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# Sediment Discharge Analysis for a Seasonal Stream (A Case Study of Maruba Stream, Machakos, Kenya)

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*Abstract* - **Rivers and streams play an important role in transport of sediment. Sediment transport in natural channels is important in order to understand watershed dynamics. Many water resources projects require accurate estimation of sediment volumes transported by rivers and streams. However, sediment data is quite seldom especially in Kenya. Therefore, this research was carried out to overcome the challenge of data unavailability for management of Maruba dam. The sedimentation study was carried out on Maruba stream at the lower reach of the stream catchment. Further, the study was carried out to demonstrate sedimentation problems particularly total suspended solids (TSS) in Maruba dam reservoir. An appropriate gauging site was identified at the catchment outlet where all the measurements were carried out. The study quantified two main important parameters notably suspended sediment concentration (mg/L) and stream discharge ($m^3/s$). Suspended sediment concentration was measured using both gravimetric and turbidity approaches. On the other hand, velocity measurements were transformed into stream discharge values using the stream's wet cross section area. The sediment finding its way into Maruba stream was believed to be strongly influenced by precipitation. Fluctuations in stream discharge (~ 0.2 to ~ 0.9 $m^3/s$) and sediment discharge (~6 to ~97 ton/day) within the measurement period were observed. From the study results, a sediment rating curve equation for Maruba stream of $Qs = 143.49\ Qw^{1.4899}$ and with a $R^2$ value of 0.9768 was obtained.**

***Keywords — Stream, sediment, discharge, catchment, sediment rating curve***

## I. INTRODUCTION

In many developing countries, rivers and streams serve as important sources of food, water and energy [1, 2]. However, human activities especially in watersheds have comprised the ability of river and stream networks to execute their functions. Landscapes are experiencing rapid modifications in order to meet the demand for the rising human population [3, 4, 5]. This is evident through development of new roadways, housing facilities, businesses among others where best management practices are not duly followed. Most of the activities involve replacing the topmost soil layers with impervious surfaces where existing ground cover is critically disturbed. As a result, land surfaces are rendered bare and the end result is increased sediment discharge whenever rain falls, [1].

Water is regarded as an important erosive factor on the earth's surface and it is responsible for transport of eroded material in solution, suspension and in bed load form [6]. The eroded material is termed as sediment. Sediments are basically solid materials which are transported and deposited in new locations [7] whenever soil erosion takes place. The constituents of sediments are mainly rock and mineral particles as well as plant and animal remains. Suspended sediment is an important variable which strongly influences water quality, contaminant transport, reservoir sedimentation, soil erosion and soil loss, siltation in addition to having clear impacts which touch on the ecology and recreation {2, 6, 8]. Reference [9] defined suspended sediment as a form of sediment that finds its way into a water body and travels without coming into contact with the bottom of the channel. Fine materials which range from fine sands to clay constitute suspended sediment yield and differ in quantity depending on the stream's hydraulic characteristics, catchment's geomorphology and pedology, prevailing climate in the area and vegetation presence [9, 10, 11]. The flow velocity is one determinants of particle size of suspended sediments in addition to affecting the particle movement [9].

Sediment load in stream channels is more pronounced during flood periods and as such the concentration of suspended sediments varies with the magnitude of the storm. Storm events account for majority of sediment and sediment related contaminants in many catchment areas across the globe. However, both flow and sediment discharges in streams vary both spatially and temporally [8]. In terms of space alterations, sediment discharge varies with position and depth in the stream channel. Similarly, within time alterations, trends vary with time in days, months, years and even decades. Studying suspended sediment concentration helps in understanding dynamics involved in sediment entrainment, transport and deposition. In this regard, sediment transport is an important aspect where the quality of water in a stream is established. Hence, sediment monitoring endeavors to create an understanding of the catchment morphology dynamics. It is quite important to understand transport of sediments during storm periods in order to obtain an accurate estimate of sediment flux [12]. However, sediment monitoring programmes strongly depend on sampling protocol and techniques for analyzing samples [13]. It further provides useful insights on soil erosion rates and soil loss on the upper reaches of a catchment area [13]. Above all, description of the sediment particle size provides critical information for investigating sediment fluxes and storage in stream channels and riparian zones [10]

## II. MATERIALS AND METHODS

### A. *Description of the Study Site*

The study was carried out in Maruba stream, in Machakos County, Kenya. The stream drains into Maruba dam reservoir which serves as the key source of water for Machakos town and its environment. The reservoir is managed by Machakos Water and Sewerage Company Limited. The stream is quite seasonal and experiences flow during the rainfall seasons. The stream catchment lies between 37 °12′ 0" to 37 °20′ 0" E and 1 °24′ 0" to 1 °34′ 0" S and occupies an area of 49 km$^2$ (figure 1). The stream originates from Iveti hills which stand at an elevation of 2119 m amsl and drains into Maruba dam. The stream catchment fluctuates from 2119 m to about 1576 m above sea level. The upper part of the stream catchment is characterized by some rugged terrain where valleys, vegetation and human settlements are predominant. The stream catchment lies within the tropical belt and receives bimodal rainfall with short and long rains falling around October to December and from March to May respectively [14]. The area's annual rainfall is about 700 mm although it is unevenly distributed and even quite unreliable [14]. The annual temperature ranges from 18 °C to 29 °C with the driest months between January to March and from August all through to October. The soils are predominantly Luvisols and have very low fertility hence reduced crop production [14]. Major land use types include settlements, croplands, forests and barren lands. Agriculture is the main economic activity with the majority of the population although it is practiced at subsistence level. Some catchments parts have natural forests although the acreage is declining because of the desire to increase agricultural activities and establishment of human settlements. The disturbance on the catchment surface has increased its vulnerability to soil erosion.

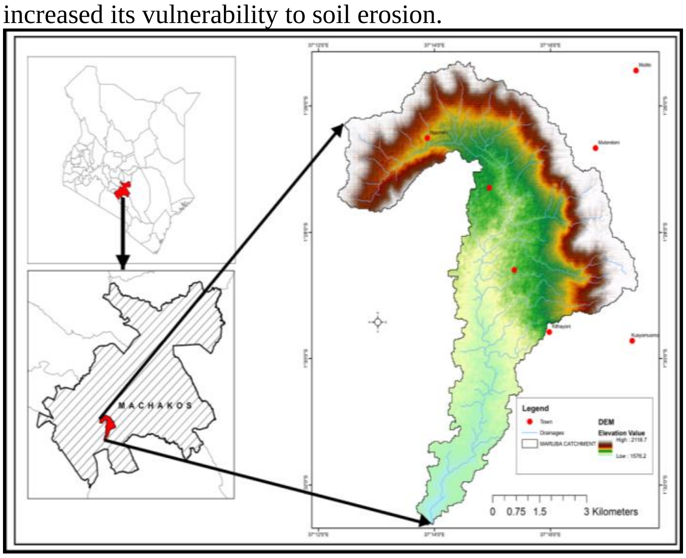


Figure 1: Location of the study area

### B. *Water Sampling*

Suspended sediment concentration was estimated from water samples which were collected during storm events [12, 15]. The horizontal and vertical viability were considered while collecting water samples within the stream channel. In this regard, samples were collected at approximately 60 percent of stream depth from the surface using the grab sampling technique [4, 16]. The objective of this methodology was to ensure that bed load sediment was not incorporated into the sample of interest [12]. The water samples were scooped at the appropriate sampling point using a 500 ml plastic bottle. Reference [4] argued that scooping gives the best estimate for the mean sediment load since concentration is more pronounced below the water surface.

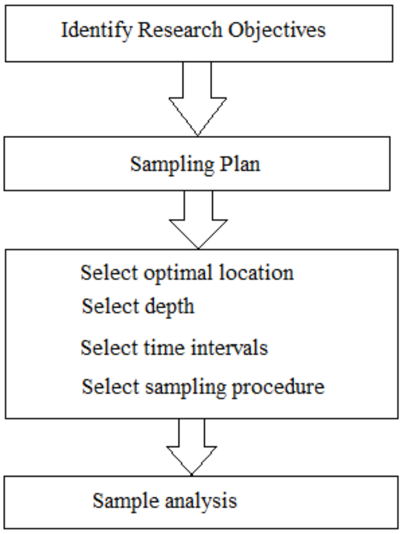


Figure 2: Sampling methodology

### C. *Water Analysis*

The presence of solid matter in a water sample is well accounted by concentration of suspended solids. In this study, suspended sediment concentration was estimated gravimetrically (mg/L) and using turbidity measurements (NTU). Gravimetric analysis procedure of water samples presented by [3, 7, 12] was used. The concentration of suspended sediments (SSC) was expressed in mg/L according to equation (1).

$$SSC = \frac{[(\text{weight of membrane filter} + \text{dry residue}) - \text{weight of membrane (mg)}]}{\text{Volume of filtered water (ml)}} \quad (1)$$

On other hand, turbidity expresses the relative clarity of a water sample by taking into account its optical properties. Turbidity arises due to presence of suspended matter and therefore its measurement would give an estimate of suspended sediment concentration [10]. In this study, turbidity was measured using nephelometric turbidimeter according to the procedure described by [1] and [10]. The turbidimeters express turbidity in Nephelometric Turbidity Units (NTU).

### D. *Streamflow Measurements*

A catchment area is better understood if the physics behind flow and sediment discharges in stream channels is better understood. Streams are vital systems in soil erosion processes and also in the hydrological cycle [2]. Measuring

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stream discharge is in important step in managing flood hazards, studying climate change related issues, management of water resources among others [16, 17). Modelling catchments, reservoir operations and flood forecasting requires information on stream velocity and flow duration [17]. However, streamflow data is very seldom especially in third world countries because of political, economic and proprietary issues. Basically, streams are natural channels which have an open channel flow since they have a free surface. Streamflow is therefore the flow volume passing a particular point over some period of time. It is commonly measured using the direct technique of determining discharge. In this study, the cross section of the stream and flow velocity were obtained at an appropriate gauging site using a set of hydrological apparatus which included the current meter, depth measuring standard, measuring tape and stake [7, 17, 18]. Velocity measurements were therefore transformed into discharge values by use of the wet cross section area which was derived as product of channel's width and depth [7, 18]. The velocity-area approach is an important methodology in estimating stream discharge [16] therefore the continuity equation was used to determine discharge at different channel sections [18].

*E. Sediment and Streamflow Discharges Analysis*

Sediment discharge (volume/time) has been obtained using several methods [6, 18]. The sediment rating curve is one such method and it incorporates sediment discharge, flow discharge, sediment concentration and a constant value [6, 19]. Published research works have utilized the sediment rating curve which takes a power function form [6, 19, 20]. In this study, sediment and observed stream discharges data were related by a rating curve equation model (equation 2) [6, 8]. The coefficient of determination ($R^2$) was used to establish how the regression equation compared the observed stream data [18]. The $R^2$ value is indicative of a relationship's strength between observed and simulated values. It ranges from 0 to 1 and in instances where the value is above 0.6, then it is regarded as satisfactory [18].

$$Qs = aQ_w^b \qquad (2)$$

Where,
$Q_s$ = suspended sediment discharge (t $day^{-1}$)
$Q_w$ = water discharge ($m^3/s$)
$Q_s$ = Average concentration of suspended sediment (mg/L)
a and b = regression constants

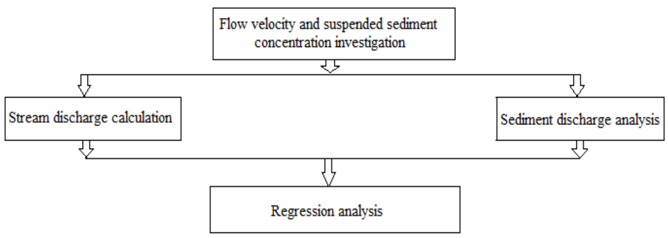


Figure 3: Overall research procedure

## III. RESULTS AND DISCUSSIONS

Measurements on streamflow and suspended sediment were done during flood flow. The datasets were subjected to analyses where flow discharge, suspended sediment concentration and sediment discharge were obtained. Regression analysis was used to establish the relationship between streamflow and sediment discharges.

*A. Rainfall and Streamflow Measurements*

Flows in Maruba stream are only experienced during the rainfall season. Table 1 presents the measured stream discharges and analyzed for respective periods of measurement. According to table 1, the lowest amount of rainfall was recorded in 31 December 2020 while the highest in 13 May 2021. Stream discharge had a strong relationship with storm rainfall (figure 2). It was noted that both flow velocity and stream discharge increased as the amount of rainfall increased. This explains the significant variation in stream discharge (~ 0.2 to ~ 0.9 $m^3/s$) for the given study duration. The amount of rainfall had a strong effect on the open stream channel. Reference [1] argued that occurrence of rainfall brings about some changes to the stream characteristics. In this regard, it was noted that the cross section area at the appropriate gauging site changed whenever the size of the storm increased. According to [20] seasonal fluctuations of flow and sediment discharge influence the variability of a stream channel. Water level rise within the stream channel and streambank erosion which resulted from turbulent flow were attributed to the variability of the stream channel [6, 20]. Further, the appropriate gauging point was located near the outlet of the catchment where silt material had accumulated. This also explains the variability in the channel with storm rainfall because silt material sheared more easily. This characteristic justifies [20] description of stream channels at the outlet of the catchment as being unstable.

Table 1: Variation of rainfall, stream cross section area and stream discharge data

| Date | Daily Rainfall (mm) | Average stream cross section area ($m^2$) | Average stream discharge ($m^3/s$) |
|---|---|---|---|
| 30-11-2020 | 2.3 | 0.40 | 0.18 |
| 31-12-2020 | 1.2 | 0.35 | 0.13 |
| 14-04-2021 | 3.6 | 0.46 | 0.21 |
| 23-04-2021 | 4.2 | 1.11 | 0.69 |
| 13-05-2021 | 28.6 | 1.50 | 0.87 |

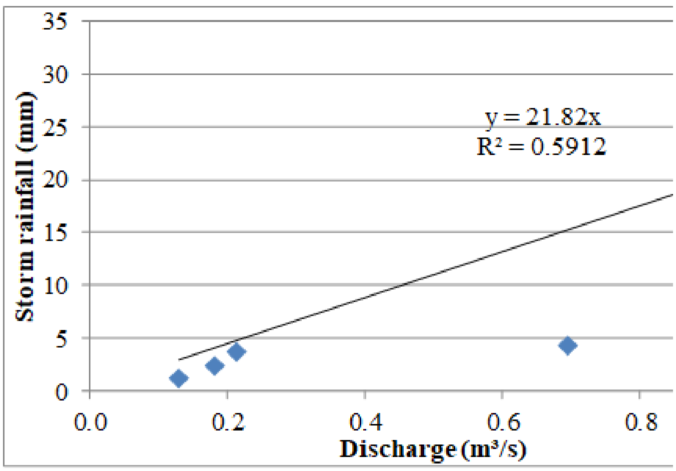


Figure 4: Discharge – rainfall relationship

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### *B. Sediment Discharge and Concentration*

According to figure 5, sediment transport was reported to be highest in 13 May 2021 (about 97 ton/day) and this was as result of high amount of rainfall received on that day (28 mm). The least was recorded in 30 November 2020 (6 ton/day) following a rainfall amount of 1.2 mm. On the basis of sediment discharge, it was noted that rainfall intensity has significant contribution to generation of sediment and its transport [20]. Figure 6 below shows the variation of suspended sediment concentration days after a storm rainfall. According to the figure, sediment concentration shows some scatter after storm rainfall. The scattering of the sediment concentration data is associated with sediment discharge dynamics [13]. Immediately after the storm rainfall, sediment concentration is very high. This is due to erosion process which is a three phase phenomenon: detachment, transportability and deposition. As the flow subsides, sediment concentration decreases exponentially. This explains the dynamics associated with sediment discharge in streams. Therefore, suspended sediment concentration measurements at the catchment outlet give valuable information regarding soil erosion rate and loss within the upper reaches of the catchment area [13].

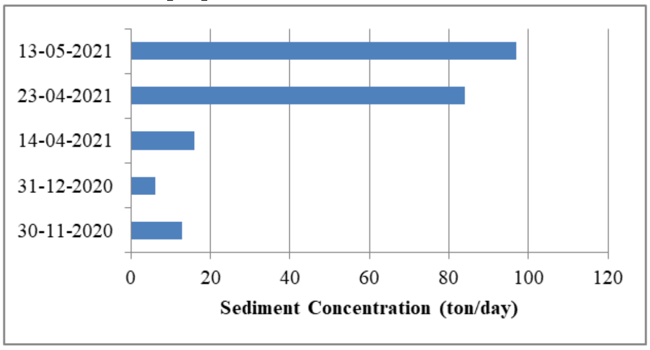


Figure 5: Sediment discharge

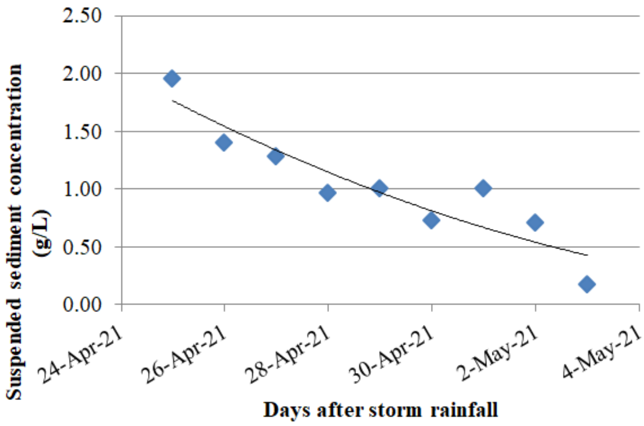


Figure 6: Variation of SSC after as single storm

### *C. Turbidity and Concentration of Suspended Sediment*

Figure 7 shows that turbidity levels increased with the concentration suspended sediment [1]. Reference [3] made similar observations although their study was not based on seasonal streams. In this study, turbidity was related to concentration of suspended sediments using a linear regression model, (figure). Just like with the research published by [13], the intercept in the regression analysis was set at zero. A strong correlation (R2 = 0.7166) was noted to exist between turbidity and suspended sediment concentration. Similar studies by [1, 13, 15] used linear regression model equations to obtain a relationship between turbidity and suspended sediment concentration.

$$NTU = a\,(SSC) \quad (3)$$

Where,
NTU = Turbidity
SSC = suspended sediment concentration
a = regression estimated coefficient

Reference [3] used a power function to report that there exists a strong correlation between turbidity and concentration of suspended sediments. This means that turbidity measurement is a good approach through which suspended sediment concentration can be estimated although it does not involve direct measurements [1].

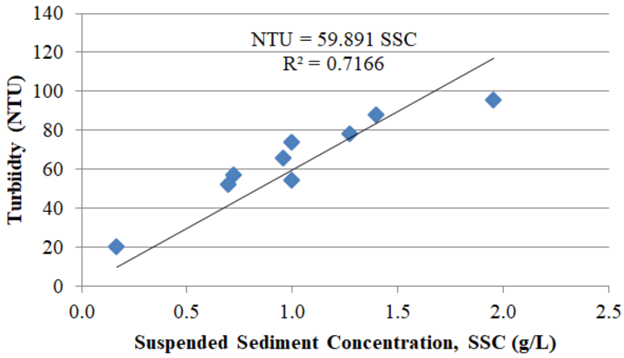


Figure 7: Relationship between Turbidity and suspended sediment concentration

### *D. Sediment Rating Curve*

Sediment transport is influenced by factors such climate, topography, geology and their relationship which is quite complex especially when it comes to calculation of sediment volume carried by stream channels [11]. Drastic changes in sediment transport rates and soil erosion have resulted due to increased population especially in rural areas. Many water resources projects for instance dams and reservoirs demand that the volume of sediment in stream channels be accurately known [17]. It becomes easier to manage a reservoir if the correct sediment loading is known [11]. False prediction results in very severe consequences in such projects for instance flooding.

Recent research touching on sediment processes in stream catchments has majored on the relation between flow and sediment discharges both in marginal settings and also in major streams [6]. The sediment rating curve as an empirical tool has been used to characterize suspended sediment regimes in streams [19]. According to [6], the sediment rating curve serves as an important tool for estimating sediment discharge since it relies on limited measured data on flow and sediment. In this study, regression analysis (figure 8) was used to establish the relation between flow discharge and sediment discharge [11, 20]. The parameters involved in the study were related using a power function [20] as shown in equation (equation)

$$Qs = 143.49\ Qw^{1.4899} \text{ and } R^2 = 0.9768 \quad (4)$$

From equation 4, the regression estimated constants were 143.49 and 1.4899 respectively. The coefficient of determination ($R^2 = 0.9768$) indicates a very strong relation between flow and sediment discharges. The interpretation is that about 98 percent of sediment discharge which occurred was strongly influenced by stream discharge an indication that the sediment rating curve was suitable for any use [18].

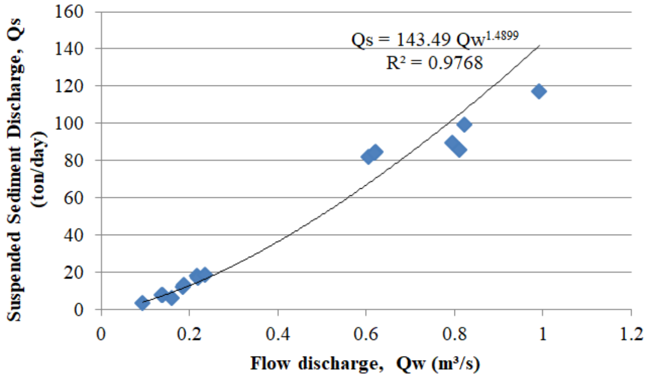


Figure 8: Sediment rating curve for Maruba stream

## IV. CONCLUSIONS

Monitoring of hydrological regimes is an important discourse especially at a time like now when climate change has overwhelmed the globe. Stream monitoring forms an important foundation in management of water resources. Most stream functions including its volume depend on hydrologic processes. These hydrological processes are defined by factors such as topography, geology, climate along with human related impacts. Hence, knowledge on stream propagation speed and flow duration helps in forecasting of floods, reservoir operations and modeling of watersheds. Monitoring of streams is achieved by use of an appropriate method and on the basis of the study's objectives, available resources, terrain, stream size and available expertize. The study shows that the highest sediment discharge occurred in 13 May 2021 and this amounted to 97 ton/day. This figure corresponded to the highest amount of rainfall experienced within the catchment area. The lowest was in 30 November 2020 (6 ton/day. The sediment rating curve for Maruba stream was $Qs = 143.49\ Qw^{1.4899}$ and the $R^2$ value was 0.9768. The sediment rating equation obtained from this study can be used to estimate sediment discharge amounts based on stream and sediment data for Maruba stream at any given location within the study area.

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