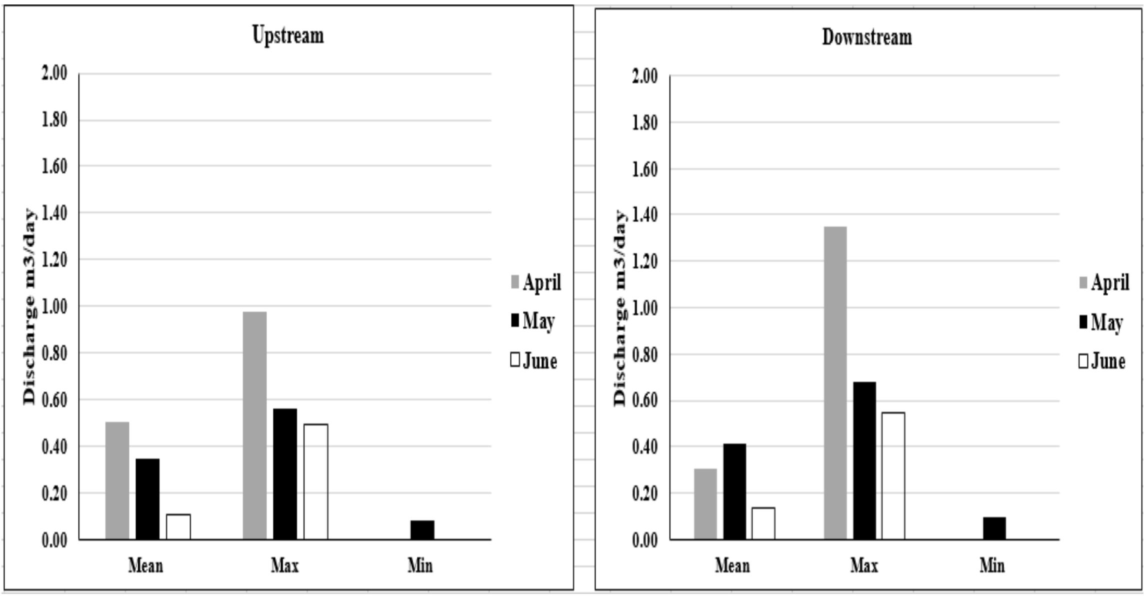


Fig. 5: Variability of KalunduRiver discharge in the upstream and downstream during the long rains (April– June 2021)

During the long rains season, the mean value of Kalundu River discharge ranged from 0.11-0.50m^3/day while the dam discharge ranged from 0.13-0.41m^3/day.The minimum river discharge ranged from 0-0.08m^3/day while the minimum dam discharge ranged from 0-0.10m^3/day. There was no river flow in April and June but a 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 zero dam discharge for several days in April.

B. Seasonal variability in the Sediment Load

During the short rains season variability of sediment load deposited into the reservoir was significantly correlated with the sediment load discharged out of the reservoir (*P-value=0.000, R^2=0.45, r= 0.67)* (Figure 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.

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 6). 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.

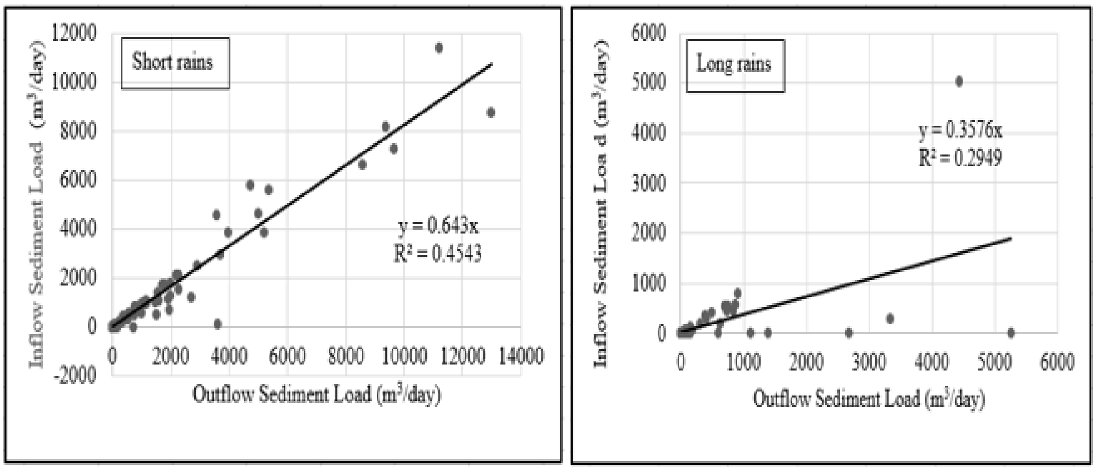


Fig. 6: Variation between sediment load in and out of Kalundu Reservoir during the short and long rainy seasons

Figure 7 shows that there is a significant relationship between river discharge and sediment load given that ($R^2=0.36$, $r=0.61$, $p\text{-value}=0.001$). 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 7 shows that below a river discharge of 0.4m^3/day the river does not transport significant amount of sediment load. It is likely that here is no discharge of sediments into the dam when river discharge is less than 0.4m^3/day.

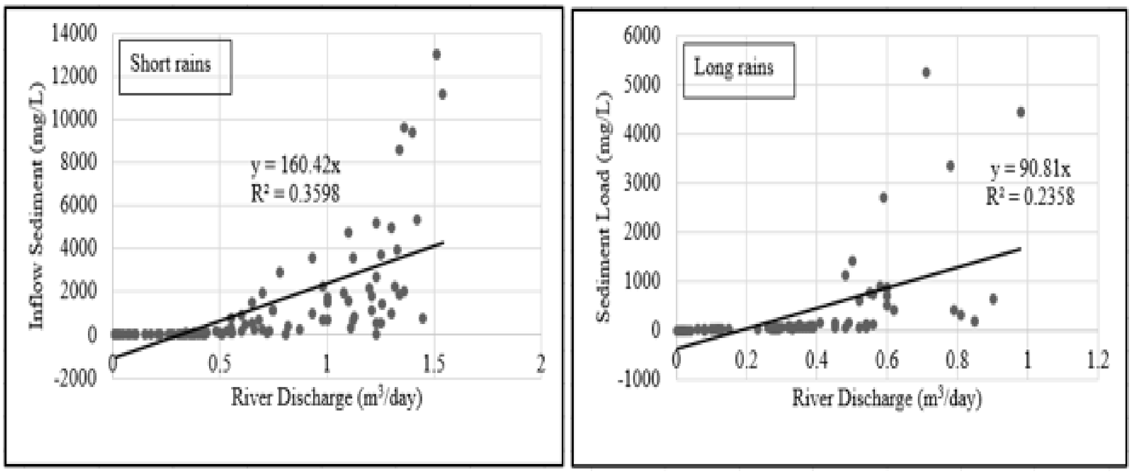


Fig. 7: Relationship between river discharge and Sediment Load inKalundu River during the short and long rainy seasons

The results presented in Figure 7 show that there is a significant relationship between river discharge and sediment load during long rain season given that ($R^2=0.24$, $r=0.49$, $P\text{-value}=0.02$). 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 0.4m^3/day the river does not transport a significant sediment load.

C. Seasonal variability of Total Suspended Sediments Concentration

There is a significant variation between TSSC in the Kalundu River. During the short rainy season, the TSSC in Kalundu River ranged from a minimum of 1 mg/L to a maximum of 8,593.21mg/L with a mean value of 1,131.57 mg/L. In the same season, the TSSC in Kalundu reservoir 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 deposited 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 $P\text{-value}=0.0001$ which signifies a relatively balanced TSSC in and out of the Kalundureservoir (Figure 8).

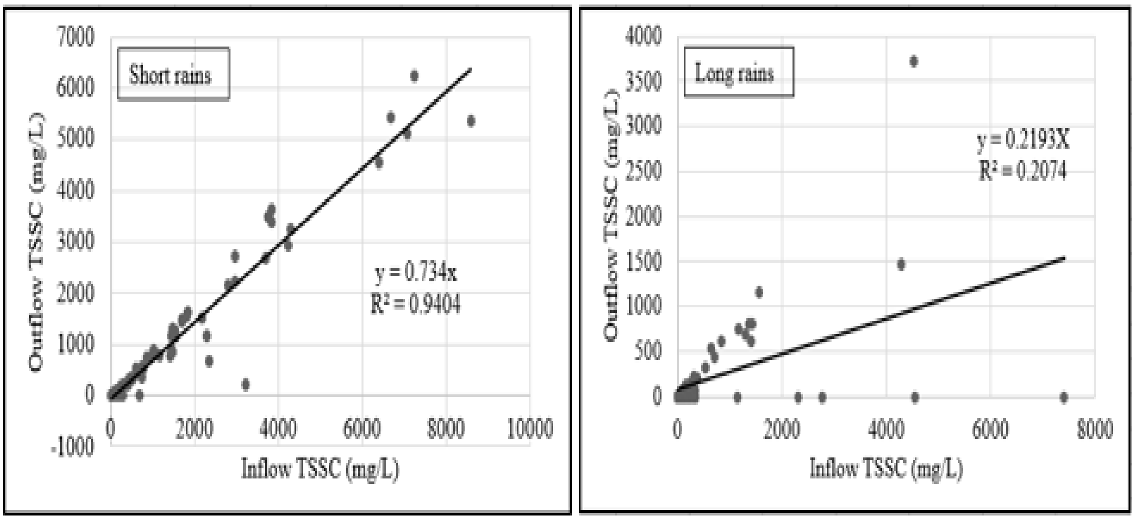


Fig. 8: Relationship between TSS (inflow) and TSS (outflow) in Kalundu Reservoir during the short and long rainy seasons

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 592.81 mg/L. In the same season, the TSSC downstream ranged from 0 - 3,727.62 mg/L with a mean value of 190.55 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 8). By comparing the two seasons, the mean TSSC deposited into the reservoir during the short rainy season was less than the TSSC discharged during the long rainy season.

D. Relationship between River Discharge and Total Suspended SedimentsConcentration

During short rainy season, there was a significant relationship between river discharge and total suspended sediments (R^2*=0.39, r=0.63, P-value=0.03*) (Figure 9).The results imply that an increase in the river discharge is likely 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 592.81 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.

During the long rainy season, 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*). 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. Relatively lower TSSC was measured during periods of lower riverdischarge. The mean river discharged measured during the long rains was 0.33m^3/day while TSSC was 190.55 mg/L. The minimum TSSC was detected at minimum river discharge of 0.4 m^3/day. This study established a significant relationship between turbidity and TSSC given(*r=0.99,*R^2*=0.996, P-value=0.03*) (Figure 9).

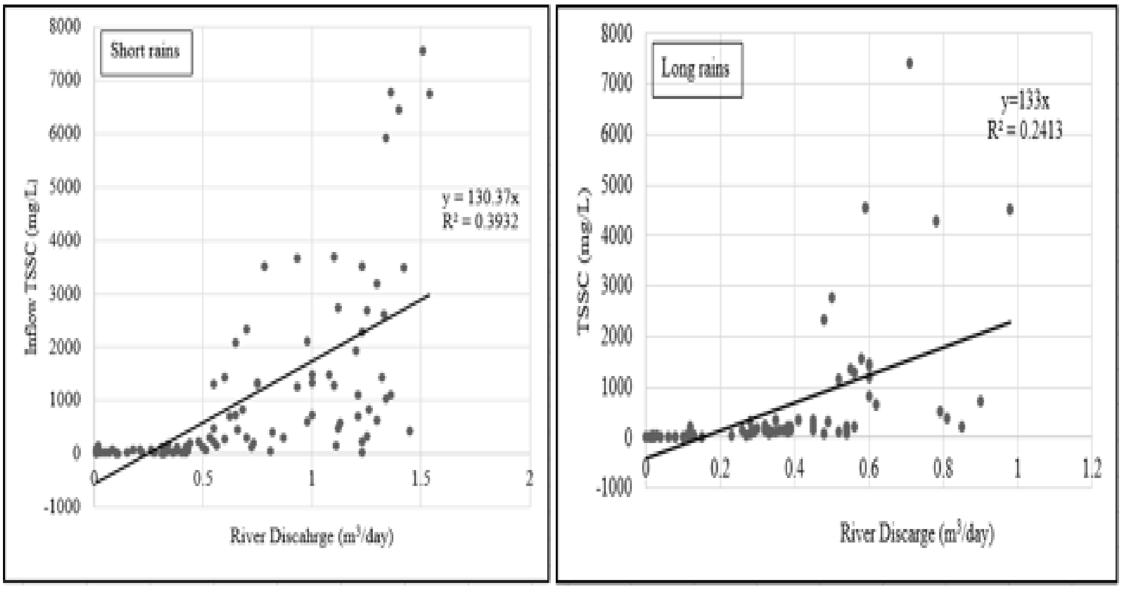


Fig. 9: Relationship between river discharge and TSSC inKalundu River during the short rains and during long rainy seasons

E. Sediment budget and the rate of Sedimentation in Kalundu Reservoir

Hydrological analysis showed that TSSC played a major role in the sedimentation of Kalundureservoir. During the short rainy season, 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. A total of 134,028.84 m^3 (200,043.045 tons) of sediments were deposited into the reservoir with an outflow of108,074.10 m^3 (161,304.478 tons) at an average of 1,038.17m^3/day (1549.51 tons/day). Sediment budget during this season was25,954.74 m^3 (38,738.418 tons)where trapping occurred at an average rate of 251.99 m^3/day (376.104 tons/day) (trap efficiency of 47.73%).During the long rains season, a total of 28,448.87m^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). Sediment budget was17,166.79 m^3 (25,622.075 tons) with trap efficiency of 55.91%.

Abathymetric survey conducted in December 2021 showed that there was a significant variation of water depth in Kalundureservoir. 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 data showed that the reservoir was relatively deeper at the lower and middle zone compared to the upper zone (Figure 10). This imply that more sediments accumulated at the upper zone of the reservoir which contributed to decrease in the water depth.

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 after the reservoir was rehabilitated in 2013 was 500,000m^3 with an original surface area (A_r) of 48,500m^{2}and a depth of 13.5m.In a span of 8 years, the total reservoir storage capacity had decreased by 350,098m^3(approximately 70%)from 500,000m^3 to 149,902m^3, a decrease that was attributed to deposition of sediment into the reservoir.

The total surface area of the reservoir decreased by 5,300.47m^2(equivalent to 11%)from 48,500m^2 to 43,199.53m^2. The design water depth decreased from 13.5m in 2013 to 3m (which is approximately 70% decrease)by December 2021.Since 2014, the lost storage capacity of the reservoir is equivalent to the volume of sediments that had accumulated that is; 350,098m^3(522,534 tons). 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.

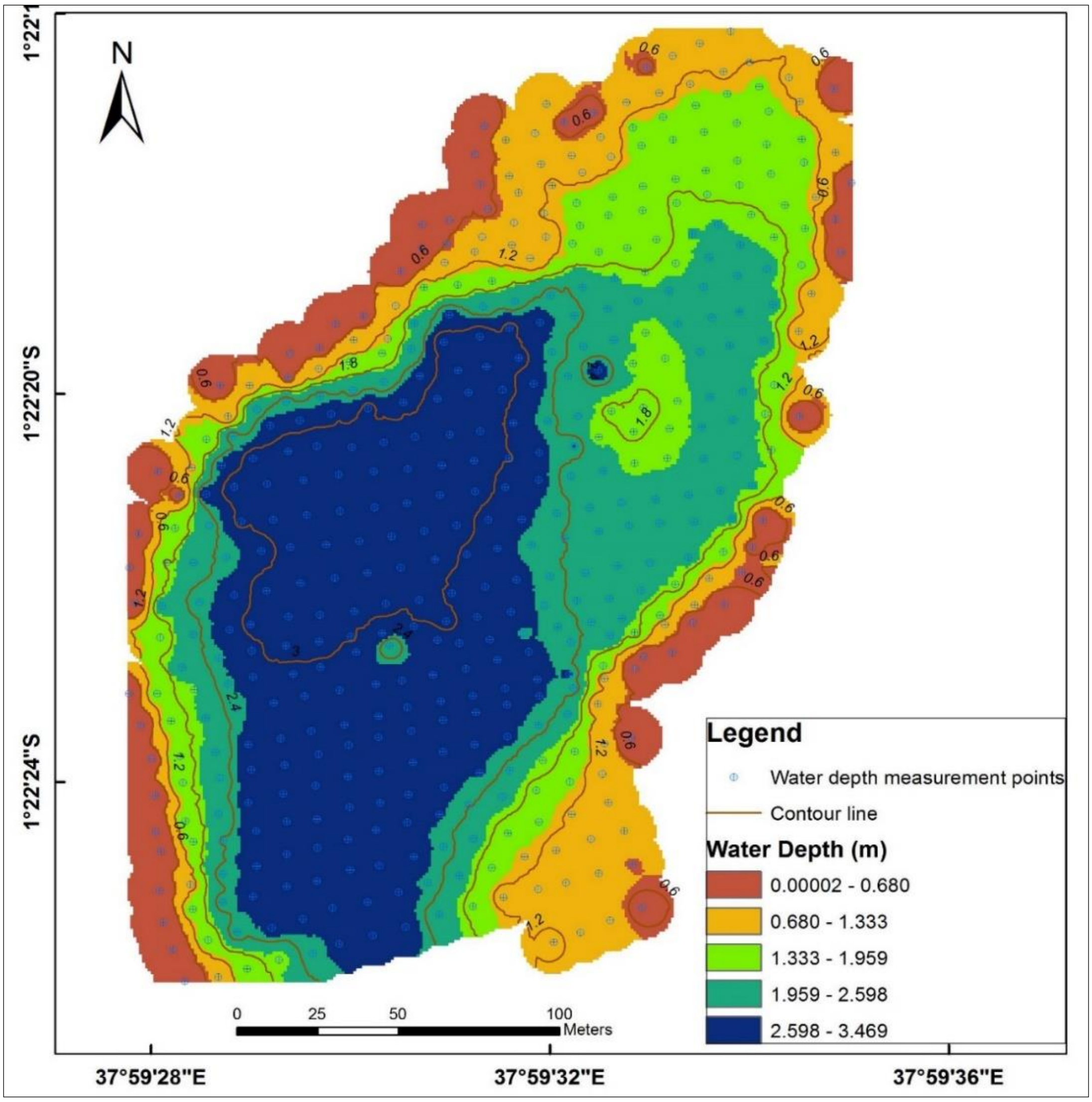


Fig. 10: Bathymetry ofKalundu reservoir based on measurements done December 2021 (Source: Kasuki, 2022)

The volume of the water in the reservoir as at December 2021was 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 volume of water. This resulted to 350,098m^3 of sediments.Based on this information, the useful life span of Kalundu reservoir (UL) was estimated using Equation 4 which gave about 3 years.

$$UL = 0.5 \left(\frac{ISCR - SCL}{MASR}\right) \text{.........................} \quad \text{Equation 4}$$

Where UL is the useful life of the reservoir in years when the initial storage capacity will have been reduced to 50%, whereby;

$ISCR$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)

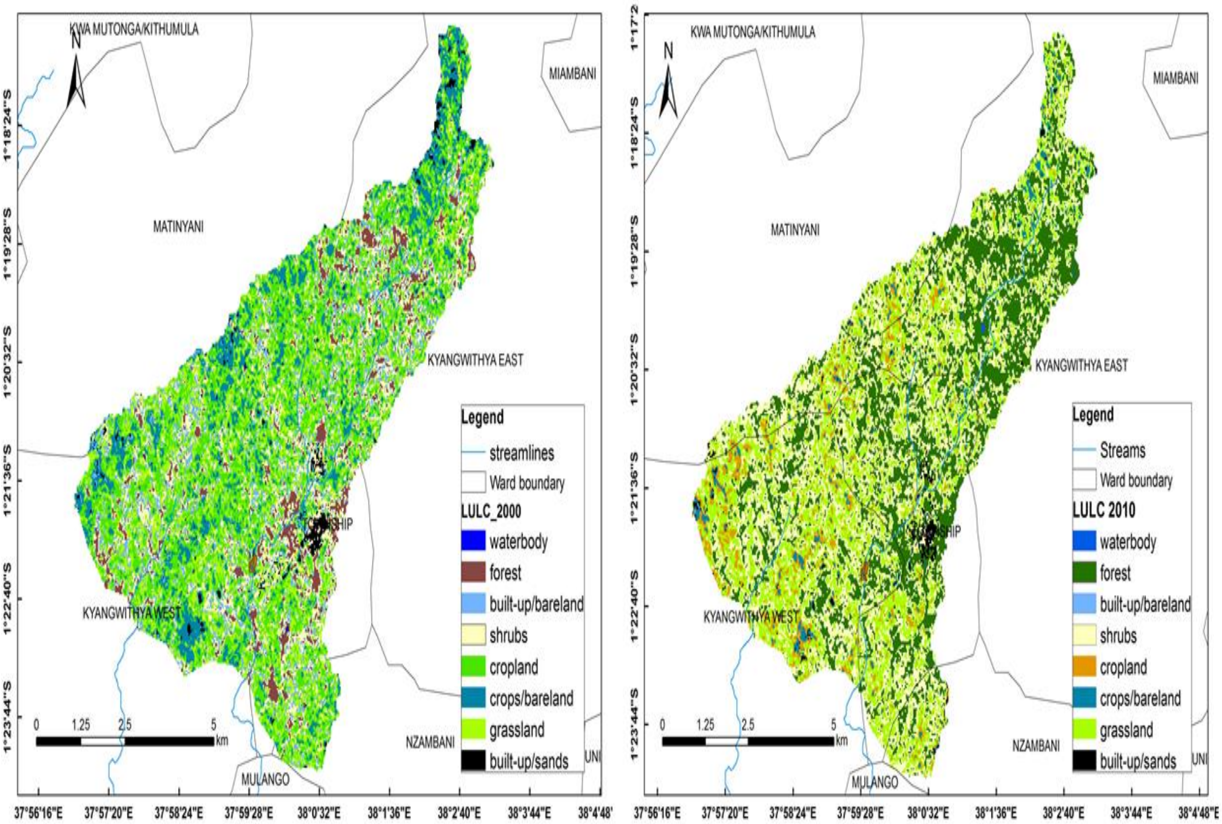
F. Effect of land use and land change in Kalundu sub-basin between 2000 and 2020

The results show that water bodies covered an area of 0.9ha in 2000 then increased to2.7ha in 2010. In the period between 2000 and 2010, the coverage of natural vegetation that is; forest lands, shrubs and grasslands increased from 362.6-1663ha, 800.4-1864.4ha and 1223-1529ha, respectively (Figure 11).This translated to 78%, 57% and 20% increase in the forests land, shrubs and grasslands respectively (Table 1).In the same period, the land that was covered with sands, bare soils and the built-up areaswas 746ha in 2000 but significantly decreasedby more than 10 times to 61.7hain 2010. A large percentage of this category of land cover was bare land which transformed to natural vegetation that is; forest, grassland and shrubs within that decade. The decreases in this land cover category were also attributed to increased sand harvesting along the seasonal rivers found in the study area. The croplands and bare land in 2000 was 1728haand 680.7ha, respectively which decreased to 292.2ha and 128.3ha, respectively in 2010.The decreased sands coverage in the study area in the period between 2000 and 2010 is thought to have been contributed byerosion of sediments from the seasonal rivers which got deposited into the Kalundu reservoir. Disturbance of soils during sand harvesting along the river beds is also thought to have contributed to increased rate of transportation of loose sediments from the rivers and sedimentation of Kalundu reservoir.

Table 1: Proportion of Land use and land cover changes inKalundu sub-basin in the period between 2000 and 2010

LULC Classes	**2000**	**2010**	**Change (ha)**	**Change Ratio**
	Area (ha)	**Area (ha)**		
Water body	0.9	2.7	1.8	0.67
forest land	362.6	1663	1300.4	0.78
built-up/sands/bare land	746	61.7	-684.3	-11.09
shrubs	800.4	1864.4	1064	0.57
cropland	1728	292.2	-1435.8	-4.91
crops/bare land	680.7	128.3	-552.4	-4.31
grassland	1223	1529.2	306.2	0.20
Grand Total	**5542**	**5542**		

*negative values represent a decrease while the positive values show the increases.



a) (b)

Fig. 11: Land use and land cover changes in Kalundu sub-basin in the period between2000 (a) and in 2010 (b)

In the period between 2010 and 2020, water bodies increased from 2.7ha in 2010 to 12ha in 2020. Forest coverage which was 30% of the land cover in 2010 slightly increased from 1663ha to 1964.3 ha in 2020 (Figure 12). The shrub lands slightly decreased from 1864.4ha in 2010 to 1488.1ha in 2020. A large portion of grasslands which covered 28% of the land decreased from 1529.2ha in 2010 to 293.8ha in 2020. The built-up, sands and barelands increased significantly from 61.7ha in 2010 to 405.5ha representing 7% of total land cover in 2020. The croplands and crops/barelands occupied 292.2ha and 128.3ha of land in 2010 but increased in 2020 to 899.8ha and 479.9ha, respectively (Table 2).

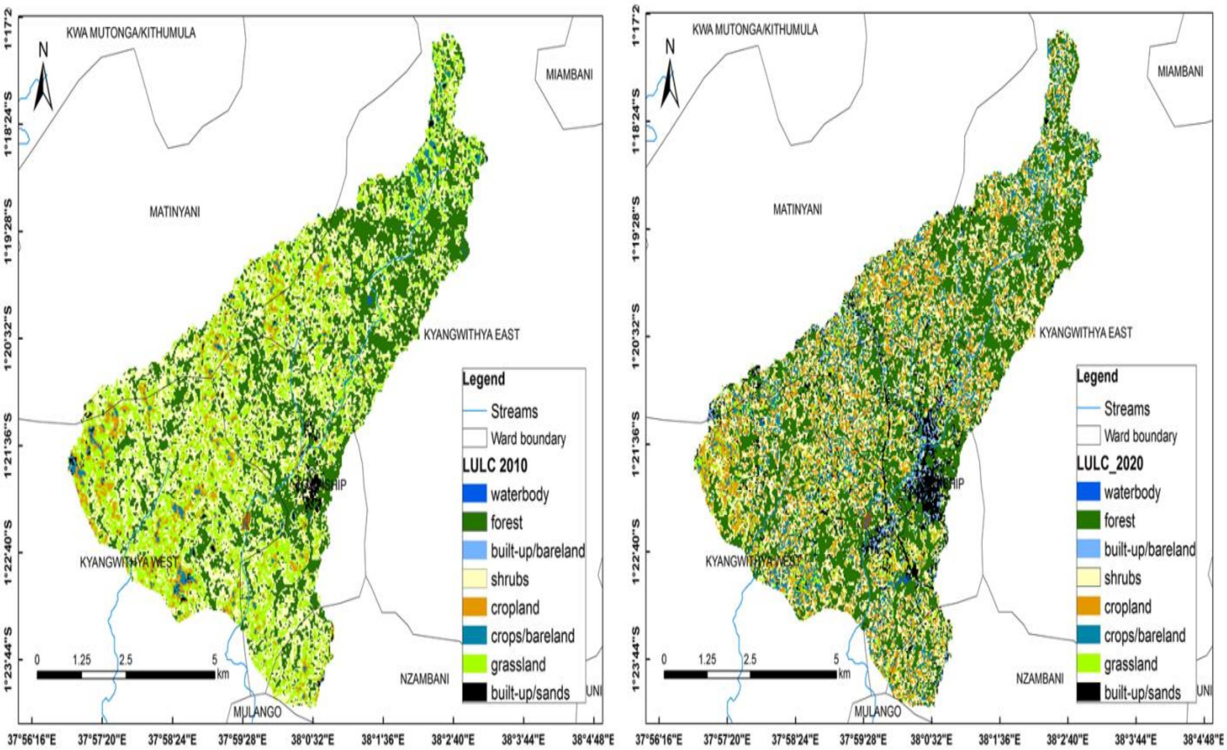


Fig. 12: Land use and land cover changes in Kalundu sub-basin in the period between2010 (a) and in 2020 (b)

Table 2shows that the LULC changes that occurred in the period between 2010 and 2020 had the coverage of water bodies significant increased by 78%from 2.7ha to 12ha.Forest cover also increased by 15% but the shrub lands and grassland decreased by 25% and more than 4 times, respectively. In the same period, the built-up, sands and bare land increased by 85%. Similarly, cultivation land which included the croplands and crops/barelands increased by 68% and 73%, respectively.

Table 2: Proportion of Land use and land cover changes in Kalundu sub-basin in the period between 2010 and 2020

LULC Classes	2010 Area (ha)	2020 Area (ha)	Change (ha)	Change Ratio
Water body	2.7	12	9.3	0.78
forest land	1663	1964.3	301.3	0.15
built-up/sands/bare land	61.7	405.5	343.8	0.85
shrubs	1864.4	1488.1	-376.3	-0.25
cropland	292.2	899.8	607.6	0.68
crops/bare land	128.3	479.9	351.6	0.73
grassland	1529.2	293.8	-1235.4	-4.20
Grand Total	**5542**	**5542**		

*negative values represent a decrease while the positive values show the increases

V. DISCUSSION

A. Variability of Stream flow in Kalundu River

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[20]. 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 of sediments along Kalundu River and deposition into the Kalundu reservoir was likely to be higher during the long rains due to high river flows than during the short rainy seasons.

This study established that there is a significant relationship between river discharge and the reservoir discharge during the rainy seasons. 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.In the current study, during short rainy season (November- January) in 2020 the river flow was quite high in Kalundu River with a peak of

1.54m^3/day. During the long rainy season, the peak river discharge was 0.98m^3/day. The mean variance was 0.44-1.00m^3/day during short rains and 0.11-0.50m^3/day during the long rainy season. This suggests that more sediments were likely to be deposited into the Kalundu reservoir during the short rainy season than during the long rains season. The total volume of water supplied during the short rainy season was 70.3m^3/day with a mean value of 23.4m^3/day. The total volume of water supplied during the long rainy season was 27.5m^3/day with a mean value of 9.2m^3/day.There is a strong relationship between river discharge measured upstream and 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.These occurrences concur with results from previous studies in the same region that observed that river discharge significantly reduced after 1978 due to reduced rainfall[21]. 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 [22].

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 1,131.57 mg/L than during the long rains with a mean of 592.81 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 592.81 mg/Lupstreams and 190.52 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 unproportioned 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.

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.

B. Reservoir Sedimentation and Sediment Budget

Like other water reservoirs located in ASALs in Kenya, Kalundu Dam is at risk of experiencing a recurrence of high accumulation of sediments and the problem of eutrophication due to accumulation of contaminated runoff from the land surface [23]. These two problems have been cited in other studies to be attributed with land use changes in local basins [24]. 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 (11,282.08 m^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, it was 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 or 2,722 tons/km^2/yrwithin a period of 8 years. At This rate of sedimentation, the Useful Life Span (UL) of the dam was estimated to be about 3 years. It was established that the dam had already lost about 70% of its storage capacity and 11% decrease in the surface area by the year 2021. However, due to time limitation and the scope of this study, the study did not account for the water lost from the reservoir through evaporation and runoff from the local land surface. Future studies can look into these attributes to enhance understanding of the spatial and temporal hydrological behavior of the Kalundu sub-basin [25]. However, the results of this study show that the high rate of soil loss and sedimentation in Kalundu Dam needs to be given priority for soil conservation need in the sub-basin [26]. 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 in rapid sedimentation of the dam. Other studies have seen similar findings associated with changes in land use practices [27, 28]. 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 impact was observed in Masinga dam 10 years ago[9].

C. *Land use and land cover perceived to contribute to sedimentation of Kalundu reservoir*

The land covered with water bodies increased significantly by 78% in the period between 2010 and 2020. This was attributed to increased water conservation technologies in Kitui County which were introduced by the county government between the year 2017 and 2021. This increase was also associated with the rehabilitated Kalundu reservoir that accumulated water between 2014 and 2021. The increase in water bodies was also attributed to increased seasonal mean precipitation during the short rainy seasons in the period between 1991-2020 [29].The forest cover slightly increased by 15% within that decade. This was as a result of reduced charcoal burning and conservation programmes initiated by the County Government of Kitui. The shrub lands slightly decreased by 25% to create space for cropping and settlements in Kalundu sub-basin. A large portion of grasslands also decreased in the period between 2010 and 2020 as a result of farmers reviving their crop lands in the study area. Decreased shrubs and grasslands within that decade was also contributed by the increasing building and heavy construction work and increasing settlements in the study area. The built-up, sands and barelands increased significantly by 85% as a result of population increase in the area. These impacts were thought to have contributed to sediments transportation into the reservoir within that decade.

The increased population translated to more built-up land than in the previous decade (2000-2010). Bareland was also as a result of construction activities and heavy infrastructural projects in Kitui Town and within Kalundu sub-basin. Part of the increase in this land cover category was due to increased volume of sands along the seasonal rivers. The County Government of Kitui had restricted sand harvesting in the region and this increased the amount of sands that accumulated in the seasonal rivers in Kalundu Sub-basin. The croplands had increased by 68% as a result of decreased shrubs and grasslands in the area. Increased sedimentation in Kalundu reservoir was attributed to increased croplands, sediments along the seasonal rivers, exposed soils due to increased construction activities, reduced shrubs and grasslands, and increased built-up areas.

VI. CONCLUSION

The analysis on these hydrological datasets aided in understanding the hydrological condition between Kalundu River and the reservoir in different season. The results showed that the river discharge and TSSC were strongly related with the sediment yield in the Kalundu reservoir. Bathymetric survey in Kalundu reservoir helped to understand the trends and extent of sedimentation in Kalundu sub-basin. The study found that, increased sedimentation of the reservoir occurred during the short rains than during the long rains. TSS played a significant role in the sedimentation of the reservoir.The storage capacity of the reservoir reduced by about 70% within 8 years after rehabilitation was done in 2013. The annual sedimentation rate was estimated to be 65,317 tons/yr and Trapping Efficiency of 55%. The estimated Useful Life Span (UL) of the reservoir was estimated to be about 3 years. 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 established that land use and land cover changes in Kalundu sub-basin played a significant role in the sedimentation of Kalundu reservoir. The increasing construction work due to infrastructural development in the study area, cultivation, abandoned crop lands and bare lands were the potential sources of sediments that got deposited into the Kalundu reservoir within the two decades' period (2000-2020). To minimize the adverse effects of this land use and land cover changes, this study 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 National Water Conservation & Pipeline Corporation should carry out regular monitoring and develop guidelines on regular maintenance of the dam. The aspect of sustainability 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, recreation and also power hydroelectric power generation. The findings of this study will guide development and management of reservoirs in ASALs that share similar catchment characteristics.

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